ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
GRADUATE STUDIES

"PARTIAL REPLACEMENT OF CEMENT WITH BAGASSE ASH IN HOT MIX ASPHALT"

By

Fikadu Alemu Wondimu

Thesis Submitted to School of Civil and Environmental Engineering of Addis Ababa Institute of Technology in Partial Fulfillment of the Requirements for the Degree of
Master of Science
In
Civil Engineering
(Road and Transport Engineering)

Advisor

Habtamu Melese Zelelew (PHD, PE)

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Addis Ababa, Ethiopia

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DECLARATION

I, the undersigned, declare that this thesis with the title of Partial Replacement of Bagasse Ash with Cement in Hot Mix Asphalt is my original work, has not been Presented for a degree or diploma in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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This thesis has been submitted for examination with my approval as a university advisor.

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ABSTRACT

Today, the increasing demand and scarcity of construction materials like cement forced most researchers around the globe to focus on finding ways of utilizing either industrial or agricultural wastes/locally available materials as a source of raw materials and ecofriendly substitutes or alternatives for the improvement of pavement quality. These wastes utilization would, not only be economical, but may also help to create a sustainable and pollution free environment as the disposing of such wastes is tedious but, promoting towards waste management. Sugar-cane bagasse is one among the fibrous waste product of the sugar processing industry. Hot Mix Asphalt Mixtures (HMA) is a composite material consisting of mineral aggregates, filler/cement, asphalt binder and air voids. In addition, the current increment in energy cost and demand evokes the need for improving pavement quality either by modifying or replacing the cement partially or totally. Moreover, this study is intended for partially replacement of cement with bagasse ash in hot mix asphalt (HMA).

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%. The 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 asphalt mixture testing includes the Marshall Mix design which was used to determine the Optimum Bitumen Content (OBC) for the conventional HMA. The asphalt binder was replaced by the 20 percentages of cement using the OBC. The results obtained shows that the Cement/BA mixes exhibit satisfactory trend result with average bitumen content of 5.5%. However, this research concluded that partial replacement of cement with bagasse ash as filler in hot mix asphalt has no significant effect on performance or volumetric properties of asphalt concrete except on stability at lower bitumen content and flow at higher bitumen content, since the percentage of filler is too small.

Key words: Hot Mix Asphalt, Bagasse Ash, Binder Content, Replacement of Cement.

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ABBREVIATIONS

AASHTO: American Association of State Highway and Transportation Officials.

ACV: Aggregate Crushing Value.

AIV: Aggregate Impact Value.

ANOVA: Analaysis of Variance

ASTM: American Society for Testing and Materials.

BA: Bagasse Ash.

BA: British Standard.

BSG: Bulk Specific Gravity.

ERA: Ethiopian Road Authority.

FI: Flekiness Index.

HMA: Hot Mix Asphalt.

LAA: Los Angeles Abrasion

MPa: Mega Pascal

MQ: Martial Quotient.

MT: Metric Tons.

MW: Mega Watt.

OBC: Optimum Binder Content.

OPC: Ordinary Portland Cement.

SCBA: Sugar Cane Bagasse Ash.

SEM: Scanning Electronic Maicroscopy.

TFV: Ten percent Fine Value.

VIM: Void In Mix.

VFA: Void Filled with Asphalt.

VMA: Void mineral Aggregate.

WMA: Warm Mix Asphalt.

XRD: X-Ray Defraction.

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Chapter 1 - Introduction

1.1. Background

Asphalt concrete is a mixture of aggregate, binder (bitumen) and filler (major cement), used for construction and maintenance of all kinds of roads, parking areas, air port, playground and sport areas/studium. Asphalt pavement design is incomplete or becomes ustable without filler. Mineral filler consists of very fine, inert 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.

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

Recently Bagasse Ash (BA), the most readily available agrecultural/industrial waste material that has found useful application in engineering and other field of studies. It is a fibrous waste product of the sugar cane refining industry, along with ethanol vapour. Its analysis from sugar industry shows that it contains unburned carbon along with the other constituents present in portland cement. BA can replace some of the raw materials; reduce the energy cost and increase revenue from the cement industry.

The use of BA as a supplementary cementitious material to partially replace Ordinary Portland Cement (OPC) not only helps reduce methane emissions from dispose of organic waste and reduce the usage of cement, which is famous for its high energy consuption and CO_2 emission, but also can improve the quality and strength of cement mixed materials to resist the impact load applied on the pavement.

As stated by Cordeiro et al., the improved compressive strength depends on both physical and chemical effects of the SCB ash. The physical effect of the filler is concerned with parking characteristics of the mixeture, which in turn depends on the size, shape and texture of SCB ash particle. The chemical effects relates to the ability of the bagasse ash to provide reactive siliceous and aluminous compounds to partiicpate in the pozzolanic reaction with calcium hydroxide and water.

Since recently, some abroad country studies have confirmed applicability of these wastes as a cement replacing material in Hot Mix Asphalt Concrete technology. However, their applicability as standalone cement replacing in asphalt concrete is still questionable especially in our country.

Therefore, this study will be geared towards evaluating some of the engineering properties of bagasse ash partially replaced with cement at ratio of 0%, 10%, 20%, 30%, 40% and 50% in hot mix asphalt concrete. If the study leads to positive outputs, bagasse ash can used as filler replacing the rather costly materials employed such as cement. In addition to evaluating the percentage proportion at which cement can replace with bagasse ash, it also addressed the suitable optimum binder content which is at 5.5% binder content for the suitable proportion of 20% bagasse ash.

1.2. Problem Statement

Nowadays, Ethiopia's construction sector is regarded as the most important and expanded pillar for the sustainable development of the country in terms of economic and social development where the country has been working hard towards providing several roads, building and water work infrastructural facilities. Hence, the availability of construction materials is very important to address the government strategy and policy on the sector. Road construction is one of the major sectors that affect the economic development, social life standard, environmental quality and interaction between the societies. So, it can be considered as a useful to achieve the best in the process of sustainable development. In addition, most of the provided roads in our country are flexible pavement which is cheaper as compared to rigid pavement. And looking to the material constituents of asphalt pavement i.e. cement, bitumen and aggregate, they are very much expensive for developing country like Ethiopia. Hence, the government can't afford all to expend sufficient costs to provide the required materials for every access road throughout the country. Moreover, most road construction projects have been also experiencing construction delay for a long period of time due to budget constraint (road projects running by Ethiopian Roads Authority).

Among the ingredient of asphalt concrete, cement is the second costly construction material next to bitumen. So, it is mandatory to find an alternative filler material for replacing it properly. As a result, the use of sugarcane bagasse ash, agricultural waste and locally available material is found an alternative option for replacing the amount of cement used in HMA.

1.3. Justifications for the Thesis

- ✓ Cost savings, because bagasse ash is typically cheaper than other filler material such as cement since it is waste product;
- ✓ The production of filler material, such as production of cement follows environmental unfriendly processes;
- ✓ The extraction of substantial amounts of non-renewable natural resources for road construction creates significant damaging impacts on the local environment and its inhabitants;
- ✓ Waste management can be done economically;
- ✓ The ongoing establishment of huge sugarcane factories in our country, Ethiopia which in turn provides bulk amount of sugarcane waste.

Therefore, using bagasse ash for improving engineering properties of the asphalt concrete is an economical solution for Ethiopia as it is available in large quantity.

1.4. Objectives

1.4.1. General Objective

The main objective of this research is to check and evaluate the suitability of bagasse ash for partially replacing cement in hot mix asphalt.

1.4.2. Specific Objectives

The specific objectives of this study are:

1. To evaluate the effect of bagasse ash in partial replacement of cement using relevant parameters and properties of asphalt concrete such as flow, stability, VMA, VFA, and air void.
2. To compare the changes in properties of asphalt concrete with respect to the change in percentage of bagasse ash.

1.5. Problem Statement

Nowadays, Ethiopia's construction sector is regarded as the most important and expanded pillar for the sustainable development of the country in terms of economic and social development where the country has been working hard towards providing several roads, building and water work infrastructural facilities. Hence, the availability of construction materials is very important to address the government strategy and policy on the sector. Road construction is one of the major sectors that affect the economic development, social life standard, environmental quality and interaction between the societies. So, it can be considered as a useful to achieve the best in the process of sustainable development. In addition, most of the provided roads in our country are flexible pavement which is cheaper as compared to rigid pavement. And looking to the material constituents of asphalt pavement i.e. cement, bitumen and aggregate, they are very much expensive for developing country like Ethiopia. Hence, the government can't afford all to expend sufficient costs to provide the required materials for every access road throughout the country. Moreover, most road construction projects have been also experiencing construction delay for a long period of time due to budget constraint.

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1.6. Scope of the Study

This study has been supported by different types of literatures and a series of laboratory experiments. However, the findings of the research are limited to the effects of bagasse ash on asphalt concrete used as filler only. In addition, the percentage constituent of filler in HMA is 2% which has no significant effect as compared to other materials. Hence, the results are also specific to the type, chemical composition and content of bagasse ash used and test procedures that have been adopted in the experimental work. Therefore, findings should be considered indicative rather than definitive for field of applications.

1.7. Organization of the Thesis

The structure of the thesis work is organized in eight Chapters. The first Chapter deals with brief description of the thesis background, objectives, scope and employed methodology. The important literatures and relevant reviews from previous studies are included under chapter two of the paper. While chapter three briefly describes the adopted methodology of the study i.e. the characterization of materials used for the study and laboratory testing procedures. Moreover, the fourth chapter presents the obtained test results i.e. analysis and discussions of results with respect to the theoretical background and findings of previous studies. Chapter five of the research comprises the environmental and economic analysis of the study whilst the conclusions and recommendations drawn from the research are presented in chapter six of the report. The utilized reference materials are forwarded under reference section which is chapter seven. Furthermore, detailed experimental test results are presented along with the performed tests under the last chapter of the paper i.e. chapter eight under Appendix title.

Chapter 2 - Literature Review

2.1. Background

This chapter discuss about the reviewed literature that had been found much more related with the title of the thesis, i.e. about sugarcane bagasse ash (SCBA). And the topic is very much important to give the information and make comparison of subtopic that has large scope related to others research. Hence, it will give a clear insight towards providing relevant emphasis and largely to maintain the flow of the research.

Pavement consists of more than one layer of different material supported by a layer called sub grade. Generally, pavement is of three types; rigid pavement, flexible pavement and composite pavement. Rigid pavement is a pavement structure which distributes loads to the subgrade having, as the main load bearing course, a Portland cement concrete slab of relatively high-bending resistance. While flexible pavement is a pavement consists of asphalt mixture placed over granular base layer supported by the compacted soil, the subgrade; 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 layers underneath. The design ensures the load transmitted to each successive layer does not exceed the layer's load bearing capacity. Typical flexible pavement structure consisting of:

- ✓ Surface course: - 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 coarse 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.
- ✓ Base course: - This is the layer directly below the HMA layer. The base coarse serves as the principal structural component of the flexible pavement and it distributes the imposed wheel load to the pavement foundation, the sub-base and the subgrade. The quality of the

base course is a function of its composition, physical properties, and compaction of the material. This layer is used in areas where frost action is severe or the subgrade soil is extremely weak. Generally, consists of aggregate (either stabilized or un-stabilized).

- ✓ Sub-base course: - This is the layer (or layers) under the base layer. It functions like the base coarse i.e. it provides additional help to the base and the upper layers in distributing the load, but the material requirements for the sub-base are not as strict as those for the base coarse since the sub-base is subjected to lower load stresses. A sub-base is not always needed. It consists of stabilized or properly compacted granular material

A typical flexible pavement section is shown in Figure 2-1, presenting the various layers composing it. This study will only concentrate on the top layer (surface), i.e., the hot mix asphalt layer or the asphalt concrete layer.

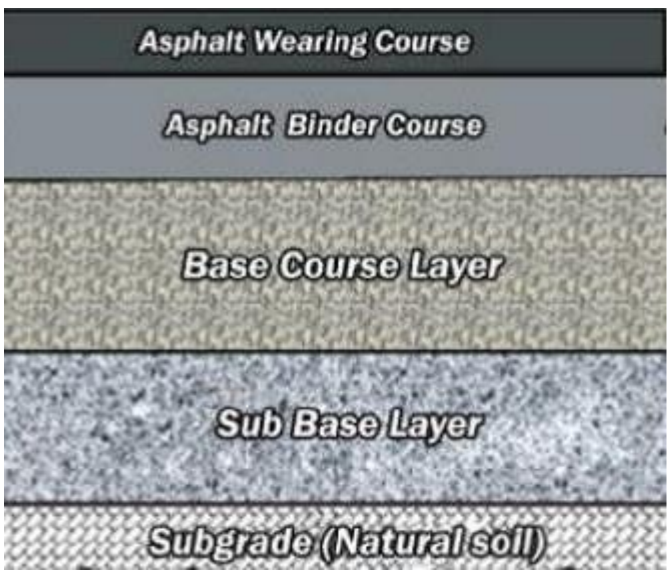

Figure 2-1: Typical Cross section of Flexible Pavement.

2.2. Asphalt Concrete (Bituminous 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.

Warm mix asphalt Concrete (WMA) is produced by adding either zeo-lites waxes, asphalt emulsions, or sometimes even water to the asphalt binder prior to mixing. This allows significantly lower mixing and laying temperatures and results in lower consumption of fossil fuels, thus releasing less carbon dioxide, aerosols and vapors. Not only are working conditions improved, but the lower laying-temperature also leads to more rapid availability of the surface for use, which is important for construction sites with critical time schedules. The usage of these additives in hot mixed asphalt (above) may afford easier compaction and allow cold weather paving or longer hauls.

- ✓ Cold mix asphalt concrete is produced by emulsifying the asphalt in water with (essentially) soap prior to mixing with the aggregate. While in its emulsified state the asphalt is less viscous and the mixture is easy to work and compact. The emulsion will break after enough water evaporates and the cold mix will, ideally, take on the properties of cold HMA. Cold mix is commonly used as a patching material and on lesser trafficked service roads.
- ✓ Cut-back asphalt concrete is produced by dissolving the binder in kerosene or another lighter fraction of petroleum prior to mixing with the aggregate. While in its dissolved state the asphalt is less viscous and the mix is easy to work and compact. After the mix is laid down the lighter fraction evaporates.

- ✓ Mastic asphalt concrete or sheet asphalt is produced by heating hard grade blown bitumen (oxidation) in a green cooker (mixer) until it has become a viscous liquid after which the aggregate mix is then added. Then bitumen aggregate mixture is cooked (matured) for around 6-8 hours and once it is ready the mastic asphalt mixer is transported to the work site where experienced layers empty the mixer and either machine or hand lay the mastic asphalt contents on to the road.
- ✓ Natural asphalt concrete can be produced from bituminous rock, found in some parts of the world, where porous sedimentary rock near the surface has been impregnated with upwelling bitumen.

2.3. Hot Mix Asphalt

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.

Requirements of Hot Mix Asphalt (HMA)

The bituminous mixture should possess the following properties

- ✓ ***Resistance to permanent deformation:*** - the mix should not distort or displace under traffic loading. The true test will come during high summer temperatures that soften the binder and, as a result, the loads will be predominantly carried by the aggregate structure.
- ✓ ***Resistance to fatigue and reflective cracking:*** - This is inversely related to the stiffness of the mix. While stiffer mixes are desirable for rut resistance, design for rut resistance alone may be detrimental to the overall performance of the HMA if fatiguing or reflective cracking occurs. Fatigue and reflective crack resistance are primarily controlled by the proper selection of the asphalt binder. Application of a specialty designed crack-resistant interlayer is another option for mitigating cracking.
- ✓ ***Resistance to low temperature (thermal) cracking:*** - cooler regions of are particularly confronted with thermal cracking concerns. Thermal cracking is mitigated by the selection of an asphalt binder with the proper low temperature properties.

- ✓ ***Durability:*** - The mix must contain sufficient asphalt cement to ensure an adequate film thickness around the aggregate particles. This helps to minimize the hardening and aging of the asphalt binder during both production and while in service. Sufficient asphalt binder content will also help ensure adequate compaction in the field, keeping air voids within a range that minimizes permeability and aging.
- ✓ ***Resistance to moisture damage (Stripping):*** - Loss 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.
- ✓ ***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. Aggregates play an important role in determining the nature and characteristics of pavement in preparing the structure of mutual-lock while the binder acts as glue between aggregate particles with layer below the surface of the road. The performance and property of HMA is mainly function of the characteristics of its constituents: asphalt binder and aggregate along with the quality of the construction process.
- ✓ ***Skid Resistance:*** - This is a concern for surface mixtures that must have sufficient resistance to skidding, particularly under wet weather conditions. Aggregate properties such as texture, shape, size, and resistance to polish are all factors related to skid resistance.

2.4. Components of Hot Mix Asphalt

HMA is a mixture that contains aggregate and bitumen fastened in to a strong mixture. Aggregates play an important role in determining the nature and characteristics of pavement in preparing the structure of mutual-lock while the binder acts as glue between aggregate particles with layer below the surface of the road.

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2.4.1. Aggregates

Aggregates (or mineral aggregates) are hard, inert materials such as sand, gravel, crushed rock, slag, or rock dust. Properly selected and graded aggregates are mixed with the asphalt binder to form HMA pavements. Aggregates are the principal load-supporting components of HMA pavement.

Aggregates can be classified to three types according to their size distribution: coarse aggregates, fine aggregates, and mineral filler. Coarse aggregates are generally defined as those retained on the 2.36-mm sieve i.e. it comprises the portion of the aggregates that has large particle sizes. Fine aggregates are those that pass through the 2.36-mm sieve and are retained on the 0.075-mm sieve. That is, the aggregate particles that can fill the voids created by the coarse aggregates in the mixture (Prowell et al., 2005). According to Chen, 2009, Mineral filler is defined as that portion of the aggregate passing the 0.075-mm sieve. It consists of very fine, inert mineral with the consistency of flour, which is added to the hot mix asphalt to improve the density and strength of the mixture. They can also be classified into two based on their ability to react with asphalt binder these are active fillers and inactive fillers.

2.4.1.1. Aggregate Gradation

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. In HMA, gradation influences almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage. Because of this, gradation is a primary concern in HMA mix design and thus most agencies specify allowable aggregate gradations. Inappropriate selections of aggregate gradation, aggregate properties, and binder grade, type and content are major contributors to rutting and cracking of HMA pavements. The effect of gradation on HMA performance has long been a controversial issue. A research done by Hand et al., 2002 revealed that strong opinions exist among industry experts as to which gradation type, ranging from fine to course to open-graded or stone matrix bituminous gradations, will provide the best performance.

The mixture resistance to permanent deformation is highly dependent on the aggregate structure. Several research studies have argued that giving more consideration to the aggregate gradation would be the solution for pavement rutting by enhancing the properties of the asphalt (Karakouzian, 1996). Aggregates are expected to provide a strong stone skeleton to resist repeated load applications. Shape, surface texture, angularity and gradation have a great influence on HMA performance.

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

- ✓ ***Dense-Graded Mixes:*** - are well-graded HMA has good proportion of all constituents are also called Dense bituminous macadam. When properly designed and constructed, a dense-graded mix is relatively impermeable. Dense-graded mixes are generally referred to by their nominal maximum aggregate size and can further be classified as either fine-graded or coarse-graded. Fine-graded mixes have finer and sand sized particles than coarse-graded mixes. It is suitable for all pavement layers and for all traffic conditions. It offers good compressive strength.
- ✓ ***Open-graded mixes:*** - are produced with relatively uniform-sized aggregate typified by an absence of intermediate-sized particles. Mixes typical of this structure are the permeable friction coarse and asphalt-treated permeable bases. Because of their open structure, precautions are taken to minimize asphalt drain-down by using modified binders like "asphalt rubber," or fibers. Stone-on-stone contact with a heavy asphalt cement particle coating typifies these mixes.
- ✓ ***Gap-graded mixes:*** - use an aggregate gradation with particles ranging from coarse to fine with some intermediate sizes missing or present in small amounts. The gradation curve may have a "flat" region denoting the absence of a particle size or a steep slope denoting small quantities of these intermediate aggregate sizes. These mixes are also typified by stone-on-stone contact and can be more permeable than dense-graded mixes or highly impermeable.
- ✓ ***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.

2.4.1.2. Properties of Aggregates

During production, construction, and during the service life of the road, the aggregates may be subjected to the effects of weather, climate, and a range of mechanical processes which together contribute to the deterioration in its physical condition. Therefore, when the construction of a road is necessary, it is important to obtain a material sufficiently durable to last the design life of the road in order that its performance is not affected by deterioration or degradation of the material.

The qualities required of aggregates are described in terms of shape, hardness, durability, cleanliness, bitumen affinity and porosity. In addition to these properties, the micro texture of the aggregate particles will also strongly influence the performance of a compacted HMA layer. Smooth-surfaced river gravel, even partly crushed, may not generate as much internal friction as a totally crushed aggregate from particles having a coarse micro texture. Therefore, aggregates should have the following characteristics. Aggregates should be:

- ✓ Angular and not excessively flaky in order to provide good mechanical interlocking between each other.
- ✓ Clean and free of clay and organic material.
- ✓ Strong enough to resist crushing during mixing, laying and providing service.
- ✓ Resistant to abrasion and polishing when exposed to traffic.
- ✓ Non-absorptive since highly absorptive aggregates are wasteful of asphalt binder and also give problem in mix design.
- ✓ Have good affinity with bitumen, hydrophilic aggregates may be acceptable only where protection from water can be guaranteed or a suitable adhesion agent is used.

2.4.2. Asphalt Binder

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 make bitumen one of the most complex molecules found in nature. On average, Bitumen is composed.

Table 2-1: ***Composition of Bitumen.***

Element	**Carbon wt, %**	**Hydrogen wt, %**	**Nitrogen wt, %**	**Sulfur wt, %**	**Oxygen wt, %**	**Vanadium, ppm**	**Nickel, ppm**
Mexican blend	83.77	9.91	0.28	5.25	0.77	180	22
Arkansas-Louisiana	85.78	10.19	0.26	3.41	0.36	7	0.4
Boscan	82.90	10.45	0.78	5.43	0.29	1380	109
California	86.77	10.94	1.10	0.99	0.20	4	6

(Source: U.S. Department of Health and Human Services).

Bitumen is the residual product obtained by fractional distillation of crude oil at the bottom fraction. It is one of the most complex molecules found in nature and the one with the highest boiling point. At ambient temperature in-situ, bitumen is solid and virtually non-volatile and the vapor pressure of in-situ bitumen is below the limit of detection for normal instrumentation. According to the publication of Asphalt Institute, 2011, bitumen is normally heated up to >140 ^{o}C in order to become liquid and to be facilitated its transportation and handling mechanisms. The physical properties of asphalt binder vary considerably with temperature. At high temperatures, asphalt binder is a fluid with low consistency similar to that of oil. At room temperature most asphalt binders will have the consistency of soft rubber. At sub-zero temperatures, asphalt binder can become very brittle. Generally, there are two sources of asphalt and these are: -

A. Natural asphalt is obtained from nature in that it is found in so called “asphalt lakes” around the world. Pit Lake, Trinidad; Gard, Auvergne, Ain and Haute Savoie in France; Central Iraq; Butin Island, Indonesia, etc are some of the sources for natural asphalt.

Further, a research by Meyer, 1991 disclosed that there is a huge deposit of Athabasca tar sands in northern Alberta which currently produces about 95% of all-natural asphalt in the world.

B. 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 types and grades of asphalt can be produced by using various operations. Vacuum and atmospheric distillations are the basic processes used in oil refineries to produce asphalt and other useful products.

2.4.2.1. Asphalt Binder Characteristics

Generally, asphalt binder has the following five characteristic properties:

- ✓ Adhesion

Bitumen has excellent adhesive qualities provided the conditions are favorable. However, in the presence of water the adhesion does create some problems. Most of the aggregates used in road construction possess a weak negative charge on the surface. The bitumen aggregate bond is because of a weak dispersion force. Water is highly polar and hence it gets strongly attached to the aggregate displacing the bituminous coating.

- ✓ Elasticity

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

- ✓ Plasticity

When temperatures are raised, as well as when a load is applied to bitumen, the bitumen will flow, but will not return to its original position when load is removed. This condition is referred to as plastic behavior.

- ✓ Visco-elasticity

Asphalt binder has a Viscoelastic character. Its behavior may be either viscous or elastic depending on the temperature or the load it is carrying. At higher temperatures and slow loading condition there is more flow or plastic behavior, while at a lower temperature, bitumen tends to be stiff and elastic. At intermediate temperatures it tends to be a combination of the two.

- ✓ Aging

Aging refers to changes in the properties of asphalt binder over time, which is caused by external condition. There are two stages of a pavement's life where oxidation can occur in the field.

- ✓ ***Hot mixing and construction:*** During the mixing and placement process the asphalt binder is exposed to elevated temperatures and a large contact area with the aggregates which can lead to rapid aging by volatilization and oxidation. The aging mechanism which includes the loss of volatiles and chemical oxidation that result from elevated mixing and placement temperatures falls under the primary process which is followed by oxidation in a secondary process during long term service.

- ✓ ***In-service:*** The constituent asphalt binder slowly ages as the oxygen from the surrounding environment percolates through the HMA and chemically reacts during the life of an in-service HMA pavement (Anderson, 1995).

2.4.2.2. Asphalt Rheology

Rheology, by definition, is the study of the flow and deformation of matter under the influence of an applied stress. Regarding the asphalt binder, the response to a stress is both dependent on temperature and loading time. Hence, the rheology of asphalt binder can be expressed by its stress-strain-time-temperature response.

Asphalt binders deform when subjected to loads and their properties also change with varying temperatures. Lay, 1990 proved on his research that the deformation is a combination of elastic response and viscous flow. In addition, study by Peterson et al., 1999 concluded that the magnitude of deformation, or mechanical response, is dependent on load magnitude, duration, and rate of application and the temperature state of the material. Since asphalt binders display both elastic and viscous response properties, they are classified as viscoelastic materials. An elastic material experiences recoverable deformation when subjected to a constant load and will immediately deform and maintain a constant strain when loaded. Also, the material will immediately return to its initial shape when the creep load is removed. A viscous Newtonian material, when subjected to a constant load, will deform at a constant rate until the load is removed. The deformation of the viscous material, however, will remain after the load is removed; hence, a viscous material experiences non-recoverable deformation.

Moreover, Kim et. al., 2003 have made an intense study and stated that, when viscoelastic material is subjected to a creep load, it experiences an immediate deformation followed by a continued time-dependent deformation. The immediate deformation corresponds to the material's elastic response and the time-dependent deformation corresponds to the material's viscous response. Once the load is removed, the viscous deformation component immediately ceases, but this deformation is not recovered and the delayed elastic deformation component is slowly recovered at a decreasing rate. Thus, a viscoelastic material experiences only a partial recovery of the deformation resulting from creep loading (Roberts et al., 2002). The viscoelastic behavior of asphalt can be characterized by its deformation resistance and the relative distribution of that resistance between the elastic component and the viscous component within the linear range (Kern and Carpenter, 1999). The relative distribution of the resistance between the elastic component and the viscous component is dependent on the asphalt cement characteristics and temperature and loading rate. The previous loading-response descriptions are for responses within the linear range, which is characterized by the deformation being directly proportional to the applied load at any time and temperature. Nonlinear loading responses are difficult to model for viscoelastic materials such as asphalt. Linear response models, however, are sufficient for the engineering analysis of asphalt binder response to the loading conditions and environmental stresses encountered in the field.

2.4.3. Filler Materials

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. It 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.

Filler material usually consists of rock powder, limestone powder, hydrated lime and Portland cement. 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.

Filler material shall pass the sieve size 0.075mm and must have properties such as cleanliness and purity, fineness and affinity for bitumen. 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. Type of filler material that often used is Portland cement, limestone and ash. The effect of filler material on pavement bituminous mixture based on type and rate such as effect of durability and deformation, potential impact, and impact value on Marshall testing.

2.5. Sugarcane Bagasse Ash

Sugar cane bagasse ash, a byproduct of sugar and alcohol production, is a potential pozzolanic material. However, its effective application in mortar and concrete requires first the controlled use of grinding and classification processes to allow it to achieve the fineness and homogeneity that are required to meet industry standards. So, this paper investigates the role of mill type and grinding circuit configuration in grinding in laboratory- and pilot plant-scale on the particle size, specific surface area and pozzolanic activity of the produced ashes. It was observed that, although different size distributions were produced by the different mills and milling configurations, the pozzolanic activity of the ground ash was directly correlated to its fineness, characterized by its 80% passing size or Blaine specific surface area. From a low pozzolanic activity of less than 50% of the as-received ash, values above 100% could be reached after prolonged grinding times.

Electric power requirements to reach the minimum pozzolanic activity were estimated to be in the order of 42 kwh/t in an industrial ball mill. Incorporation of an ultra-finely-ground ash in a high-performance concrete in partial replacement of Portland cement (10, 15 and 20% by mass) resulted in no measurable change in mechanical behavior, but improved rheology and resistance to penetration of chloride ions. (G.C. Cordeiro, R.D. Toledo Filho, L.M. Tavares, 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). It is in this light that a laboratory-based investigation for the replacement of cement with BA in Hot Mix Asphalt (HMA) was conducted. Tests on the suitability of materials used and their performance in terms of known engineering properties were carried out. Bitumen content of 4.5%, 5.5%, 6.5% and 7.5% was adopted. The focus involves the partial replacement of cement with BA in the following order, 0% (control), 10%, 20%, 30%, 40% and 50%. Seventy-two mix specimens were produced. The results obtained shows that the Cement/BA mixes exhibit satisfactory trend result with an average bitumen content of 5.5%.The results obtained shows that stability increases as BA content decreases, flows at 5.5% bitumen Content was observed to be fairly constant at roughly 2.5mm, the per cent air voids in the mix decreases with increasing bitumen content, the VMA values all fall within specification except for 30% BA replacement, the VMA value was 16% at 5.5% of Bitumen Content. Research by two scholars, 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%.

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

Port Harcourt, Nigeria, George Rowland Otoko, the initial setting time at 2% bagasse content is almost the same as for 0% but increase thereafter, may be due to reduction in the density of the mixture. The water cement ratio of 0.4 is kept constant for the different percentage replacement of cement by bagasse ash.

As 2 % replacement is rather small, it may not be of much economic value, replacing only 2% of the cement. It could therefore be concluded that no concrete strength increase was found by adding bagasse ash to concrete. As a result, the use of bagasse ash as concrete additive or cement replacement may need to be combined with other bonding materials such as, fly ash or slag. Only the pozzolanic reaction between SiO_2 in the fly ash or slag and CaO in the bagasse ash, along with the addition of water reducer or super plasticizer can improve the strength of bagasse ash concrete.

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

Several studies made by various researchers such as David D.M. Huwae, L.R.Parera and J.Tanijaya disclosed that the HRS mixture with a variation of filler containing 60% Bagasse-ash is the optimal composition than the others (20%, 40%, 80% and 100%). Result indicates that Bagasse-ash is suitable as filler based on testing with a variety of Bagasse-ash and cement content (Marshall-stability test 1205.040 kg; flow test 4.427 mm; Marshall- Quotient 273.717 kN/mm; VMA 20.249%; VFA 74.206% and VIM 5.223%). The use of Bagasse ash as filler can be reduced both the needs of cements filler and provides a fairly high economic value in addition to overcoming the existing waste.

Keeping the above stated researches in mind, the laboratory tests of this study was conducted using different specimen to check the possibilities of partially replacing cement with Sugarcane Bagasse Ash in Hot Mix Asphalt.

Filler is needed to stabilize the asphalt mixture. Asphalt mixture design is incomplete without filler. Filler is commonly selected for its ability to improve the adhesion between binders and aggregate (Imam, 2010). Various waste products can be used for several purposes, such as the replacement for a filler or binder material. These waste products can include industrial, agricultural and municipal solid waste. All these wastes should not be incinerated or discarded, but all of them can be utilized (Murana et al., 2013). This utilization of waste products can solve not only the environmental issue due to its disposal, but also can increase its economic value (Huwae and Tanijaya, 2013). Bagasse-ash is a combustion residual of sugar-cane with only 1% weight-loss and contains 73% silica. It can be categorized as a fibrous waste-product with ethanol vapor. It contains unburned carbon along with the other constituent presented in

Portland cement (Mohammed et al., 2009). The use of Bagasse-ash as a supplementary cementitious material to partially replaced Ordinary Portland Cement (OPC) not only helps reducing the methane emissions from organic waste, but also can improve its compressive strength (Sirirat and Supaporn, 2010). Previous research by Murana and Sani, 2015, shows that the mix containing 10% Bagasse-ash and 90% OPC at varying percentages of bitumen content have strength values which meet the standard specified in Asphalt Institute. The aggregate property of Bagasse-ash has also fulfilled the required properties of bitumen as binder. Therefore, it can be used for asphalt pavement. Both physical (size, shape and texture) and chemical composition (reactive silica and aluminous compound) of Bagasse-ash affect the improved compressive strength. Previous research by Osinubi and Thomas, 2007, shows that the tropical black cotton clay treated with a 10% of Bagasse-ash by weight of dry soil can increase soil strength properties. Therefore, Bagasse-ash with all its advantageous properties can be used as a substitute of fine aggregate. Previous researches indicate that Bagasse-ash mechanical properties (weight-density, aggregate size, fine aggregate absorption, and sand-equivalent) have fulfilled the requirements as filler in HRS mix (Mardhika, 2006). Kebon Agung sugar factory in Malang, Indonesia, can produce Bagasse-ash approximately 2737 tons/year. It should be used economically by utilizing Bagasse-ash as filler in asphalt mixture. Therefore, it will provide a fairly high economic value in addition to overcoming the existing waste. Bagasse-ash is also usually used as soil embankment for housing construction in the area surrounding the plant. Kebon Agung sugar factory, as a factory of sugar-cane processing, produce the waste (Bagasse-ash) which can be a source of pollution if not treated in proper ways of waste handling. The disposal of Bagasse-ash into the river is one example of the lack of waste treatment (Riza, 2001).

Bagasse is the fibrous residue obtained from sugarcane after the extraction of sugar juice at sugar cane mills. Bagasse ash is the residue obtained from the incineration of bagasse. Previously, bagasse was burnt as a means of solid waste disposal. However, as the cost of fuel oil, natural gas and electricity has increased, bagasse has come to be regarded as a fuel rather than refuse in the sugar mills. The fibrous residue used for this purpose leaves behind about 8-10% ash, known as bagasse ash (Aigbodion, V. S., 2010; Hailu, B., 2011).

R.Srinivasan and K.Sathiya revealed that sugarcane bagasse consists of approximately 50% of cellulose, 25% of hemicellulose and 25% of lignin. Each ton of sugarcane generates approximately 26% of bagasse (at a moisture content of 50%) and 0.62% of residual ash. The residue after combustion presents a chemical composition dominates by silicon dioxide (SiO_2). In spite of being a material of hard degradation and that presents few nutrients, the ash is used on the farms as a fertilizer in the sugarcane harvests. In this sugarcane bagasse ash was collected during the cleaning operation of a boiler operating.

On the other hand, three scholars, G. C. CORDEIRO, R. D. TOLEDO FILHO and E. M. R. FAIRBAIRN**,** recommended that the sugar cane bagasse can be an important raw material for the pozzolan production, mainly in tropical countries, where the culture of sugar cane is very important. Specifically, an amorphous ash with high specific surface area and reduced loss on ignition can be produced with burning at 600 °C in muffle oven. The pozzolanic activity of the bagasse can be attributed to the amorphous silica; Pozzolans can be produced with vibratory grinding of the sugar cane bagasse residual ash. In this case, the grinding in vibratory mill for 120 min enables the production of an ash with pozzolanic activity index of 100%; With the produced residual ash in ultrafine grinding during 120 min the cement replacement up to 20% is possible in high performance concrete with the improvement of the rheological properties, non-reduction of the compressive strength and with “very low” chloride-ion penetration.

The study by Rowland Otoko, 2014 reported that up to 2% of cement can only be replaced by the SCBA without adverse effect. In addition, the research of two Ethiopian scholars, Hailu and Prof. Abebe Dinku (2012), concluded that it is appropriate to replace 10% of cement with bagasse ash for expecting better concrete properties. Similarly, Abdolkarim Abbasi and Amin Zargar (2013) suggested that replacing cement by 10% of bagasse ash will optimize the workability and flow ability of the concrete. In addition, the compressive strength at 28 days is also increased by 25% as compared to normal concrete. Subsequently, research by Abdulkadir, et al (2014) concluded that 10% replacement of SCBA has the highest PAI and also, based on the compressive strength results 10% and 20% replacement of SCBA with compressive strengths of 22.3N/mm2 and 20.1N/mm2 are recommended for concrete. On the other hand, Srinivasan and Sathiya (2010) concluded that it is appropriate to partially replacing cement with SCBA up to 25% and the strength of concrete increased as the percentage of replacement increased. Kawade et al (2013) characterized SCBA and partially replaced cement with bagasse and observed that the strength of concrete increased up to 15% SCBA replacement. In conclusion, considering the achievements of the above stated studies, it is appropriate to partially replace cement with Bagasse ash in production and works of construction materials such as concrete and hot mix asphalt concrete.

2.5.1. Uses of 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 soil stabilization, specifically expansive clay.

A. Bagasse Ash as fuel/Ethanol producing Material

Bagasse is often used as a primary fuel source for sugar mills. When burned in quantity, it produces sufficient heat energy to supply all the needs of a typical sugar mill, with energy to spare. To this end, a secondary use for this waste product is in cogeneration, the use of a fuel source to provide both heat energy, which used in the mill, and electricity, which is typically sold on to the consumer electrical grid.

The resulting CO_2 emissions are less than the amount of CO_2 that the sugarcane plant absorbed from the atmosphere during its growing phase, which makes the process of cogeneration greenhouse gas neutral. In countries such as Australia, sugar factories contribute "green" power to the electricity grid. Florida Crystals Corporation, one of America's largest sugar companies, owns and operates the largest biomass power plant in North America. The 140 MW facilities use bagasse and urban wood waste as fuel to generate enough energy to power its milling and refining operations as well as supply enough renewable electricity for nearly 60,000 homes. Hawaiian Electric Industries also burns bagasse for cogeneration.

Ethanol produced from the sugar in sugarcane is a popular fuel in Brazil. The cellulose-rich bagasse is being widely investigated for its potential for producing commercial quantities of cellulosic ethanol. For example, until May 2015 BP was operating a cellulosic ethanol demonstration plant based on cellulosic materials in Jennings, Louisiana.

Bagasse's potential for advanced biofuels has been shown by several researchers. However, the compatibility with conventional fuels and suitability of these crude fuels in conventional engines has yet to be proven.

B. Bagasse as a Source of Raw Material for Pulp and Paper Manufacturing

Bagasse, as a non-wood fibrous, raw material for paper making is widely used in India, China and many parts of the world where the supply of forest based raw material is not adequate (Kumar and Singh, 2009). According to Kumar, *et. al.*, (2009) bagasse pulps are capable of producing paper with excellent formation, surface, smoothness, and sufficient strength as required in many grades of paper. The relatively low optical scattering power of bagasse pulp which has been considered as a major drawback of bagasse fibers can generally be increased by using more filler in paper, although w0ith usually some reduction in paper strength and stiffness (Kumar *et. al.*, 2009). On the other hand, bagasse, the sugar cane residue is found to be one of the best alternatives because of its low cost, longer fiber than straw, low refining energy consumption, and good sheet formation and paper smoothness, which enable the sugarcane bagasse to meet the quality requirements for news print and fine paper manufacture (Agnihotri, *et*. *al*, 2010). Thomas Rainey (2009), described bagasse as the fibrous residue that remains after sugar is extracted from sugar cane, is normally burnt in Australia (his country) to generate steam and electricity for the sugar factory. According to him, a study in to bagasse pulp was motivated by the possibility of making highly value-added pulp product from bagasse for the financial benefit of sugarcane millers and growers, and emphasized that bagasse pulp could replace eucalypt pulp which is more widely used in the local production of paper products. It seems, from the fact discussed above, that using one of the agricultural residues, bagasse, as a source of alternative raw material (fiber) seem to offer advantages over the use of trees for paper making. But as noted above, it is important to carry out careful life cycle analysis of any new raw materials before concluding that they would be preferable both from economic and environmental perspectives and evaluating such an alternative is the main application area of interest for this study. Historically, the first truly successful utilization of bagasse as a fibrous raw material on a commercial scale was for the manufacture of insulation board in 1920 by the

Cellotex Corporation in Marrero, Louisiana and later in 1939, the initial bagasse- based pulp and paper mill operations were carried out in Peru, Taiwan, and the Philippines (Singh, 2007). The use of bagasse in the manufacture of pulp and paper was regularly considered over the last 150 years whenever fiber shortages presented themselves and much research has been done, and still continuous, in the hope of strengthening the role of bagasse in the pulp and paper industry (Singh, 2007). According to this researcher, from all the non-wood fiber available to the pulp and paper industry in South Africa, bagasse seems the most favorable to use, since it is a byproduct of an established industry.

Chiparus (2004) is also in agreement with Singh (2007) that bagasse will be ahead of other crops as a source for the pulp and paper industry and estimated that the amount of bagasse produced annually about 80,000,000 metric tons (MT), from which 25,000,000 metric tons will be used for pulping (13% of the total paper making pulp capacity).

C. Bagasse Ash as a Soil Stabilizing 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 conform the suitability of this material for soil stabilization as an admixture with lime and cement. But still its suitability as a standalone material is still questionable.

2.5.2. Availability of Bagasse Ash in the World

India is the second largest producer of sugarcane in the world next to Brazil. India contributes 15% of the total sugarcane production 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. The agricultural area in India under sugarcane cultivation spans about 4.175 million hectares with an average yield of 70 tonnes 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. World sugarcane production of major countries during 2010-11 is illustrated in Figure1 below.

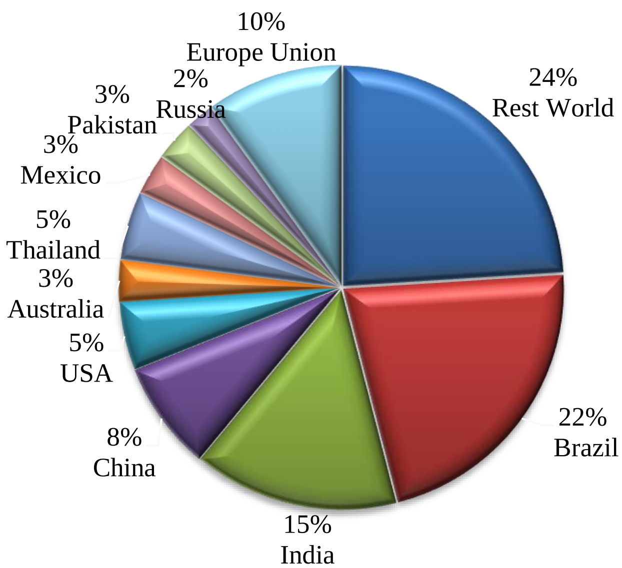


Figure 2-2: World Sugarcane Production (India statistics).

2.5.3. Availability of Bagasse Ash in 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. Table 3.5 summarizes the expected future sugar production of the country and the respective bagasse ash potential.

Table 2-2: ***Estimated bagasse ash potential of Ethiopia (Hailu, B., 2011).***

Factory	Expected future production of sugar (tons/year)	Estimated Bagasse (tons/year)	Estimated Bagasse Ash (tons/year)
Wonji-shoa	350,000	1,050,000	84,000
Methara	190,000	570,000	45,600
Fencha'a	270,000	810,000	648,000
Tendaho	600,000	1,800,000	144,000
New	2,500,000	7,500,000	600,000
Total	**3,910,000**	**11,730,000**	**938,000**

The above estimation is based on the targeted annual future sugar production in the country. Sugarcane consist about 30% bagasse, whereas sugar recovered is about 10% of the sugarcane, the bagasse leaves about 8-10% bagasse ash as a waste. As can be seen from the

Table 2-2 presents that about 0.94 million tons of bagasse ash is going to be generated annually when the five-year strategic plan comes into reality. Currently with sugar production of about 300,000 tons annually, the bagasse ash potential is about 72,000 tons annually.

Figure 2-3: Location of Sugar Factories in Ethiopia (Source: ESC).

2.5.4. Cement

Cement is a fine grey powder which when reacted with water hardens to form a rigid chemical mineral structure which holds the aggregates together acting as glue and gives concrete its strengths. The credit for its discovery is given to the Romans, who mixed lime ($CaCO_3$) with volcanic ash, producing a cement mortar which was used during construction of such impressive structures as the Colosseum. Naik T. et al reported that in 2000, the worldwide cement clinker production was approximately 1.6 billion tons. The consumption of cement correlates to the economic development of a country as a base for new building, factories and infrastructures which are the root of development. As a result of this cement manufacturing has increased sharply in those developing countries.

2.5.4.1. Types of cement

There are different types of cement depending on their composition, method of manufacturing (grinding, burning, etc.) and also the relative proportion of the different compounds. One of these types and the most commonly used one is Portland cement, which in turn is divided into many types. The other common type of cement is Portland pozzolana cement which contains some amount of pozzolanic materials.

2.5.4.1.1. Portland cement

Portland cement is one of the most widely used cement and is the most important hydraulic cement. It can also be used for mortar & plaster production. It is used in all types of structural concrete like walls, floors, bridges, tunnels, etc. It is further used in all types of masonry works like foundations, footings, dams, retaining walls, and pavements.

The origin of the name “Portland cement" is usually attributed to Joseph Aspdin, a brick mason in England who in 1824 took out a patent for making a powder made from mixed and ground hard limestone and finely divided clay. This forms into slurry and then is calcined in a furnace till the CO_2 was expelled. He called the resulting material Portland cement because when the mortar made with it hardened it produced a material resembling the stone which was quarried near Portland, England. The method of making cement has been improved upon since that time but the basic process has remained the same.

Modern Portland cement is made from materials which must contain the proper proportions of lime (CaO), silica (SiO_2), alumina (Al_2O_3), iron (Fe_2O_3) with minor amounts of magnesia and sulfur trioxide.

The most common classification of Portland cement is that of ASTM. It classifies Portland cement mainly into five groups (non-air entrained) differing only on the relative amount of the compounds and the degree of fineness.

- ASTM type I cement is a general-purpose Portland cement used when there is no special property required by the concrete.
- ASTM type II cement is Moderate Portland cement. It is also a general-purpose cement to be used when moderate sulphate resistance or moderate heat of hydration is desired.

- ASTM type III cement is High early strength Portland cement which is used when high early strength is desired, usually less than one week, it is usually used when a structure must be put into service as quickly as possible.
- ASTM type IV cement is Low -Heat of Hydration Portland cement which is used, when a low heat of hydration is required, like in mass concrete.
- Finally, ASTM type V is Sulphate -resisting Portland cement which is used when high sulphate resistance is desired.

2.5.4.1.2. Portland Pozzolana cement

Portland pozzolana cement (PPC) is manufactured by the inter-grinding of OPC clinker with 15 to 35 % of pozzolanic materials. Pozzolanic materials are siliceous or aluminous materials which by themselves possess little or no cementitious properties. But in the presence of water they react with calcium hydroxide which is liberated from the hydration of cement to form a compound possessing cementitious property.

The reaction of the pozzolanic materials with calcium hydroxide results in many advantages of PPC over OPC. If these pozzolanic materials were not reacted with the calcium hydroxide, free calcium hydroxide would have been present in the concrete resulting in higher permeability of the concrete and susceptibility to other attacks. The pozzolanic reaction reduces the porosity of the concrete by producing cementitious compound. It also reduces the heat of hydration since its reaction is slower than that of OPC, which implies that it has slower rate of strength than OPC, making it suitable for mass concrete construction.

In addition to these cement types there are also other types of cement which are produced by either adding other materials to the clinker or by forming other compounds during burning. They are collectively called modified Portland cements. Expansive cement, calcium sulfoaluminate cement, masonry cement, oil well cement, white cement etc. can be an example for this. There are also non-Portland inorganic cements which are used to some extent.

2.5.4.2. Hydration of cement

When water and Portland cement are mixed, the constituent compounds of the cement and the water undergo a chemical reaction resulting in hardening of the concrete. This chemical reaction of the cement and the water is called hydration, and it results in new compounds called hydration products. Both C3S and C2S react with water to produce an amorphous calcium silicate hydrate known as C–S–H gel which is the main „glue" which binds the sand and coarse aggregate particles together in concrete.

Each of the compounds found in the cement react with water, but the rate at which they react is different. C3S and C3A are the most reactive compounds, whereas C2S reacts much more slowly. Approximately half of the C3S present in typical cement will be hydrated by 3 days and 80% by 28 days, in contrast, the hydration of C2S does not normally proceed to a significant extent until approximately 14 days. Gypsum is added to lower the rate of

The rate and amount of heat of hydration are affected by various factors. Among these cement composition and fineness, water to cement ratio of the concrete, age of the paste and ambient conditions are the most common ones. Varying the cement composition affects the rate of reaction because the different compounds present in the cement have different speed of hydration.

The hydration of Portland cement as a whole is more complex than the individual compounds. This is because the different compounds have different products, reaction rate, and each of the compounds consumes water.

When cement is first mixed with water some of the added calcium sulfate, dissolve rapidly. The purpose of adding calcium sulfate is in order to retard the hydration of C3A, which

Bagasse ash as a cement replacing material without calcium sulfate results in flash set due its high rate of reaction with water. This is because C3A is more reactive than any of the compounds in the cement and if allowed will take much of the water. The order of reaction is C3A > C3S > C4AF > C2S. But the rate of hydration of these compounds differs from cement to cement depending on the fineness, the rate of cooling of the clinker and other factors like presence of impurities and other cement compounds.

2.5.4.3. Emissions from cement Manufacturing

Cement is a basic component of concrete used for infrastructure and civil engineering construction. On average approximately 1 ton of cement is produced each year for every human being in the world. Therefore cement is one of the World's most significant manufactured materials. Because of its abundance in the world market, understanding the environmental implications of cement manufacturing are becoming increasingly important. In Europe the use of cement and concrete (a mixture of cement, aggregates, sand and water) in large civic works can be traced back to antiquity. In 2008 there were 268 installations producing cement clinker and finished cement in the European Union with a total of 377 kilns. The cement industry is an energy intensive industry with energy typically accounting for about 40 % of operational costs, i.e. excluding capital costs but including electricity costs. In addition to this, the production of cement involves the consumption of large quantities of raw materials, energy, and heat. Cement production also results in the release of a significant amount of solid waste materials and gaseous emissions which is the most significant environment health and safety issue of cement manufacturing.

Cement manufacturing process is very complex, involving a large number of materials (with varying material properties), pyroprocessing techniques (e.g., wet and dry kiln, preheating, recirculation), and fuel sources (e.g., coal, fuel oil, natural gas, tires, hazardous wastes, petroleum coke). Cement manufacturing industry is under close scrutiny these days because of the large volumes of CO2 emitted. Actually this industrial sector is thought to represent 5–7% of the total CO2 anthropogenic emissions. Concern over the impact of anthropogenic carbon emissions on the global climate has increased in recent years due to growth in global warming awareness. In addition to the generation of CO2 the cement manufacturing process produces millions of tons of the waste product cement kiln dust each year contributing to respiratory and pollution health risks. The industry has made significant progress in reducing CO2 emissions through improvements in process and efficiency, but further improvements are limited because CO2 production is inherent to the basic process of calcinating limestone.
Life cycle assessment (LCA) is used to evaluate the impact of processes or products on the environment (Stajanca M., Estokova A., 2012).

Chapter 3 - Methodology

The preferred methodology of the research was experimental method. Generally, the study consists of three major experiment parts. The first part includes investigation of aggregate quality while the second part deals with the investigation of asphalt quality. Finally, the last experimental part deals with preparation of mix design for asphalt binder, aggregate and filler (cement and/or bagasse ash).

3.1. Materials

Materials used in the mix design of asphalt includes filler materials (BA and OPC), aggregates (fine and coarse) and binder(bitumen). The fibrous residue after crushing and extraction of juice from sugarcane was obtained from Wonji Shoa in Oromia Reginal State where it is found in abundance amount. Besides, it was burnt in open air to obtain the required ash. The fresh coarse and fine aggregate were obtained from road Contractor, Chinese Company IFH Engineering. The employed brand of the OPC was Mugar while the utilized bitumen was obtained from Addis Ababa IFH Engineering.

3.1.1. Material properties

Materials needed for this study are the constituents of hot mix asphalt and bagasse ash, Table 3-1 present sources of these materials.

Table 3.1: ***Material source***

Material	**Source**
Aggregate	Crushed stone
Binder	85/100 Penetration Bitumen Grade
Filler/ Cement	Mugar/OPC
Bagasse Ash	Wonji Shoa Sugar Factor

3.1.2. Aggregate

A wide variety of mineral aggregates have been used to produce asphalt concrete mixtures. The aggregate selected for this study was a crushed rock obtained from IFH Engineering of four different sizes to produce aggregate blend that meets the gradation specifications for asphalt mix. Accordingly, available aggregate materials; coarse aggregate (20-26.5) and (14-20), intermediate aggregate (6-14) and (3-6), fine aggregate (0-3) and filler, were integrated in order to get the proper gradation within the allowable limits according to ERA specifications using mathematical trial method.

Table 3-1: ***Particle Size Distribution for wearing Coarse for Nominal Size 19 mm (ERA, 2002)***

Sieve Size	Percentage of Passing
26.5	100
19	85-100
12.5	71-84
9.5	62-76
4.75	42-60
2.36	30-48
1.180	22-38
0.600	16-28
0.300	12-20
0.150	8-15
0.075	4-10

In order to define the properties of these aggregates, numerous laboratory tests have been conducted, these tests include:

- Sand Equivalent, (AASHTO: T176-86)
- Sieve Analysis (AASHTO T 27)
- Aggregate Impact Value, AIV, (BS 812, part 112)
- Specific gravity test (AASHTO T 85)
- Water absorption (ASTM C 127)
- Los Angles abrasion (AASHTO T 96-94)
- Flakiness Index (%), (BS: 812: Section 105.1:1989)
- Soundness loss by NaSO4, (AASHTO: T104-97)
- Aggregate Crushing Value, (BS: 812 Part 110 (1990)

- Ten Percent Fines Value, (BS: 812 part 110: 1990)

Results of the aggregate properties are presented in **Appendix-A,** in detail and summarized in chapter four of the paper.

3.1.3. Asphalt Binder

Asphalt binder 85/100 was used in this research. In order to evaluate bitumen properties number of laboratory tests have been performed. These tests include:

- Penetration (AASHTO M20-70)
- Softening point (AASHTO M20-70)
- Ductility (AASHTO T 51)
- Specific gravity (AASHTO T 228)
- Flash point (AASHTO T 48)
- Fire Point (AASHTO T 48)
- Loss on Heat (AASHTO-T47)

Results of the bitumen Tests are presented in **Appendix –B,** in detail and summarized in chapter eight of the paper.

3.1.4. Bagasse Ash

For this research the Sugarcane Bagasse Ash from Wonji sugar factory was used which is by product of the factory. Tests on Bagasse Ash are chemical composition (using complete silicate test).

3.1.5. Cement

The cement used for this research is obtained from Mugar cement factory of OPC type. Tests conducted were initial and final setting time and specific gravity. Results of the cement properties are presented in **Appendix –C,** in detail and summarized in chapter seven of the paper.

3.1.6. Optimum Bitumen Content

15 samples each of 1200 gm in weight were prepared using five different percentage of bitumen contents i.e. Three samples for one – percentage of bitumen content to have an average value. First the aggregates were heated to a temperature of 175 ^{o}C to 190 ^{o}C the compaction mould assembly and rammer were cleaned and kept pre-heated to a temperature of 100C to150 ^{o}C. The bitumen was also heated to a temperature of 135-170 ^{o}C and the required amount of first trial of bitumen and bagasse ash was added to the heated aggregate and thoroughly mixed. The mix was

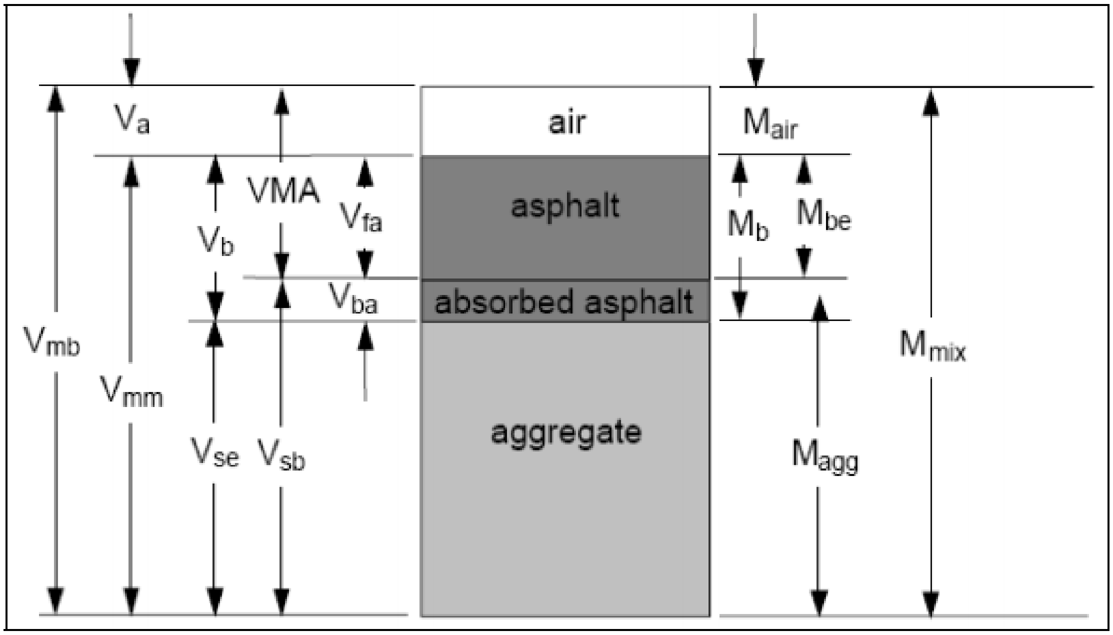
placed in a mould and compacted with 75 numbers of blows. The sample is taken out of the mould after minimum of an hour using sample extractor. Marshall Properties of the asphalt mix such as stability, flow, density and volumetric properties were obtained for various bitumen contents. Then the following graphs were utilized in order to determine the optimum bitumen content for the mix.

- Stability vs. Bitumen Content
- Flow vs. Bitumen Content
- Bulk Specific Gravity vs. bitumen Content
- Air voids (Va) vs. Bitumen Content
- Voids Filled with Bitumen (VFB) vs. Bitumen Content

According to Asphalt Institute the optimum bitumen content (OBC) for proposed mix is the average of three values of bitumen content i.e. bitumen content at the highest stability, bitumen content at the highest value of bulk density and bitumen content at 4% of air voids. 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.

3.1.7. Volumetric Properties of HMA Mixes

The volumetric properties of HMA mixes are air voids, voids in mineral aggregates and void filled with asphalt. These properties indicate the performance of the mixes in the field. The volumetric component diagram of HMA is shown in Figure 8 below.



All the components are defined in the following:

VMA = Volume of voids in mineral aggregate

V_{mb} = Bulk volume of compacted mix

V_{mm} = Voidless volume of paving mix

V_{fa} (VFA) = Volume of voids filled with asphalt

V_a = Volume of air voids

V_b = Volume of asphalt binder

V_{ba} = Volume of absorbed asphalt binder

V_{sb} = Volume of mineral aggregate (by bulk specific gravity)

M_{se} = Volume of mineral aggregate (by effective specific gravity)

M = Total mass of asphalt mixture

M_{be} = Mass of effective asphalt binder

M_{agg} = Mass of aggregate

M_{air} = Mass of air = 0

M_b = Mass of asphalt binder

For many years, three other volumetric parameters Va, VMA, and VFA, have been widely used and at various times have formed critical design thresholds (Christensen and Bonaquist, 2005). They are:

✓ **Percent Air Voids in compacted Mixture:-** The small air spaces between the coated aggregate particles in the total compacted paving mixture are called air voids. It can be determined by using the equation below.

$$Va = \frac{100 * Gmm - Gmb}{Gmm}$$

Where, Va = Air voids in compacted mixture, percent of total volume, Gmm= maximum specific gravity of paving mixture, Gmb= bulk specific gravity of compacted mixture.

✓ **Percent VMA in compacted Paving Mixture:-** It is the inter-granular void space between the aggregate particles in a compacted paving mixture. It includes the air voids and the effective asphalt content, expressed as a percent of the total volume. The objective is to furnish enough space for asphalt binder so as to provide adequate adhesion required to bind the aggregate. It is calculated as

$$VMA = \frac{100 * Gmb - Ps}{Gsb}$$

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

✓ **Percent VFA in Compacted Mixture:-** The percentage of the voids in mineral aggregates that contain asphalt, and not the absorbed asphalt is called Voids filled with asphalt (VFA). It is determined as

$$VFA = \frac{100 * VMA - Va}{VMA}$$

Where, VFA = Voids filled with asphalt, percent of VMA, VMA = Voids in mineral aggregates, percent of the bulk volume, Va = Air voids in compacted mixture, percent of total volume.

3.1.8. Statistical Analysis of Volumetric Test of Bagasse Ash Using ANOVA

Finally, the statistical analysis were performed to evaluate the significances of replacing Bagasse Ash instead of cement on marshal flow stability and volumetric properties of asphalt concrete using one-way analysis of variance (ANOVA) at constant bitumen content. The evaluation was done for percentage replacement of cement with bagasse ash 0%, 10%, 20%, 30%, 40% and 50%.

Chapter 4 - Analysis and Discussion

The results obtained from the conducted tests on aggregates all falls within the permissible and specified values quoted in the ERA Manual of specifications. Therefore, the adopted aggregate was found suitable for preparing the HMA design.

4.1. Aggregate

4.1.1. Gradation

Particle Size Distribution Curve for Aggregates

The results of particle size distribution test performed on the coarse and fine aggregates are presented in Figures 1. Coarse aggregate can be defined as all materials retained in sieve 2.36mm sieve. Since the coarse aggregate used for this study has zero percent (0%) passing sieve 2.36mm, it can be inferred that the aggregates meet the requirements. Fine aggregate is also defined as all materials passing 2.36mm sieve size. Since the fine aggregate used for this study satisfies this requirement, then it is suitable for use in asphalt concrete.

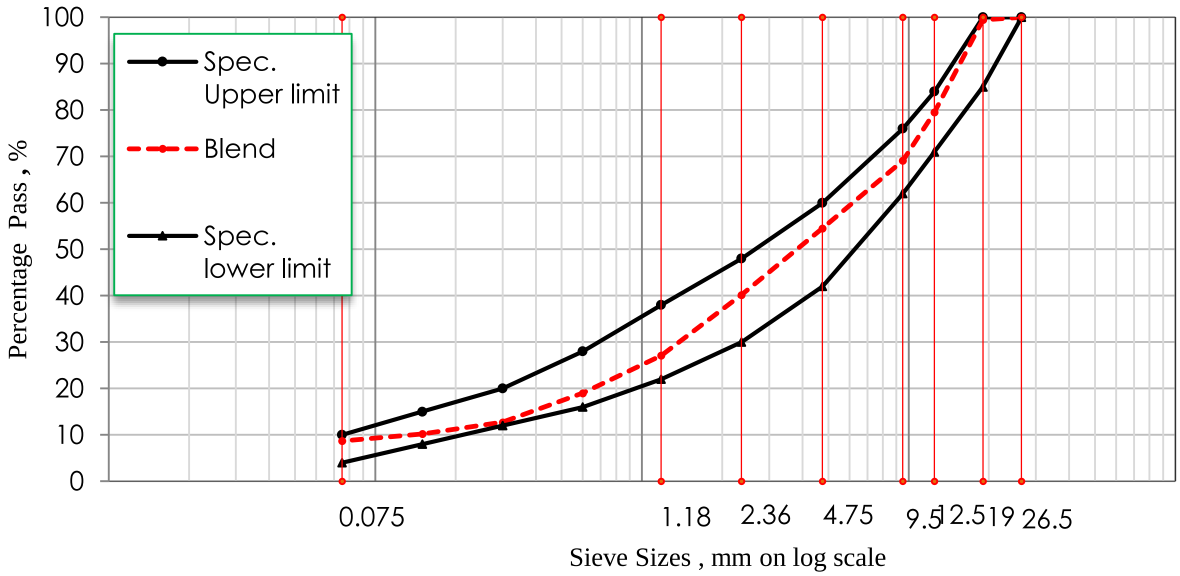


Figure 4-1: Particle Size Distribution Curve for Coarse and Fine Aggregate

Table 4-1: Individual & Blended Hot Bin Gradation for Hot Mixed Asphalt Mix Design

BA=0%																
Sieve size (mm)	**[Bin # 4] Average % pass**	**[Bin #4] 26.5 - 12.5 mm**	**[Bin # 3] Average % pass**	**[Bin #3] 12.5 - 9.5 mm**	**[Bin # 2] Average % pass**	**[Bin #2] 9.5 - 4.75 mm**	**[Bin # 1] Average % pass**	**[Bin #1] <4.75 mm**	**Cement Average % Pass**	**BA**	**BA Average % Pass**	**Cement**	**Blend**	**Specification limit [ERA Manual 2002]**		**Remark**
		27%		**17%**		**14%**		**40%**		**0.0%**		**2.0%**		**Lower Limit**	**Upper Limit**	
26.5	100.0	27.0	100.0	17.0	100.0	14.0	100.0	40.0	100.0	0.0	100.0	2.0	**100.0**	100	100	Ok!
19	98.0	26.5	100.0	17.0	100.0	14.0	100.0	40.0	100.0	0.0	100.0	2.0	**99.5**	85	100	Ok!
12.5	25.2	6.8	98.5	16.8	100.0	14.0	100.0	40.0	100.0	0.0	100.0	2.0	**79.6**	71	84	Ok!
9.5	1.2	0.3	75.8	12.9	99.2	13.9	100.0	40.0	100.0	0.0	100.0	2.0	**69.1**	62	76	Ok!
4.75	0.1	0.0	2.3	0.4	88.0	12.3	99.5	39.8	100.0	0.0	100.0	2.0	**54.5**	42	60	Ok!
2.36	0.1	0.0	0.1	0.0	8.5	1.2	92.4	37.0	100.0	0.0	100.0	2.0	**40.2**	30	48	Ok!
1.180	0.1	0.0	0.1	0.0	0.9	0.1	62.4	25.0	100.0	0.0	100.0	2.0	**27.1**	22	38	Ok!
0.600	0.1	0.0	0.1	0.0	0.4	0.1	42.3	16.9	100.0	0.0	100.0	2.0	**19.0**	16	28	Ok!
0.300	0.1	0.0	0.1	0.0	0.2	0.0	26.6	10.7	100.0	0.0	100.0	2.0	**12.7**	12	20	Ok!
0.150	0.1	0.0	0.1	0.0	0.2	0.0	20.3	8.1	100.0	0.0	100.0	2.0	**10.2**	8	15	Ok!
0.075	0.1	0.0	0.1	0.0	0.2	0.0	11.9	4.8	100.0	0.0	100.0	2.0	**6.8**	4	10	Ok!

Table 4-2: Percentage of Passing/Retained and Hot Bin Batch by Weight.

Hot bin Passing/Retained, %						
Fraction, mm	**26.5 - 12.5 mm**	**12.5 - 9.5 mm**	**9.5 - 4.75 mm**	**<4.75 mm**	**Cement**	**BA**
	Bin # 4	**Bin # 3**	**Bin # 2**	**Bin # 1**		
Plus 19.0 mm	2.0	0.0	0.0	0.0	0.0	0.0
19.0 mm to 9.5 mm	96.8	24.2	0.8	0.0	0.0	0.0
9.5 mm to 4.75 mm	1.2	73.5	11.2	0.5	0.0	0.0
4.75 mm to 2.36 mm	0.0	2.1	79.6	7.1	0.0	0.0
minus 2.36 mm	0.1	0.1	8.5	92.4	100.0	100.0
Total	100	100	100	100	100	100
Hot bin Batch Weights, g						
Fraction, mm	**26.5 - 12.5 mm**	**12.5 - 9.5 mm**	**9.5 - 4.75 mm**	**<4.75 mm**	**BA**	**Cement**
	Bin # 4	**Bin # 3**	**Bin # 2**	**Bin # 1**		
Plus 19.0 mm	6.3	0.0	0.0	0.0	0.0	0.0
19.0 mm to 9.5 mm	313.7	49.5	1.3	0.0	0.0	0.0
9.5 mm to 4.75 mm	3.7	149.9	18.8	2.4	0.0	0.0
4.75 mm to 2.36 mm	0.0	4.4	133.7	34.1	0.0	0.0
minus 2.36 mm	0.2	0.3	14.2	443.4	0.0	24.0
Total	324	204	168	480	0.0	24.0

Table 4-3: Individual & Blended Hot Bin Gradation for Hot Mixed Asphalt Mix Design.

BA=20 %																
PERCENT PASSING																
Sieve size (mm)	**[Bin # 4] Average % pass**	**[Bin #4] 26.5 - 12.5 mm**	**[Bin # 3] Average % pass**	**[Bin #3] 12.5 - 9.5 mm**	**[Bin # 2] Average % pass**	**[Bin #2] 9.5 - 4.75 mm**	**[Bin # 1] Average % pass**	**[Bin #1] <4.75 mm**	**BA Average % Pass**	**BA**	**Cement Average % Pass**	**Cement**	**Blend**	**Specification limit [ERA Manual 2002]**		**Remark**
		27%		**17%**		**14%**		**40%**		**0.4%**		**1.6%**		**Lower Limit**	**Upper Limit**	
26.5	100.0	27.0	100.0	17.0	100.0	14.0	100.0	40.0	100.0	0.4	100.0	1.6	**100.0**	100	100	Ok
19	98.0	26.5	100.0	17.0	100.0	14.0	100.0	40.0	100.0	0.4	100.0	1.6	**99.5**	85	100	Ok
12.5	25.2	6.8	98.5	16.8	100.0	14.0	100.0	40.0	100.0	0.4	100.0	1.6	**79.6**	71	84	Ok
9.5	1.2	0.3	75.8	12.9	99.2	13.9	100.0	40.0	100.0	0.4	100.0	1.6	**69.1**	62	76	Ok
4.75	0.1	0.0	2.3	0.4	88.0	12.3	99.5	39.8	100.0	0.4	100.0	1.6	**54.5**	42	60	Ok
2.36	0.1	0.0	0.1	0.0	8.5	1.2	92.4	37.0	100.0	0.4	100.0	1.6	**40.2**	30	48	Ok
1.180	0.1	0.0	0.1	0.0	0.9	0.1	62.4	25.0	100.0	0.4	100.0	1.6	**27.1**	22	38	Ok
0.600	0.1	0.0	0.1	0.0	0.4	0.1	42.3	16.9	100.0	0.4	100.0	1.6	**19.0**	16	28	Ok
0.300	0.1	0.0	0.1	0.0	0.2	0.0	26.6	10.7	100.0	0.4	100.0	1.6	**12.7**	12	20	Ok
0.150	0.1	0.0	0.1	0.0	0.2	0.0	20.3	8.1	100.0	0.4	100.0	1.6	**10.2**	8	15	Ok
0.075	0.1	0.0	0.1	0.0	0.2	0.0	11.9	4.8	100.0	0.4	100.0	1.6	**6.8**	4	10	Ok

Table 4-4: Percentage of Passing/Retained and Hot Bin Batch by Weight.

Hot bin Passing/Retained, %						
Fraction, mm	**26.5 - 12.5 mm**	**12.5 - 9.5 mm**	**9.5 - 4.75 mm**	**<4.75 mm**	**Cement**	**BA**
	Bin # 4	**Bin # 3**	**Bin # 2**	**Bin # 1**		
Plus 19.0 mm	2.0	0.0	0.0	0.0	0.0	0.0
19.0 mm to 9.5 mm	96.8	24.2	0.8	0.0	0.0	0.0
9.5 mm to 4.75 mm	1.2	73.5	11.2	0.5	0.0	0.0
4.75 mm to 2.36 mm	0.0	2.1	79.6	7.1	0.0	0.0
minus 2.36 mm	0.1	0.1	8.5	92.4	100.0	100.0
Total	100	100	100	100	100	100
Hot bin Batch Weights, g						
Fraction, mm	**26.5 - 12.5 mm**	**12.5 - 9.5 mm**	**9.5 - 4.75 mm**	**<4.75 mm**	**BA**	**Cement**
	Bin # 4	**Bin # 3**	**Bin # 2**	**Bin # 1**		
Plus 19.0 mm	6.3	0.0	0.0	0.0	0.0	0.0
19.0 mm to 9.5 mm	313.7	49.5	1.3	0.0	0.0	0.0
9.5 mm to 4.75 mm	3.7	149.9	18.8	2.4	0.0	0.0
4.75 mm to 2.36 mm	0.0	4.4	133.7	34.1	0.0	0.0
minus 2.36 mm	0.2	0.3	14.2	443.4	4.8	19.2
Total	324	204	168	480	4.8	19.2

4.1.2. Aggregate Quality

Table 4-5, presents with the strength properties which are the measures of mechanical properties of aggregate, crushing and impact tests such as Los Angeles Abrasion test, Flakiness Index, Sand Equivalent, Soundness test and specific gravity (measure of aggregates density).

Table 4-5: ***Comparison of test result on aggregates with standard specifications***

Test Type	*Test Method*	*Av. Test Result*	*Standard Deviation*	*Specification Requirement*
Aggregate Crushing Value, ACV	BS:812 Part 110 (1990)	12	0.1643079	max.25%
Ten Percent Fine Value, TFV	BS: 812 part 110:1990	90	1.2082178	>35
Los Angeles Abrasion, LAA	AASHTO: T 96-94	13	0.12472	max.30%
Aggregate Impact Value, AIV	BS 812, part 112	8.1		max 25%
Flakiness Index, FI	BS: 812: Section 105.1:1989	22		max.35%
Soundness	AASHTO: T104-97	4.403	0.466813	max.12%
Sand Equivalent	AASHTO: T176-86	76.8	1.4580567	-
Specific Gravity of Coarse Aggregate	AASHTO: T85-91	2.639		-
Water Absorption	ASTM C 127	1.9	0.0721	max 2%
Stripping	-	>95		>95

4.2. Bitumen

The results obtained on the table below, Table 4-6 are compared with the standard code of practice to assess for its quality for usage. The obtained results of the conducted tests indicated that the selected bitumen is relevant to use for preparing the required mix.

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. The comparison was as shown in Table 4-6 below. According to the test results, the penetration, viscosity, flash and fire point, ductility, solubility and specific gravity of the bitumen falls within the permissible limit ranges that is specified on ERA Manual code, 2002. Therefore, the material can be used in preparation of HMA mix design.

Table 4-6: ***Bitumen Test Result Comparison***

Test Type	Test Method	Av. Test Result	Standard Deviation	Qualification Requirement
Penetration (25C^o,100g, 5Sec)	AASHTO M20-70	91.5	0.54433	85-100
Softening point (C^o)	AASHTO M20-70	48.3	6.18241	42-51
Ductility (25C^o)	AASHTO M20-70	120	0.12472	>100
Specific Gravity	AASHTO-T228	1.014	0.0003	1.010-1.060
Flash Point (C^o)	AASHTO-T228	310	0.471405	>232
Fire Point (C^o)	AASHTO-T228	345	0.816497	-

4.3. Bagasse Ash

The chemical composition of bagasse ash was determined by using complete silicate test and its constituents are shown on the table below, Table 4-7. and according to the specified ASTM standard, materials which contains a combined ingredient weight of silica, aluminum and iron oxides more than 50% by its weight of fraction can be deduced to be class C (Statistically, $Si0_2$ + Al_20_3 + Fe_20_3 = 68.48%). Hence, it can partially replace cement and used as a mineral filler in HMA design. Moreover, 100% of the adopted Bagasse Ash passes 0.075 mm sieve which is almost the same size with cement and signifies that the bagasse ash is suitable for use in HMA.

Table 4-7: ***Chemical Composition of Bagasse Ash***

Component	Weight of Fraction (%)
SiO_2	57.04
Al_2O_3	6.88
Fe_2O_3	4.56
CaO	1
MgO	1.96
Na_2O	6.2
K_2O	5.08
MnO	0.2
P_2O_5	1.18
TiO_2	0.21
H_2O	2.47
LOI	14.72

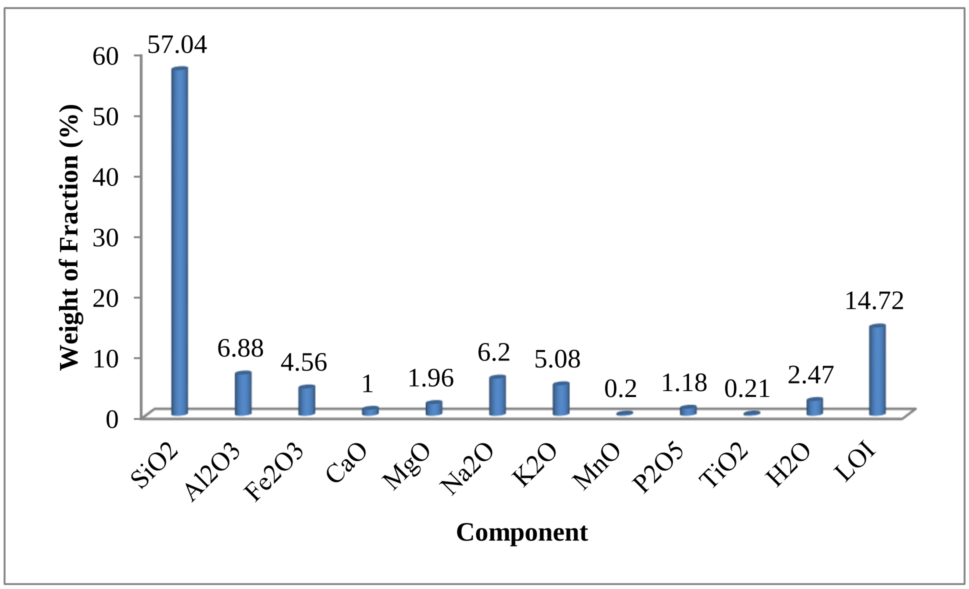


Figure 4-2: Chemical Composition of Bagasse Ash

4.4. Cement

The obtained results were compared with the standard specification and it was observed that the adopted OPC fulfills the requirements stipulated on the specification. Hence, the cement is suitable for use in HMA pavement work. The detailed results and comparative analysis is presented on Table 4-8 below.

Table 4-8: ***Comparison of Test Result on Cement with Standard Specification***

Test	Av. Test Result	Standard Deviation	Standard Specification
Specific Gravity	3.152		3.152
Initial Setting Time	2 hrs & 20 min	-	≥45min
Final setting Time	6 hrs & 42 min	-	≤10hr
Compressive Strength (Mpa)			
1day	9.9	2.708423	-
7day	22.4	0.634210	≥16MPa
28day	44.5	0.665000	≥42.5MPa
Bending Strength (Mpa)			
1day	2.4	0.509902	-
7day	4.7	0.329983	≥3.5MPa
28day	7.2	0.244949	≥6.5MPa

4.5. Marshall Test

The variation of Marshall Properties with several bitumen contents for mixes containing varying proportion of filler are shown through Figure 4-3 to Figure 4-9. Consequently, discussion on Marshall Mix design is presented accordingly.

4.5.1. Bulk Specific Gravity

Figure 4-3, shows the relationship between Bulk Specific Gravity and Bitumen Content. The test result shows that Bulk Specific Gravity slightly increases with increasing bitumen content. Among the proportion, 30% bagasse ash has higher Bulk specific gravity value and the bulk specific gravity decreased as the proportion of Bagasse increased from 0% bagasse ash to 50% bagasse ash.

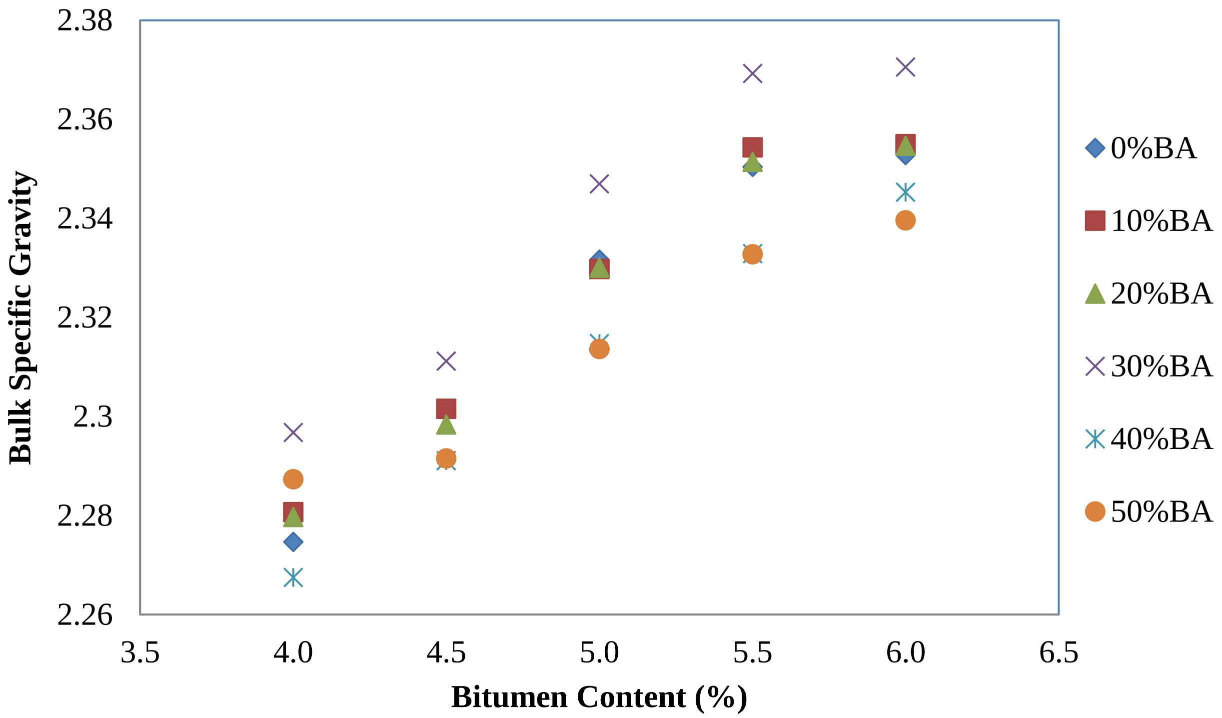


Figure 4-3: Variation of Bulk Specific Gravity (BSG) with Binder Content

4.5.2. Theoretical Maximum Specific Gravity

Figure 4-4, presents the relationship between Marshall Test results of Theoretical Maximum Specific Gravity and binder content. The test results indicated that the theoretical maximum specific gravity decrease with increasing of binder content for all proportions. However, the result for the proportion of 30% bagasse ash higher than the others while rest are almost in similar manner increasing from lower to higher bagasse ash percentage proportion for all binder content.

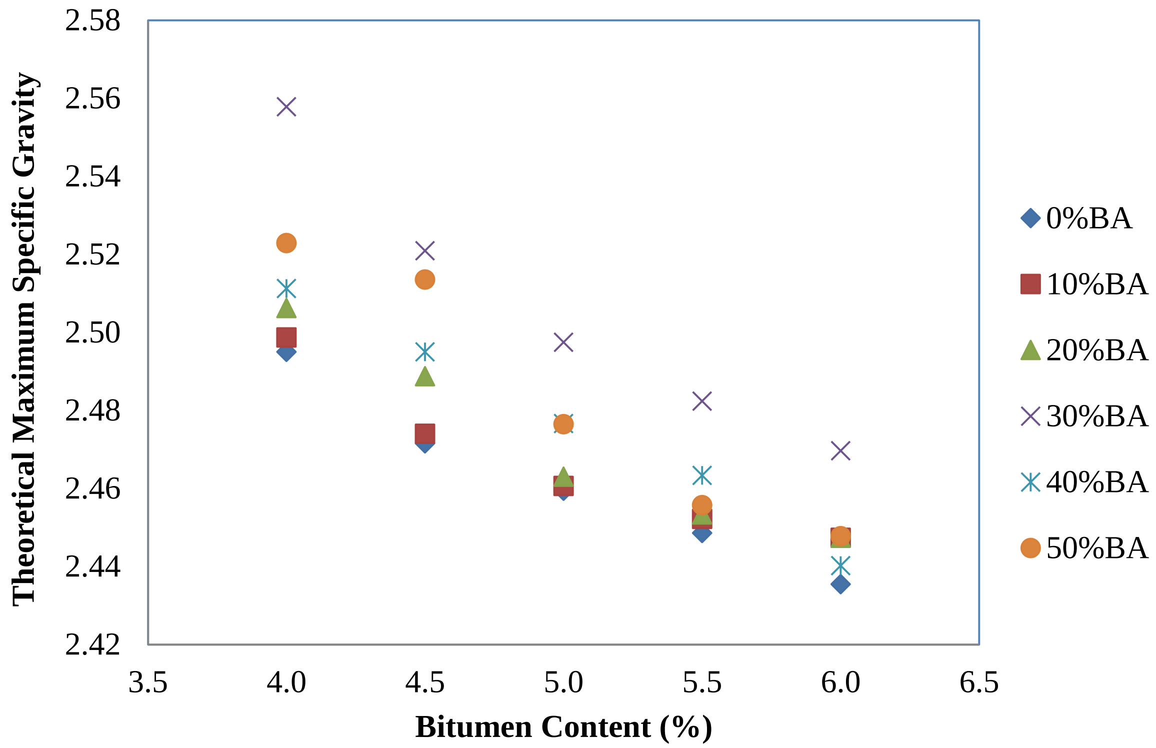


Figure 4-4: Variation of Maximum Specific Gravity (Gmm) with Binder Content

4.5.3. Void in Mix

Figure 4-5, shows the relationship between laboratory test results of void in mix with bitumen content. As indicated on the figure, the void in mix decreases as bitumen content increase in which most of them falls within 3 to 5. The value for the proportions with 0%, 10% and 20% bagasse ash has shown a good trend as most of the points fall within the specification limit.

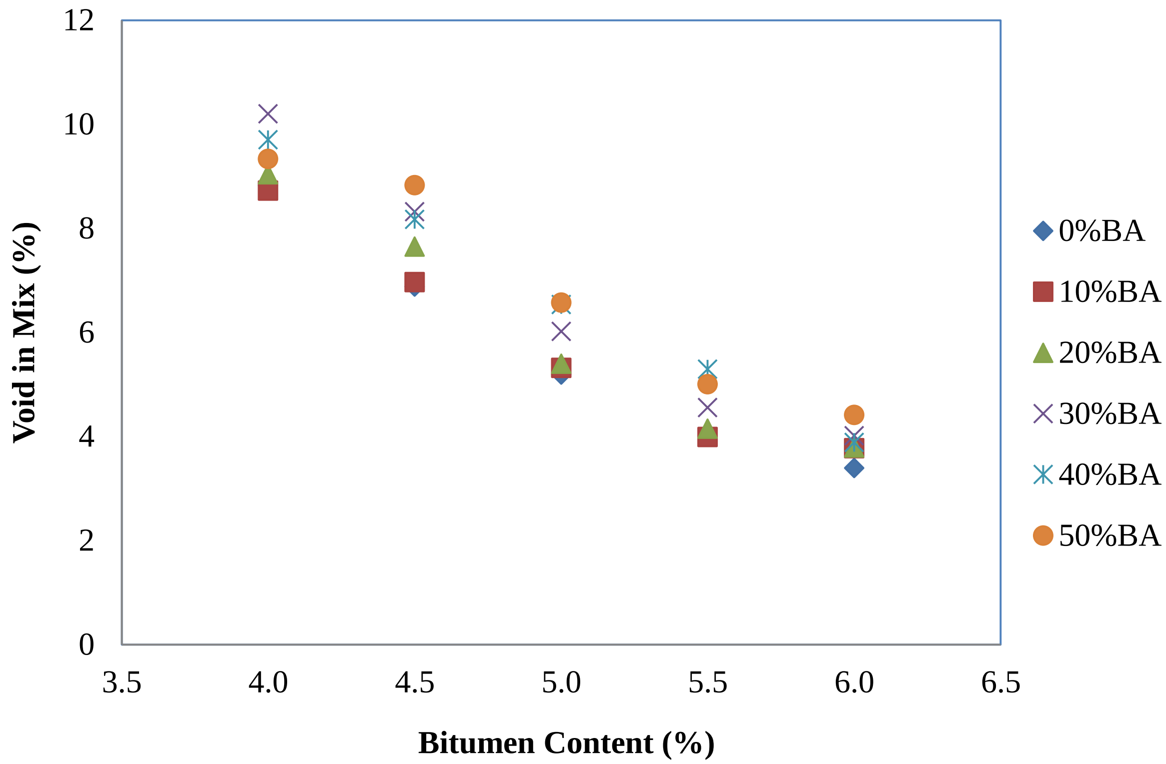


Figure 4-5: Variation of Void in Mix (VIM) with Binder Content

4.5.4. Void Filled with Asphalt

Figure 4-6, presents the relationship between Void filled with asphalt and binder content. The combined graph shows all percentage proportion of bagasse ash void filled with asphalt increase with increasing of bitumen content. Accordingly, from the given proportion the void filled with asphalt value for 20% bagasse ash are fall within the standard requirement (65 to 75).

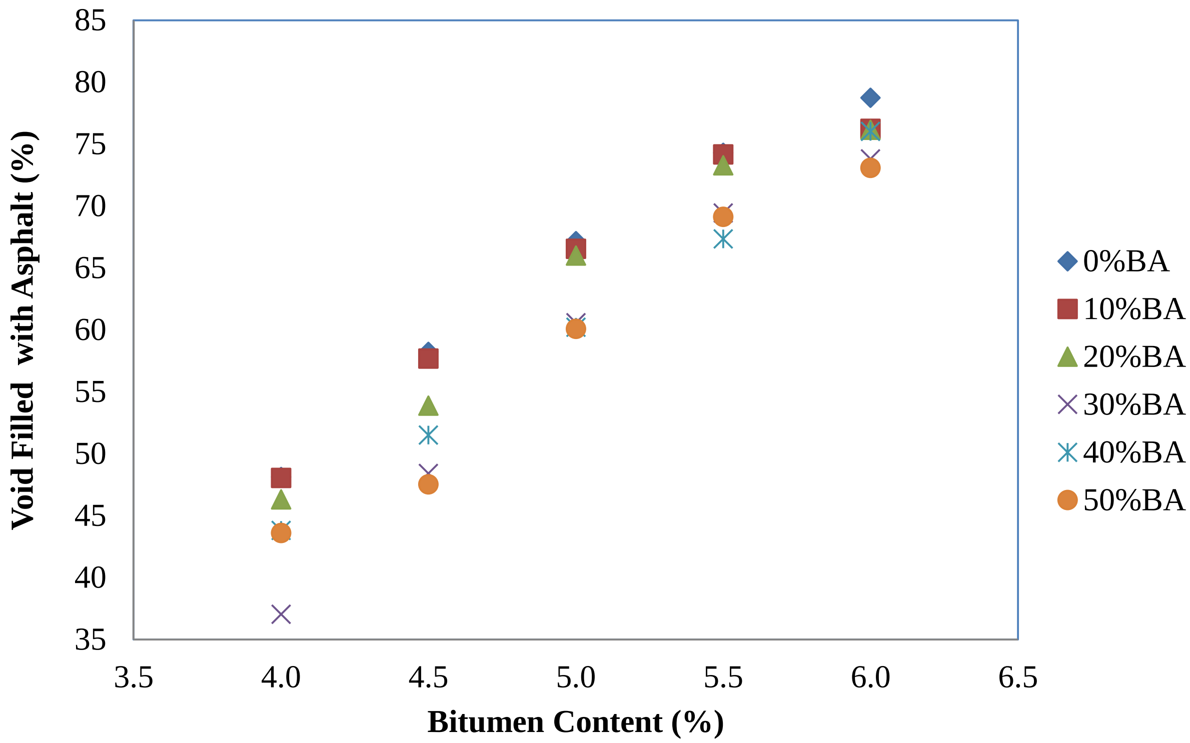


Figure 4-6: Variation of Void Filled with Asphalt (VFA) with Binder Content

4.5.5. Stability

Figure 4-7 presents the relationship between the test result of stability and bitumen content. According to design criteria stated in Asphalt Institute Marshall design, stability increases first and then decrease as percentage of bitumen content increase. As it seen from the figure 30% bagasse ash is out of the requirement while the rests have almost a similar manner with the standard requirement. Overall it is observed that, 20% bagasse ash content has better fit the requirement as it increased first with the increasing of bitumen and then decrease as bitumen continue to increase. The value of 5.5% of bitumen content gave rise to approximately constant Stability value of 20% bagasse ash.

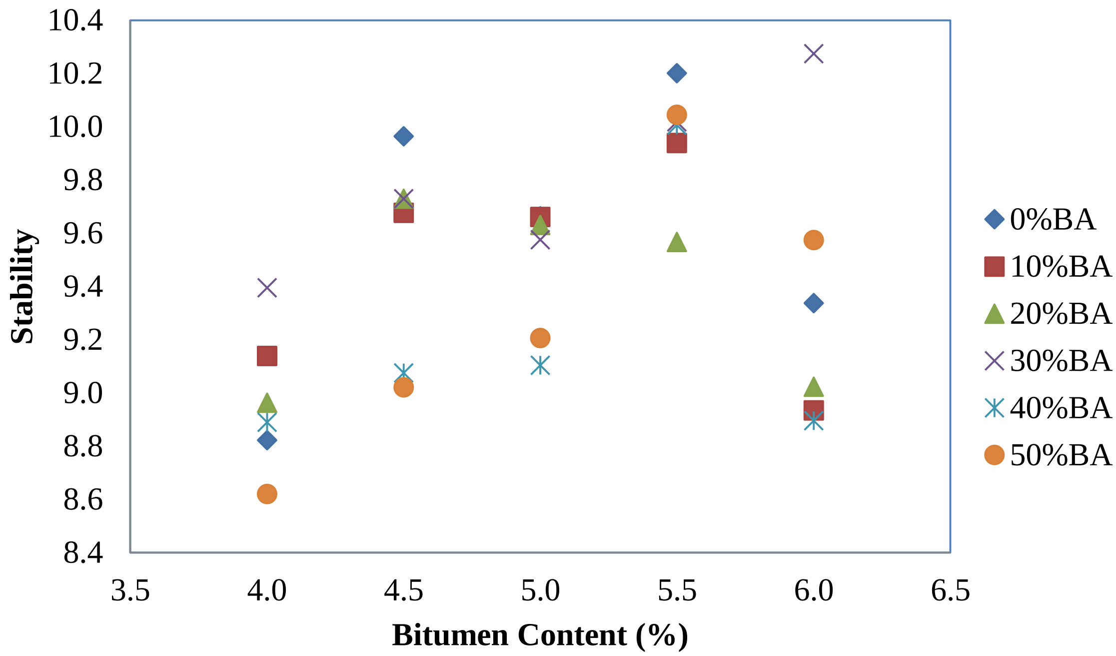


Figure 4-7: Variation of Stability with Binder Content

4.5.6. Marshall Quotient (Stability to Flow Ratio)

Since Marshall Quotient (MQ) is an indicator of the resistance against the deformation of the asphalt concrete, MQ values are calculated to evaluate the resistance of the deformation of the asphalt concrete with different percentage proportion of bagasse ash filler. A higher value of MQ indicates a stiffer mixture and, hence, indicates that the mixture is likely more resistant to permanent deformation. Accordingly, Figure 4-8 presents the relationship between Marshall Quotient test result and binder content.

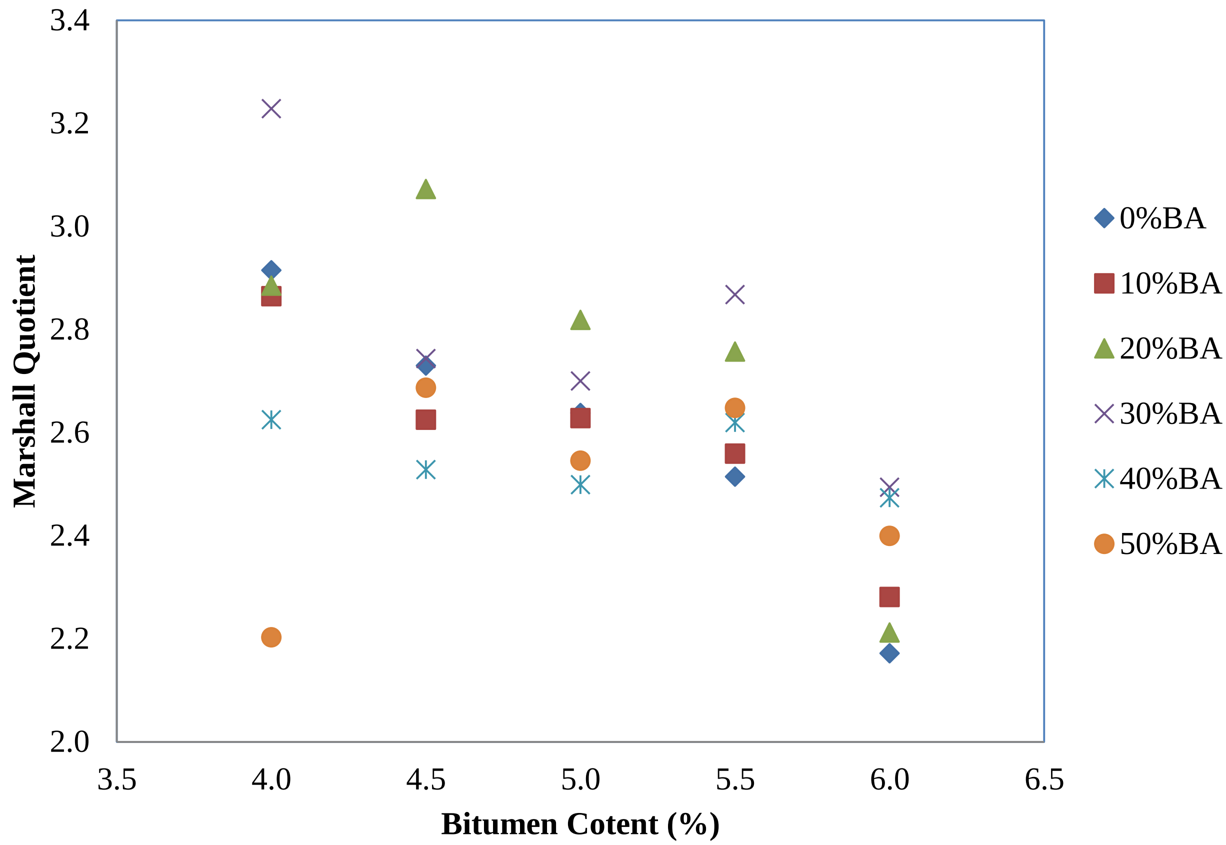


Figure 4-8: Variation of Marshall Quotient with Binder Content

4.5.7. Flow

The combined graph of flow with bitumen content show how the flow value increases with the increasing of bitumen content. As shown on the figure the flow value for 20% bagasse ash happen to be perfect while others fail. It can also deduce that flow at 5.5% bagasse ash, are fairly constant. At this binder content, the flow value for all bagasse ash proportion shows the same manner (increasing).

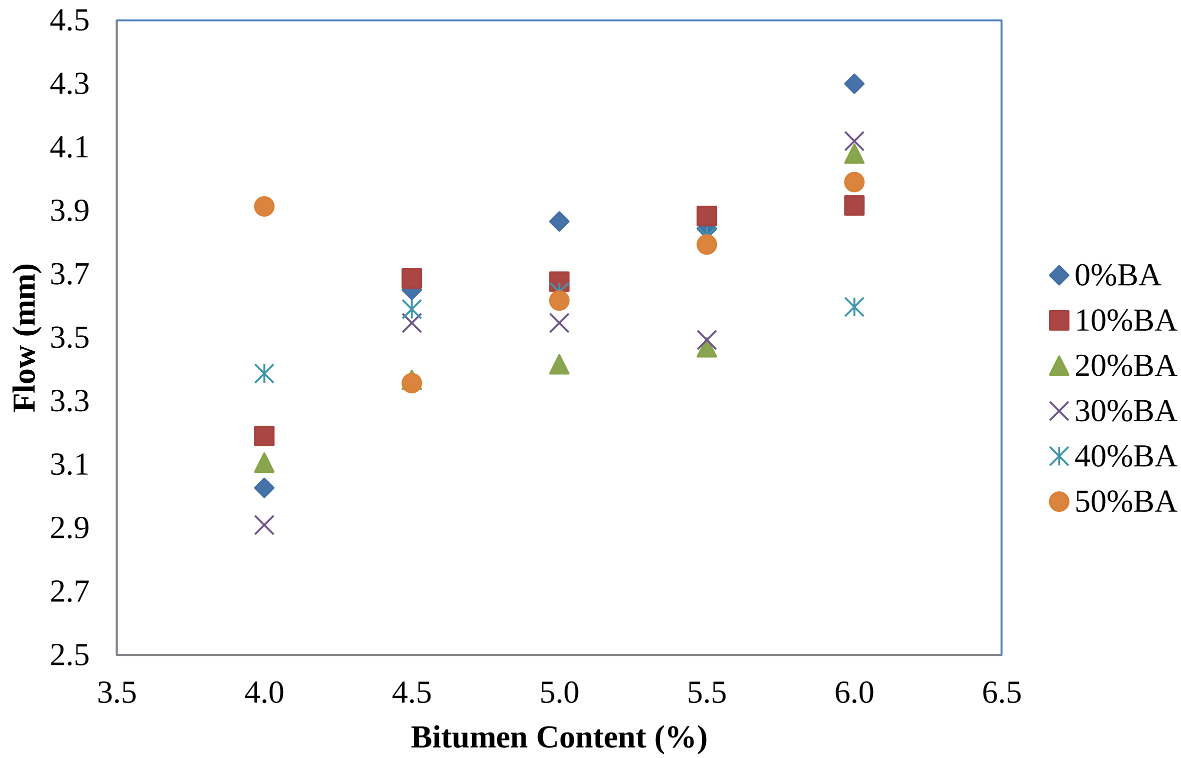


Figure 4-9: Variation of Flow with Binder Content

4.5.8. Void in Mineral Aggregate

Figure 4-10, presents the relationship between Void in Mineral Aggregate and binder content. The combined graph shows all percentage proportion of bagasse ash void in mineral aggregate decrease with increasing of bitumen content up to 5.5% bitumen content and then increase with bitumen content. Accordingly, for all the given proportion the void in mineral aggregate (VMA) value is fall within the standard requirement i.e. >14.

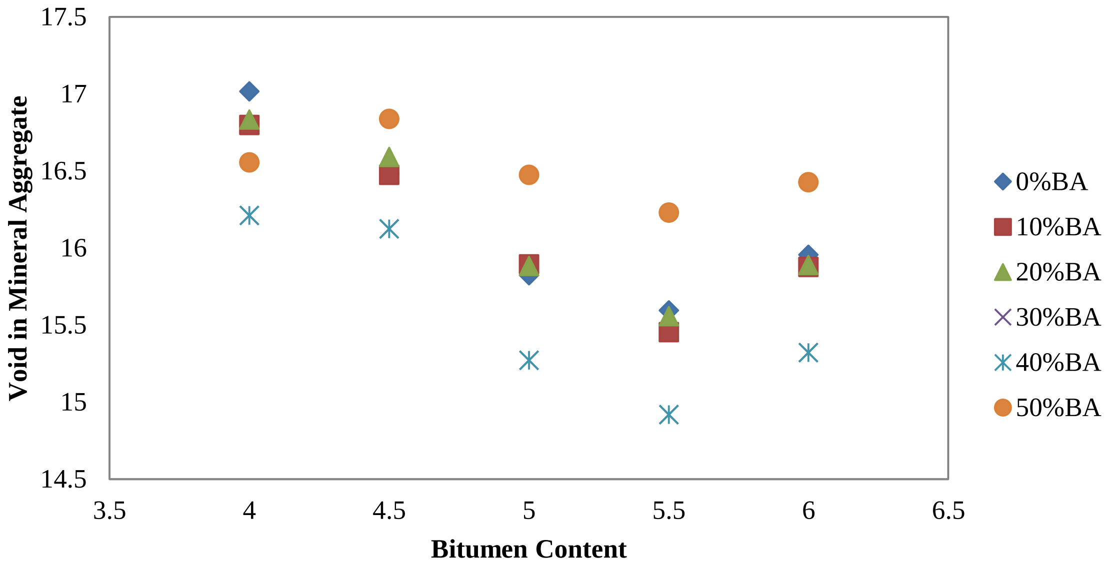


Figure 4-10: Void in Mineral Aggregate with Bitumen Content.

4.5.9. Optimum Binder Content (OBC)

In order to produced asphalt concrete using 20% bagasse ash which is suitable and fulfill the all requirements for partial replacement of cement with bagasse ash filler material, the optimum bitumen content should be obtained. Accordingly, OBC was determined based on Marshall testing analysis using the average value of the binder content corresponding to maximum stability, maximum bulk specific gravity and 4% air void was calculated. Total conventional sample was 15 samples with 3 samples for each percentage and it was conducted for 4% to 6% bitumen content. Therefore, from the calculation optimum binder content became 5.5% and the corresponding values of asphalt performance tests (density, stability, flow, void fill with bitumen and void in total mix) shown on the graph from Figure 4-11 through Figure 4-16 below.

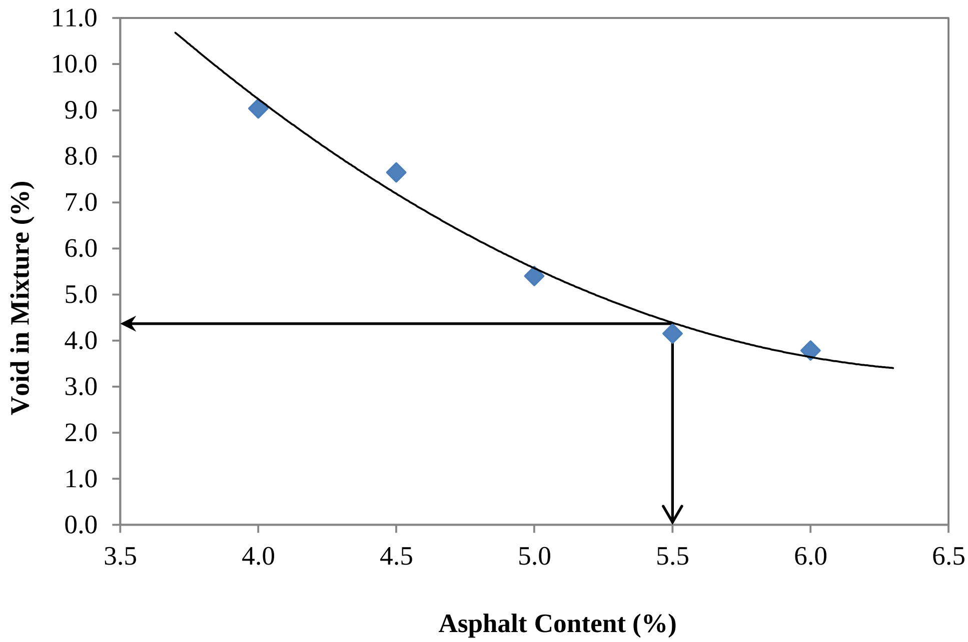


Figure 4-11: Void in Mixture at Optimum Binder Content

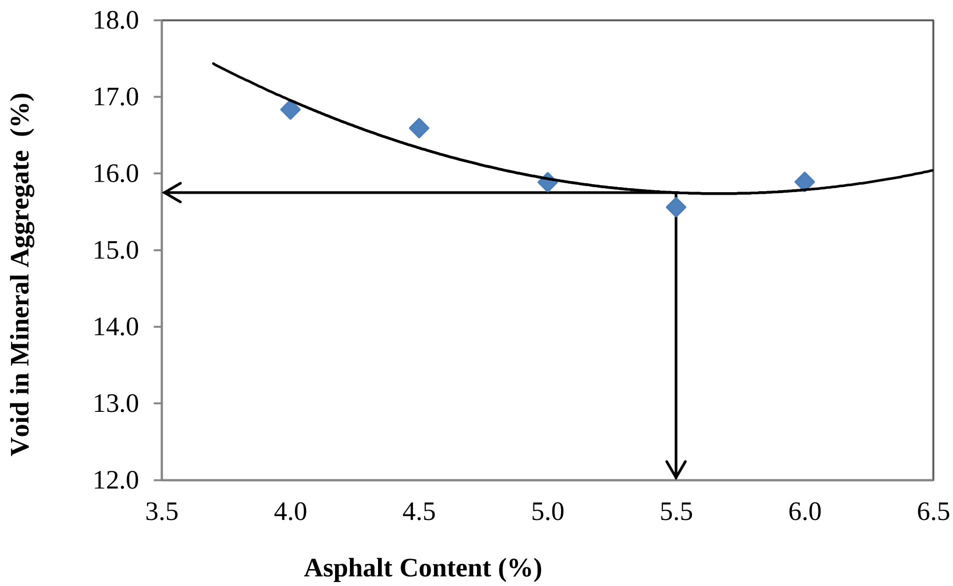


Figure 4-12: Void in Mineral Aggregate at Optimum Binder Content

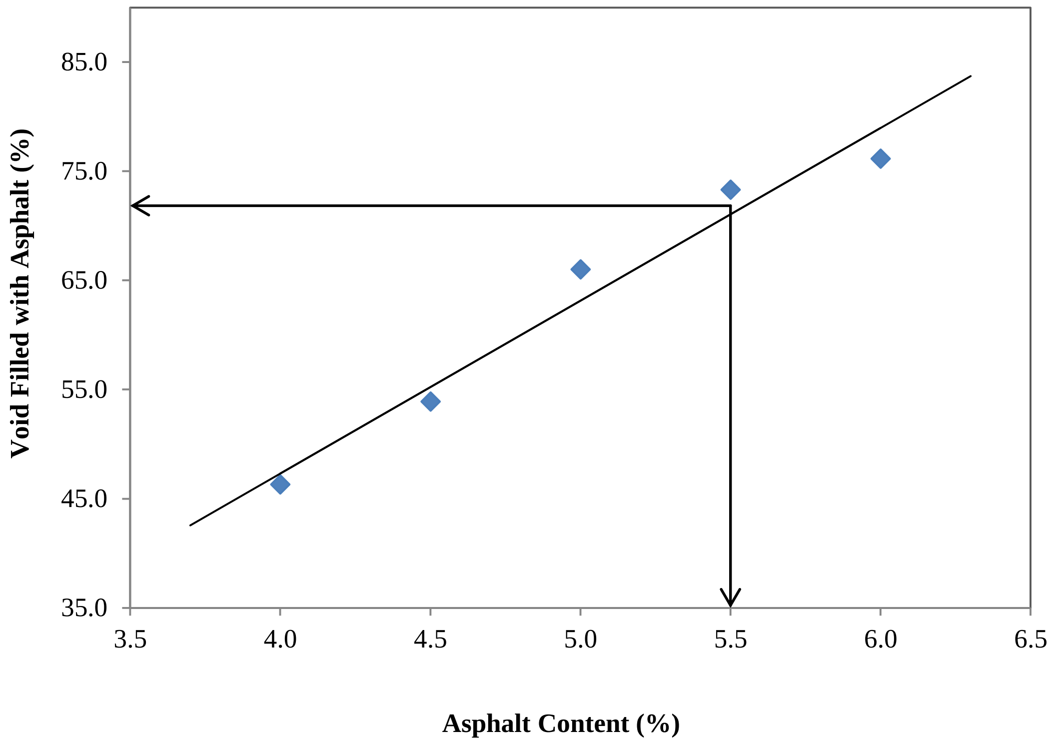


Figure 4-13: Void Filled with Asphalt at Optimum Binder Content

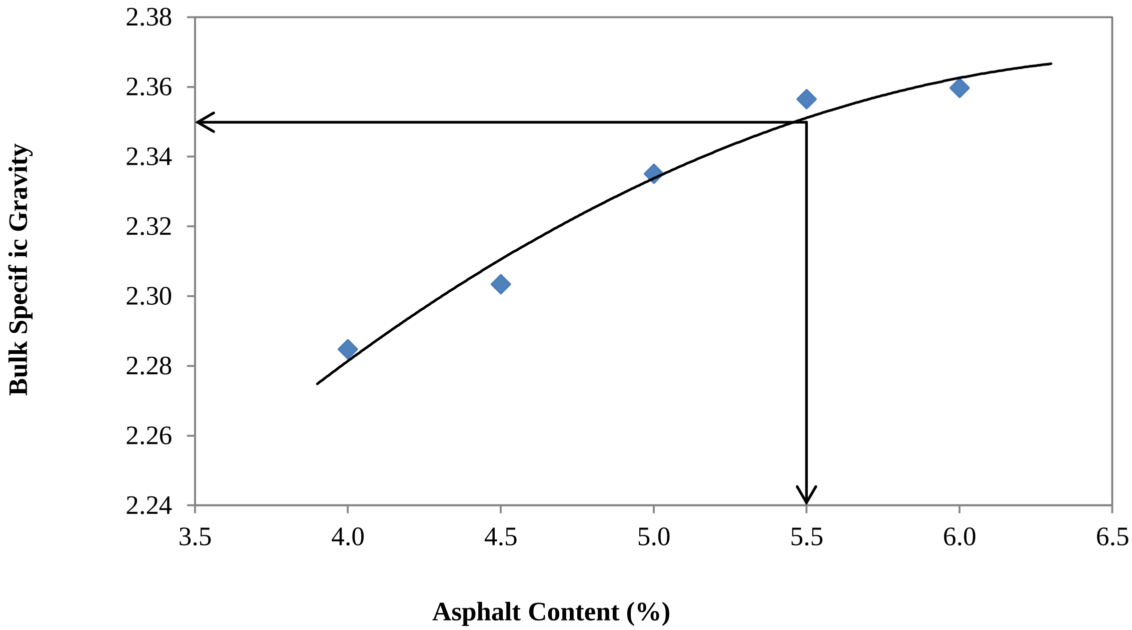


Figure 4-14: Bulk Specific Gravity at Optimum Binder Content

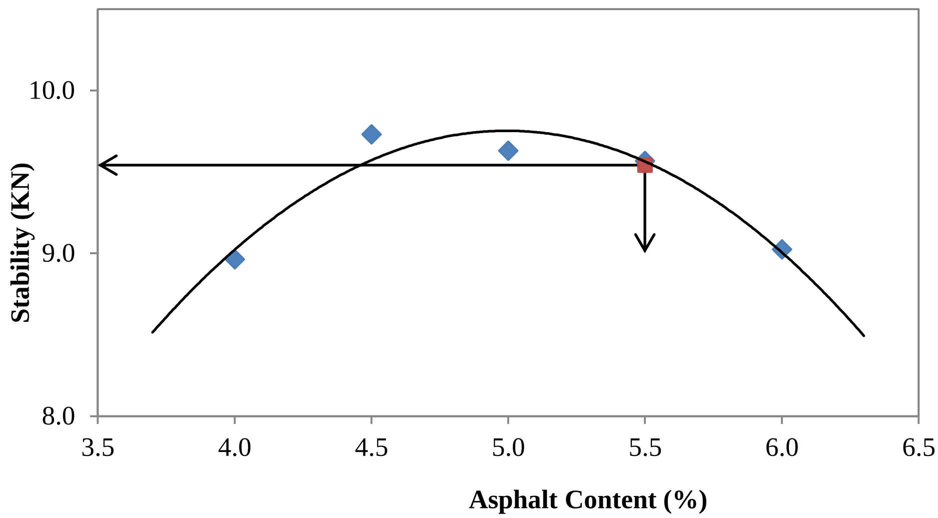


Figure 4-15: Stability at Optimum Binder Content

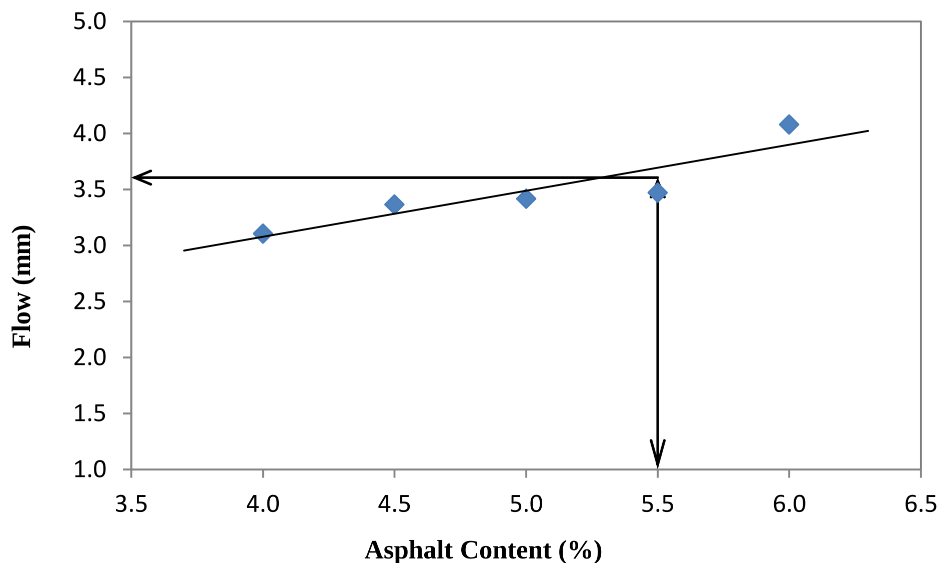


Figure 4-16: Parameter in Optimum Binder Content for 20% Bagasse Ash

The value of performance tests at optimum binder content (5.5%) shown on figures above were checked against the standard specification and summarize in Table 4-9.

Table 4-9: ***Summary of parameter on OBC value***

Marshall properties	Test Result	Standard Specification	Remark
Optimum Binder Content, %	5.5	-	OK
Bulk Specific Gravity	2.351	-	OK
Theoretical Maximum Specific Gravity	2.453	-	OK
Air void in Mix, %	4.2	3-5	OK
Void in Mineral Aggregate, %	15.6	>14	OK
Void Filled with Asphalt, %	73.3	65-75	OK
Stability, KN	9.6	>9	OK
Flow, mm	3.2	2-4	OK
Marshall Quotient, KN/mm	2.8	2-4.5	OK
Filler to Bitumen Ratio	1.2	0.6-1.2	OK

4.6. Statistical Analysis of Volumetric Test of Bagasse Ash Using ANOVA

After finalizing the laboratory works and organization of data, statistical analysis was performed to evaluate the significance of addition of Bagasse Ash to cement in asphalt concrete using one-way analysis of variance (ANOVA) at constant bitumen content. A one-way ANOVA uses two different estimates of sample variance. The first estimate is called the between-group variance, and it involves finding the variance of the means. The second estimate, the within-group variance, is made by computing the variance using all the data and is not affected by differences in the means. The six groups of independent variables i.e. 0%, 10%, 20% and 30%, 40% and 50% were considered in this research work.

In this research the ANOVA consists of three random samples from each of six independent groups. The assumption of null hypothesis (Ho) is that the cement and the five percentages i.e. 10%, 20%, 30%, 40% and 50% of Bagasse Ash are equally effective.

This means, there is no performance change and/or volumetric property in asphalt concrete up on addition of different percentages of Bagasse Ash instead of cement. Therefore, the null hypothesis, Ho: μ1 = μ2= μ3= μ4= μ5= μ6, whereas the alternative hypothesis, H1: at least one percentage has a change in rheological property/performance and volumetric properties of asphalt concrete due to the replacement of cement with Bagasse Ash. The hypothesis testing analysis was done at 5% level of significance. The test statistics for one-way ANOVA is the F ratio i.e. the ratio between the group variance and the within group variance. For each of the six percentages three samples were tested. For F test, degree of freedom for between-group variance is k-1, where k is the number of groups and the degree of freedom within-group variance N- k, where N is the sum of the sample sizes of the groups. Therefore, degree of freedom for between-group variance is 6-1= 5 and degree of freedom within-group variance is 18- 6= 12.

Accordingly, one-way ANOVA results are summarized herein the tables shown below, Table 4-10.

Table 4-10: ***Summary of ANOVA hypothesis for Bulk Specific Gravity of Asphalt Concrete***

Bulk Specific Gravity				
Bitumen Content (%)	**F-value**	**P-value**	**$F_{critical}$**	**Decision**
4.0	13.63895	0.000134		Rejected
4.5	8.899408	0.00996		Rejected
5.0	20.48543	$16.94*10^{-6}$	3.105875	Rejected
5.5	39.59885	$4.73*10^{-7}$		Rejected
6.0	15.25295	$7.69*10^{-5}$		Rejected

The decision to accept or reject the null hypothesis is made by comparing the test statistics computed F with the critical value obtained from the table. If the computed F value exceeds the critical value, the hypothesis will be rejected; if not, the hypothesis will be accepted. As per the result presented on the above table, the ANOVA result for Bulk Specific Gravity indicates that the F value exceeds the critical value from the table, at 5% level of significance.

Thus, the decision shows that the null hypothesis is rejected. Hence, concluded that, replacing bagasse ash instead of cement in hot mix asphalt affects the volumetric property of asphalt concrete.

Table 4-11: ***Summary of ANOVA hypothesis for Air Void of Asphalt Concrete***

Air void (Va)				
Bitumen Content (%)	**F-value**	**P-value**	**$F_{critical}$**	**Decision**
4.0	27.11369	$3.8*10^{-6}$		Rejected
4.5	59.90254	$4.56*10^{-8}$		Rejected
5.0	32.22989	$1.48*10^{-6}$	3.105875	Rejected
5.5	37.50322	$6.4*10^{-7}$		Rejected
6.0	7.654615	0.001925		Rejected

As it is presented in the above table, Table 4-11, the ANOVA result for Air Void (Va) indicates that the F value exceeds the critical value from the table, at 5% level of significance. Thus, the null hypothesis is rejected. Hence, it is concluded that, replacement of cement with bagasse ash in hot mix asphalt affects the air void existed in the pavement.

Table 4-12: ***Summary of ANOVA hypothesis for Void in Mineral Aggregate of Asphalt Concrete***

Void in Mineral Aggregate (VMA)				
Bitumen Content (%)	**F-value**	**P-value**	**$F_{critical}$**	**Decision**
4.0	13.63895	0.000134		Rejected
4.5	8.899408	0.00996		Rejected
5.0	20.48543	$16.94*10^{-6}$	3.105875	Rejected
5.5	39.59885	$4.73*10^{-7}$		Rejected
6.0	20.21407	$1.82*10^{-5}$		Rejected

As per the result of the above table, Table 4-12, the ANOVA result for Void in Mineral Aggregate shows F value exceeds the critical value obtained from the table, at 5% level of significance. Thus, the null hypothesis is rejected. Replacement of cement with bagasse ash in hot mix asphalt affects the void to be existed in mineral aggregate of the pavement.

Table 4-13: ***Summary of ANOVA hypothesis for Void Filled with Asphalt in Asphalt Concrete***

Void Filled with Asphalt (VFA)				
Bitumen Content (%)	**F-value**	**P-value**	**$F_{critical}$**	**Decision**
4.0	168	$1.09*10^{-9}$	3.105875	Rejected
4.5	169.508	$1.07*10^{-10}$		Rejected
5.0	54.72833	$7.63*10^{-8}$		Rejected
5.5	47.3695	$1.73*10^{-7}$		Rejected
6.0	17.71079	$3.6*10^{-5}$		Rejected

The ANOVA analysis presented in Table 4-13 above for Void filled with asphalt shows F value exceeds the critical value obtained from the table, at 5% level of significance. Thus, the null hypothesis is rejected. It implies that, replacement of cement with bagasse ash in hot mix asphalt affects the void to be filled with asphalt/volumetric property in the asphalt concrete mix design.

Table 4-14: ***Summary of ANOVA hypothesis for Stability of Asphalt Concrete***

Stability				
Bitumen Content (%)	**F-value**	**P-value**	**$F_{critical}$**	**Decision**
4.0	0.789791	0.576792	3.105875	Accepted
4.5	2.237458	0.117492		Accepted
5.0	0.884719	0.52465		Accepted
5.5	0.480111	0.784628		Accepted
6.0	4.569873	0.0114484		Rejected

The ANOVA analysis presented in the above table, Table 4-14 for Stability shows F value less that the critical value obtained from the table for 4%, 4.5%, 5.0%, and 5.5%, and exceeds for 6.0% of bitumen content, at 5% level of significance. Hence, the null hypothesis is accepted for 4%, 4.5%, 5.0%, and 5.5%, and rejected for 6.0% bitumen content. It implies that, replacement of cement with bagasse ash in hot mix asphalt affects the rheological properties of asphalt concrete for lower percentage of bitumen content and does not affect at higher percentage of bitumen content.

Table 4-15: ***Summary of ANOVA hypothesis for Flow of Asphalt Concrete***

Flow				
Bitumen Content (%)	**F-value**	**P-value**	**$F_{critical}$**	**Decision**
4.0	3.465742	0.036074	3.105875	Rejected
4.5	0.327586	0.88676		Accepted
5.0	0.354821	0.869475		Accepted
5.5	0.60689	0.696532		Accepted
6.0	1.284554	0.332715		Accepted

The ANOVA analysis presented in the above table, Table 4-15 for Flow shows F value exceeds the critical value obtained from the table for 4%, and less than for 4.5%, 5.0%, 5.5%, and 6.0% of bitumen content, at 5% level of significance. Therefore, the null hypothesis is rejected for 4.0% and accepted for 4.5%, 5.0%, 5.5%, and 6.0% bitumen content. It implies that, replacement of cement with bagasse ash in hot mix asphalt does not affects the performance property of asphalt concrete for lowest percentage of bitumen content and affect at higher percentage of bitumen content.

Chapter 5 - Conclusion and Recommendation

The decisive goal of this research study was to investigate the partially replacement of cement with Bagasse Ash in order to provide more economical pavement structure with better quality and to enhance the mechanism of using locally available material. Accordingly, it has been found that the addition of Bagasse Ash to filler/cement has influenced on overall property and performance of asphalt concrete.

5.1. Conclusion

The following conclusions can be drawn from the results of the study/investigation carried out within the scope of the study.

A. BA as a partial replacement for cement will help to solve environmental problems may encounter where Bagasse is disposed; hence this can help in the actualization of change the waste to valuable product which can be explained with the phrase "waste to wealth".
B. The desirable properties of aggregates used in this study fell within the value specified by the relevant standards. Also, the required properties of bitumen as a binder also conform to the standard specified by the relevant codes. Therefore, they can be used in the design of asphalt pavement.
C. The recommended properties of mineral filler in terms of pozzolanic characteristics and fineness was met by the BA since the combined percentage of Silica, Aluminum and Iron oxides meets the specification in ASTM standard ($Si0_2 + Al_20_3 + Fe_20_3 = 68.48\% > 50\%$).
D. 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.
E. Therefore, the Optimum BA content to be partially replaced with OPC in asphalt concrete mix should be 20%.

5.2. Recommendation

In Ethiopia, even though the construction industry is booming these days, it is still in its infant stage and needs much more effort to be made on the different construction materials. The awareness about the different cement replacing materials and their advantages is negligible, implying more work to be done on the area.

Therefore, based on the findings of this research, the following recommendations are forwarded:

A. Further research should be carried out to investigate the detail cost effectiveness/cost implication on asphalt construction when compared to cement and affordability of BA for the use filler in asphalt concrete mix. Besides, the cost quantification for bagasse ash should be the focusing area for upcoming researchers, to clearly understand and address the actual cost saving of using bagasse ash instead of cement in hot mix asphalt.

B. Further research should be conduct on partial replacement of cement with BA as a dust material including filler passing sieve size 0.075mm to clearly identify the effect of BA in HMA.

C. Sugarcane bagasse ash as investigated in this research work can be used as a cement replacing material with economical, technical and environmental benefits. Therefore concerned government and private companies like sugar industries, cement industries and higher government institutions should be made aware about this potential cement replacing material and promote its standardized production, usage and conduct further investigate to come up with sound conclusion of the importance of Bagasse Ash.

D. The sugar and cement 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 as a cement replacing material and/or uses of bagasse ash in construction industry and to reprocess waste products.

E. This research studied some of the basic physical and chemical properties of Wonji sugar factory bagasse ash as a cement replacing material. However, further studies are required on the following :

   - ✓ Further Studies should be made using controlled burning of the bagasse at different temperature and holding time.

- ✓ The effects of different fineness of the bagasse ash should be studied as well (gradation of bagasse ash).
- ✓ The chemical and physical properties of bagasse ash from different sources/ factories like, Kuraz, Tendaho, Arjo Dedessa, Metahara, Fincha and the currently establishing sugar factories should be carefully studied.
- ✓ Studies should be made to check the pozzolanic reaction, chemical constituents and skeletal structure of bagasse ash using more advanced methods like X-ray Diffraction (XRD) Analysis, Scanning Electron Microscopy (SEM) and Thermal Analysis (TGA) which are rarely available Ethiopia now a day.

Chapter 6 - Reference

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Chapter 7 – Appendix

7.1. APPENDIX A: - Tests on Aggregate

A.1. Specific Gravity and Absorption of Coarse (>No.4) or (14-25) Aggregate.

TEST METHOD: AASHTO T 85-91

Trial		**1**	**2**	**3**	**Average**
B. Mass of SSD sample in air	G	2582	2575	2579	
Bs. Mass of basket in water	G				
Bs+C Basket + Sample in water	G				
C.Mass of saturated sample in water	G	1613.2	1608.9	1611.6	
A. Mass of oven dry sample in air	G	2537.2	2529	2532	
Water Temperature					

^oC	18	19	20	21	22	23	.	25	26	27	28	29
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9989	0.9986	0.9983	0.998	0.9977

Bulk sp. gravity (oven dry) Sd = A*k/(B-C)	2.617	2.615		**2.616**
Bulk sp. gravity (SSD) Ss = B*k/(B-C)	2.663	2.663		**2.663**
Apparent specific gravity Sr = A*k/(A-C)	2.743	2.746		**2.745**
Water absorption Aw = (B-A)*100/A	1.8	1.8		**1.8**

A.2. Specific Gravity and Absorption of Coarse (>No.4) or (6-14) Aggregate.

TEST METHOD: AASHTO T 85-91												
Trial					**1**		**2**		**3**		**Average**	
B. Mass of SSD sample in air				g	2439.5		2418.5		2429			
Bs. Mass of basket in water				g								
Bs+C Basket + Sample in water				g								
C.Mass of saturated sample in water				g	1526		1513.5		1519.5			
A. Mass of oven dry sample in air				g	2395.3		2370.6		2382.5			
Water Temperature												
ºC	18	19	20	21	22	23	.	25	26	27	28	29
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9989	0.9986	0.9983	0.998	0.9977
Bulk sp. gravity (oven dry) Sd = A*k/(B-C)					2.62		2.617		2.616		**2.618**	
Bulk sp. gravity (SSD) Ss = B*k/(B-C)					2.668		2.67		2.667		**2.668**	
Apparent specific gravity Sr = A*k/(A-C)					2.753		2.763		2.757		**2.758**	
Water absorption Aw = (B-A)*100/A					1.8		2		2		**1.9**	

A.3. Specific Gravity and Absorption of Coarse (>No.4) or (3-6) Aggregate

TEST METHOD: AASHTO T 85-91												
Trial					1		2		3		Average	
B. Mass of Pycnometer+Weter				g	682.8		682.5		682.5			
S. Mass of SSD Sample in air				g	250		250		250			
C. Mass of Pycnometer+Weter +Sample				G	836.6		836.5		836.5			
A. Mass of Oven dry sample in air				G	244.8		244.9		245			
Water Temperature												
ºC	18	19	20	21	22	23	24	25	26	27	28	29
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9989	0.9986	0.9983	0.998	0.9977
Bulk sp. gravity (oven dry) Sd = A*k/(B-C)					2.545		2.556		2.552		**2.551**	
Bulk sp. gravity (SSD) Ss = B*k/(B-C)					2.599		2.61		2.604		**2.604**	
Apparent specific gravity Sr = A*k/(A-C)					2.69		2.7		2.692		**2.695**	
Water absorption Aw = (B-A)*100/A					**2.1**		**2.1**		**2**		**2.1**	

A.4. Specific Gravity and Absorption of Fine (<No.4) or (0-3) Aggregates.

TEST METHOD: AASHTO T 84-95					
Trial No.		1	2	3	Average
B. Mass of Pycnometer+Water	g	682.5	682.5	682.5	682.5
S. Mass of SSD sample	g	250	250	250	250
C. Mass of pycnometer+water+sample	g	838.6	838.7	838.1	838.5
A. Mass of oven dry sample in air		244.8	244.9	244.8	244.8
Water Temperature					

ºC	18	19	20	21	22	23	24	25	26	27	28	29
K	1.0004	1.0002	1	0.9998	0.9996	0.9993	0.9991	0.9989	0.9986	0.9983	0.998	0.9977

	1	2	3	Average
Bulk sp. gravity (oven dry) Sd = A*k/(B+S-C)	2.604	2.608	2.589	2.606
Bulk sp. gravity (SSD) Ss = S*k/(B+S-C)	2.659	2.662	2.644	2.661
Apparent specific gravity Sr = A*k/(A+B-C)	2.757	2.758	2.74	2.757
Water absorption (%) Aw = (S-A)*100/A	2.1	2.1	2.1	2.1

A.5. Aggregate Crushing Value

TEST METHOD: BS:812 Part 110 (1990)			
TRIAL No.	1	2	3
Mass of sample (14mm pass and 10mm Retain)	2395	2390	2392
Mass of sample retained on B.S Sieve,2.36mm	2105	2091	2096
Mass of sample passing B.S Sieve,2.36mm	290	299	294
Aggregate Crushing Value (ACV)	12.1	12.5	12.3
Average ACV	**12**		

A.6. 10 Percent Fine Value and Wet / Dry Ratio

BS 812 part 110:1990					
		DRY SAMPLE		**WET SAMPLE**	
Test no.		1	2	3	4
Mass of the test specimen					
(Passing 14mm & Retained on 10mm Sieve	M1 (gm)	2391	2384	2301	2300
Mass of Aggregate Retained on the 2.36mm sieve	M2 (gm)	2145	2141	2043	2045
Mass of Aggr passing the 2.36mm sieve	M1(gm)-M2(gm)	246	243	258	255
% Pass	((M1- M2) M1)*100	10.3	10.2	11.2	11.1
Maximum force	(KN)	325	325	315.5	315.5
T.F.V.	(KN)	318.4	326	290.4	292.8
AVERAGE T.F.V.	(KN)	322		292	
WET / DRY RATIO	(%)	**90**			

A.7. Resistance to Abrasion of Small Size Coarse Aggregate

- ✓ **By Use of the Los Angeles Machine**

TEST METHOD: AASHTO T 96-94							
MATERIAL DESCRIPTION :	**Crushed Stone**						
SIEVE SIZES	1 1/2 - 1"	1 - 3/4 "	3/4 - 1/2 "	1/2 - 3/8 "	3/8 - 1/4 "	1/4" - No.4	No.4-No.8
GRADE	A				C		D
NUMBER OF BALLS	12 BALLS				8 BALLS		6 BALLS
WT. OF INDICATED SIZE	1250 ± 25	1250 ± 25	1250 ± 10	1250 ± 10	2500 ± 10	2500 ± 10	5000 ± 10
WT.OF TESTED SAMPLE							
GRADE			B				
NUMBER OF BALLS			12 BALLS				
WT. OF INDICATED SIZE			2500 ± 10	2500 ± 10			
WT.OF TESTED SAMPLE							

TEST RESULTS				
TRIAL	1	2	3	Average
NUMBER OF REVOLUTION	500	500	500	500
TOTAL WT. OF SAMPLE TESTED, (g)	5000	5000	5000	5000
WT. OF TESTED SAMPLE RETAINED ON No. 12 SIEVE (g)	4355	4360	4345	4353.33
PERCENT LOSS (%)	**13**	**13**	**13**	**13**

A.8. Flakiness Index Record

BS 812: Section 105.1:1989		
Sieve Size / Nominal Size	**Retained Sample**	**% Retained**
(mm)	**(gm)**	
63	**0**	**0.0**
50	**0**	**0.0**
37.5	**0**	**0.0**
28	**0**	**0.0**
20	**786**	**44.0**
14	**500**	**28.0**
10	**250**	**14.0**
6.3	**250**	**14.0**
Sum	**1786**	**100.0**
Take Mass Retained in gm for FI Calculation only that of % Retained >5%.		

A.9. Flakiness Index Calculation

Sieve Size (mm)		**Mass Retained (gm)**	**Mass Passing (gm)**
100% Passing	**100% Retained**		
63	**50**	**0**	**0**
50	**37.5**	**0**	**0**
37.5	**28**	**0**	**0**
28	**20**	**786**	**101**
20	**14**	**500**	**98**
14	**10**	**250**	**108**
10	**6.3**	**250**	**85**
	TOTAL	**1786**	**392**
		FI=Total Mass Passing / Total Mass Retained * 100	
		FI=22	
		Put Flakiness Index to the nearest Whole number.	

A.10. Sand Equivalent Value

TEST METHOD: AASHTO T 176-86				
Test No.		1	2	3
A. Sand Reading,	**mm**	96	99	98
B. Clay Reading, mm	**mm**	128	126	127.6
Sand Equivalent =	**A / B x 100 %**	75	78.6	76.8
Average Sand Equivalent, %		**76.8**		

A.11. Individual & Blended Hot Bin Gradation for Hot Mixed Asphalt Mix Design

BA= 10 %

PERCENT PASSING

Sieve size (mm)	[Bin # 4] Average % pass	[Bin #4] 26.5 - 12.5 mm	[Bin # 3] Average % pass	[Bin #3] 12.5 - 9.5 mm	[Bin # 2] Average % pass	[Bin #2] 9.5 - 4.75 mm	[Bin # 1] Average % pass	[Bin #1] <4.75 mm	Cement Average % Pass	BA	BA Average % Pass	Cement	Blend	Specification limit [ERA Manual 2002]		Remark
		27%		17%		14%		40%		0.2%		1.8%		Lower Limit	Upper Limit	
26.5	100.0	27.0	100.0	17.0	100.0	14.0	100.0	40.0	100.0	0.2	100.0	1.8	**100.0**	100	100	Ok!
19	98.0	26.5	100.0	17.0	100.0	14.0	100.0	40.0	100.0	0.2	100.0	1.8	**99.5**	85	100	Ok!
12.5	25.2	6.8	98.5	16.8	100.0	14.0	100.0	40.0	100.0	0.2	100.0	1.8	**79.6**	71	84	Ok!
9.5	1.2	0.3	75.8	12.9	99.2	13.9	100.0	40.0	100.0	0.2	100.0	1.8	**69.1**	62	76	Ok!
4.75	0.1	0.0	2.3	0.4	88.0	12.3	99.5	39.8	100.0	0.2	100.0	1.8	**54.5**	42	60	Ok!
2.36	0.1	0.0	0.1	0.0	8.5	1.2	92.4	37.0	100.0	0.2	100.0	1.8	**40.2**	30	48	Ok!
1.180	0.1	0.0	0.1	0.0	0.9	0.1	62.4	25.0	100.0	0.2	100.0	1.8	**27.1**	22	38	Ok!
0.600	0.1	0.0	0.1	0.0	0.4	0.1	42.3	16.9	100.0	0.2	100.0	1.8	**19.0**	16	28	Ok!
0.300	0.1	0.0	0.1	0.0	0.2	0.0	26.6	10.7	100.0	0.2	100.0	1.8	**12.7**	12	20	Ok!
0.150	0.1	0.0	0.1	0.0	0.2	0.0	20.3	8.1	100.0	0.2	100.0	1.8	**10.2**	8	15	Ok!
0.075	0.1	0.0	0.1	0.0	0.2	0.0	11.9	4.8	100.0	0.2	100.0	1.8	**6.8**	4	10	Ok!

8.1. APPENDIX B: - Tests on Bitumen

B.1. Tests on Bitumen

TRIAL NO.		1	2	3
A	**Stripping Value %**	**>95**	**>95**	**>95**
B	**Average Stripping Value %**	**>95**		

B.2. Test Record of Flash Point Bituminous materials

Trial No.	Flash Point Temperature (ºC)	Fire Point Temperature (ºC)	Av. Flash Point (ºC)	Av. Fire Point (ºC)
1	310	345	310	345
2	311	344		
3	310	346		

B.3. Specific Gravity and Absorption Test

SPECIFIC GRAVITY OF SEMI-SOLID BITUMINOUS MATERIALS (T228)		
Source:	**Asphalt Batching Plant**	
Determination	1	2
1. Weight of Pycnometer , g	41.58	41.58
2. Weight of Pycnometer Filled With Sample , g.	58.97	58.96
3. Weight of Pycnometer Filled with Water , g @ 25 ± 0.1^{0}C	65.39	65.38
4. Weight of Pycnometer + Sample + Water , g @ 25± 0.1^{0}C	65.64	65.64
5. Weight of Water replaced by Sample , g {(3-1)+2} – 4	17.14	17.12
6. Specific Gravity ,(2-1)/5	1.015	1.015
7. Average Specific Gravity (g/ Cm3)	1.015	
8. Density , 7*w_T (25 ºC,w_T =0.9971 g/cm3)	1.012	
9. Density , 7*w_T (15.6 ºC, w_T =0.9990 g/cm3)	1.014	

B.4. Test Record of Penetration, Ductility, Softening Point of Bituminous Materials

	Trial No.	Test Temperature (^{0}C)	Time of Test (S)	Test Load (g)	Reading Date (0.1mm)			Average(0.1mm)
					First Time	Second Time	Third Time	
Penetration	1	25	5	100	91	93	90	91
	2	√	√	√	89	92	91	91
	3	√	√	√	88	90	92	90

	Trial	Test Temperature (^{0}C)	Speed (cm/min)	Ductility (cm)			Average(cm)
				1	2	3	
Ductility	1	25	5	115	129	117	120.3

	Trial No.	Temperature when starting heating(^{0}C)	Record of liquid temperature in beaker												Softening point (^{0}C)	Average (^{0}C)
			1min	2min	3min	4min	5min	6min	7min	8min	9min	10min	11min	12min		
Softening point	1	6 c^o				√									48.1	48.3
	2	6 c^o				√									48.4	
	3	6 c^o				√									48.3	

B.5. Test Record of Bitumen Loss on Heating

Method Used	AASHTO-T-47		Test condition	163^{o}C 5 Hours		
Trial No.	Wt of container m_1 (g)	Wt of container + sample before test m_2 (g)	Wt of sample m_3(g)	Mass of container + sample after test m_4 (g)	Loss of sample (%) $L_b=(m_4-m_1)/m_3$	Average Loss (%)
1	74.97	124.97	50	124.91	0.048	0.044
2	76.1	126.3	50	126.25	0.044	
3	75.9	125.9	50	125.85	0.04	

8.2. APPENDIX C: - Test on Cement

C.1. Specific Gravity of Cement

Test Method: AASHTO T 84-95

<table>
<tr><td colspan="5">Pycnometer No.</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">3</td><td colspan="2">Average</td></tr>
<tr><td colspan="5">B. Mass of Pycnometer+Water, gm</td><td colspan="2">76.8</td><td colspan="2">76.8</td><td colspan="2">76.8</td><td colspan="2">76.8</td></tr>
<tr><td colspan="5">S. Mass of SSD sample, gm</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="5">C. Mass of pycnometer+water+sample, gm</td><td colspan="2">83.12</td><td colspan="2">83.11</td><td colspan="2">83.13</td><td colspan="2">83.12</td></tr>
<tr><td colspan="5">A. Mass of oven dry sample in air</td><td colspan="2">10</td><td colspan="2">10</td><td colspan="2">10</td><td colspan="2">10</td></tr>
<tr><td colspan="5">Water Temperature</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>°C</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td></tr>
<tr><td>k</td><td>1.0004</td><td>1.0002</td><td>1</td><td>0.9998</td><td>0.9996</td><td>0.9993</td><td>0.9991</td><td>0.9989</td><td>0.9986</td><td>0.9983</td><td>0.998</td><td>0.9977</td></tr>
<tr><td colspan="5">Bulk sp. gravity (oven dry) Sd = A*k/(B+S-C)</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td></tr>
<tr><td colspan="5">Bulk sp. gravity (SSD) Ss = S*k/(B+S-C)</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td></tr>
<tr><td colspan="5">Apparent specific gravity Sr = A*k/(A+B-C)</td><td colspan="2">3.152</td><td colspan="2">3.152</td><td colspan="2">3.151</td><td colspan="2">3.152</td></tr>
<tr><td colspan="5">Water absorption (%) Aw = (S-A)*100/A</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td></tr>
</table>

C.2. Tests on Cement Quality

Specification Used		**BS EN 197**				
Result of Cement Test						
Test Item		Result				Specification Required
Water Requirement of Normal Consistency		130ml				0.26-0.33
Initial condensation Time		2 hrs & 20 min				≥45min
Final condensation Time		6 hrs & 42 min				≤10h
Strength of Cement		Strength (Mpa)			Average	Specification Required
Bending Strength (Mpa)	1d	1.7	2.6	2.9	2.4	
	7d	4.6	5.1	4.3	4.7	≥3.5MPa
	28d	7.2	6.9	7.5	7.2	≥6.5MPa
Compressive Strength (Mpa)	1d	9.1	7.0		9.9	
	7d	23.0	22.6		22.4	≥16MPa
	28d	45.1	43.6		44.5	≥42.5MPa

8.3. APPENDIX D: - ANOVA Analysis

D.1. Statistical analysis for Flow @4.0% bitumen content using ANOVA analysis method.

Bitumen Content	Flow						
4%	Bagasse Ash (%)	**0**	**10**	**20**	**30**	**40**	**50**
	Sample 1	3.41	3.25	2.94	2.91	3.31	4.6
	Sample 2	2.78	3.26	3.1	2.56	3.29	3.71
	Sample 3	2.89	3.06	3.28	3.26	3.56	3.43
	Mean ($\bar{x}$)	3.02667	3.19	3.10667	2.91	3.38667	3.91333
	Variance (Si)	0.113233	0.0127	0.028933	0.1225	0.022633	0.373233
	Grand Mean (XGM)	3.2556					
	N= 18			K= 6			
Between Group	$S_B^2 = \frac{\sum n_i (Xi\text{-}XGM)}{(k\text{-}1)}$						
	$S_B^2 = \frac{(3)[(3.02667-3.2556)^2 + (3.19-3.2556)^2 + (3.10667-3.2556)^2 + (2.91-3.2556)^2 + (3.38667-3.2556)^2 + (3.9133-3.2556)^2]}{(6-1)}$						
	$S_B^2 = 0.388844$						
Within Group	$S_w^2 = \frac{\sum (n_i - 1)\, Si^2}{(N\text{-}k)}$						
	$S_w^2 = \frac{(3-1)[(0.113233+0.0127+0.028933+0.1225+0.022633+0.373233)]}{(18-6)}$						
	$S_w^2 = 0.11220$						
F	F=	$\frac{S_B^2}{S_w^2}$	P value			F critical (α =0.05)	
	F=	3.4657	0.0361			3.11	

D.2. Statistical analysis for Stability @4.0% bitumen content using ANOVA analysis method.

Bitumen Content	Stability						
4%	Bagasse Ash (%)	**0**	**10**	**20**	**30**	**40**	**50**
	Sample 1	9.5424	9.3696	9.072	9.1968	8.6496	9.3984
	Sample 2	8.304	9.1488	8.3904	10.0032	8.8032	7.9776
	Sample 3	8.6208	8.8992	9.4272	8.9856	9.216	8.4864
	Mean ($\bar{x}$)	8.82240	9.1392	8.96320	9.3952	8.88960	8.62080
	Variance (Si)	0.413891	0.05538816	0.277617	0.28839936	0.085801	0.518216
	Grand Mean (XGM)	8.9717					
	N= 18			K= 6			
Between Group	$S_B^2 = \dfrac{\sum n_i\,(Xi\text{-}XGM)}{(k-1)}$						
	$S_B^2 = \dfrac{(3)[(8.82240-8.9717)^2 + (9.1392-8.9717)^2 + (8.96320-8.9717)^2 + (9.3952-8.9717)^2 + (8.88960-8.9717)^2 + (8.62080-8.9717)^2]}{(6-1)}$						
	$S_B^2 = 0.215785476$						
Within Group	$S_w^2 = \dfrac{\sum (n_i-1)\,Si^2}{(N-k)}$						
	$S_w^2 = \dfrac{(3-1)[(0.413891+0.05538816+0.277617+0.28839936+0.085801+0.518216)]}{(18-6)}$						
	$S_w^2 = 0.273219$						
F	$F = \dfrac{S_B^2}{S_w^2}$		P value			F critical (α =0.05)	
	F= 0.78979		0.5768			3.11	

D.3. Statistical analysis for Stability @4.0% bitumen content using ANOVA analysis method.

Bitumen Content	Void Filled with Asphalt						
4%	Bagasse Ash (%)	**0**	**10**	**20**	**30**	**40**	**50**
	Sample 1	48.16957047	48.09488408	46.23401625	36.68063287	43.55608228	43.55838476
	Sample 2	47.42642936	47.71172395	45.62514824	37.59423272	44.47408463	44.06448657
	Sample 3	48.76989219	48.36522557	47.083114	36.86888723	43.45881888	43.20483555
	Mean ($\bar{x}$)	48.12196	48.05727787	46.31409	37.04791761	43.82966	43.60924
	Variance (Si)	0.452923	0.107826763	0.536225	0.23270508	0.313826	0.186689
	Grand Mean (XGM)	44.4967					
	N= 18			K= 6			
Between Group	$S_B^2 = \frac{\sum n_i (Xi\text{-}XGM)}{(k-1)}$						
	$S_B^2 = \frac{(3)[(48.12196-44.4967)^2 + (48.05727787-44.4967)^2 + (46.31409-44.4967)^2 + (37.04791761-44.4967)^2 + (43.82966-44.4967)^2 + (43.60924-44.4967)^2]}{(6-1)}$						
	$S_B^2 = 51.50404$						
Within Group	$S_w^2 = \frac{\sum (n_i-1) Si^2}{(N-k)}$						
	$S_w^2 = \frac{(3-1)[(0.452923+0.107826763+0.536225+0.23270508+0.313826+0.186689)]}{(18-6)}$						
	$S_w^2 = 0.305032$						
F	F=	$\frac{S_B^2}{S_w^2}$	P value			F critical (α =0.05)	
	F=	168.8477	0.000000000109			3.11	