EVALUATION OF SAW DUST ASH AS MINERAL FILLER IN ASPHALT MIXTURE

BY

Elijah OKOBIA

DEPARTMENT OF CIVIL ENGINEERING,
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA

SEPTEMBER, 2016

EVALUATION OF SAW DUST ASH AS MINERAL FILLER IN ASPHALT MIXTURE

BY

Elijah OKOBIA
M.Sc. /ENG/5398/2011-2012

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF

MASTER OF SCIENCE DEGREE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING,

FACULTY OF ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

SEPTEMBER, 2016.

DECLARATION

I hereby declare that the work in this dissertation titled **"Evaluation of Saw Dust Ash as Mineral Filler in Asphalt Mixture"** was performed by me in the Civil Engineering Laboratory under the supervision of Dr. A.T. Olowosulu and Dr. M. Joel. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this work was previously presented for another degree or diploma at this or any other institution.

Elijah OKOBIA

.....	.....	.....
Name of Student	Signature	Date

CERTIFICATION

This dissertation titled "**Evaluation of Saw Dust Ash as Mineral Filler in Asphalt Mixture**" meets the regulation governing the award of the degree of Master of Science (Civil Engineering) of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

Dr. A. T. Olowosulu

…….. …….. ……..

Chairman, Supervisory Committee Signature Date

Dr. M. Joel

…….. …….. ……..

Member, Supervisory Committee Signature Date

Dr. Y. D. Amartey

…….. …….. ……..

Head of Department Signature Date

Prof. K. Bala

…….. …… ……..

Dean, School of Postgraduate Studies Signature Date

DEDICATION

This work is dedicated to the memory of my late parents, Mr. and Mrs. Okobia Eigege and late brother, Mr. Ikobulu Okobia.

ACKNOWLEDGEMENTS

It is a difficult task to identify and thank all the people that contributed to the success of this work. Those who assisted me in the collection of materials for this research work, and those who assisted me in one way or other that I cannot readily mention their names here, I remain eternally grateful.

I am particularly grateful to my major supervisor, Dr. A.T. Olowosulu for shaping and reshaping my research skills, for his relentless effort in going through every piece of work at each stage for needed corrections. I am highly indebted to him for being there for me any time I called and for all his patience and input to make this research a master piece.

I am deeply indebted to my minor supervisor Dr. M. Joel for his patience and tolerance in going into the details of the work and also for the laudable roles he played in shaping the outcome of this work. I am grateful to him especially for his preparedness to attend to me any time.

I also express my sincere thanks to the Head of Department, Civil Engineering, Dr. Y.D. Amartey for his valuable suggestions and encouragement throughout the course of this work. I am also grateful to Professor S.P. Ejeh, Professor K.J. Osinubi, Professor I. Abubakar, Professor O.S. Abejide, Postgraduate Co-ordinator, Dr. T.S. Ijimdiya, Assistant Postgraduate Co-ordinator, Dr. J.M. Kaura, Dr. A. Ocholi, Dr. A. O. Eberemu and the entire staff of Civil Engineering Department for their useful advice and assistance in the course of this work.

I am grateful to my parents, late Mr. and Mrs. Okobia Eigege for their financial and moral support towards the pursuit of my academic goals as well as my late elder brother, Mr. Ikobulu Okobia.

I am indebted to my able and dynamic sisters, Mrs. Obo Ibrahim and Mrs. Ikani Audu for their financial and moral support towards the pursuit of my academic goals.

My gratitude goes to Engr. A.A. Murana, Engr. H.S. Otuoze, Engr. J. Ochepo, J. Engr. M. Ashiru, Engr. A.A. Shuaibu, Engr. A.A. Aliyu, Engr. A. Ibrahim, Dr. Onaji, E.C., Engr. Isah, N. and Engr. Paul Yohanna for their contributions in no small measure towards the success of this work.

Also deserving of mention are my brother, Mr. Okobia Ngbede and sister, Mrs. Aipu Otene for their prayers and support.

I must express my gratitude to my wife and children, who bore my absence from home, in the course of this research, with love and affection.

Finally and the most important, I remain grateful and thankful to God who has been my guide, provider and protector over the years.

Elijah Okobia

ABSTRACT

The quest for economy in asphalt production using locally available materials necessitated this research which is aimed at evaluating the suitability of Saw Dust Ash (SDA) as mineral filler in asphalt mixture.Chemical analysis, sieve analysis, specific gravity and plasticity index tests were performed on SDA. Asphalt briquettes prepared using Ordinary Portland Cement (OPC) without saw dust as filler serve as the control. SDA was used to replace the Portland cement at 0% to 100% at an interval of 10% by weight. Marshall Test was conducted on all briquettes produced with SDA and OPC. Results of tests show that increase in SDA resulted in reduction in the value of bulk density. It was also observed that the total voids in the mix increased with SDA content, while the values of stability and flow decreased with SDA. The optimum bitumen content of 6.0% was used to prepare specimens. The flow value of asphalt decreased from 2.0mm when only the cement was used as filler to 1.0mm when the cement was completely replaced with 100% SDA. Voids in mineral aggregate increased from 18.28% when 100 % cement was used as filler to 26.32% when cement was completely replaced with SDA. Based on results of tests, the use of cement partially replaced with 10% SDA at 6% bitumen content is recommended for use in asphalt production.

TABLE OF C+ONTENTS

CHAPTER FOUR: ANALYSIS, RESULTS AND D+ISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

CHAPTER ONE

INTRODUCTION

1.1 Preamble

Continuous generation of wastes arising from industrial by-products and agricultural residue, create acute environmental problems both in terms of their treatment and disposal. The construction industry has been identified as one of the areas where the waste can be absorbed, with the majority of such materials used as filler in concrete (Antihos *et al.,* 2005). If these fillers have pozzolanic properties, they impart technical advantages to the resulting concrete and also enable larger quantities of cement replacement to be achieved (Hossain, 2003). Approximate utilization of these materials brings ecological and economic benefits. Waste material recycling into useful products has been the current method of solving waste problems (Ahmed, 2006). Material recycling has been a common practice for most of human history with record as far back as Plato in 400 BC (Grosse, 2010). Recycling is a process to change waste materials into new products to prevent hazards associated with waste, reduces the consumption of fresh raw materials, and it also reduces greenhouse gas emissions arising from the conventional method of disposing such wastes (Grosse, 2010).

Many highway agencies are conducting wide variety of studies and research work on the feasibility, environmental suitability, and performance of using recycled products in highway construction (Ahmed, 2006). Saw dust is a waste material from the timber industry. It is produced as timber is sawn into planks at saw mills located in virtually all major towns in the country. This process is a daily activity causing heaps of saw dust to

be generated after each day. The need to convert this waste product into a useful by-product is the main focus of this study.

Some industrial wastes have been studied for use as supplementary cementing materials such as flyash (Siddique, 2004; Wang and Baxter; 2007), silica fume (Lee, et. al. 2005; Turker et al. 1977, pulverized fuel ash (Balendran and Martin Buades; 2000), volcanic ash (Hossain, 2005), rice husk ash (Waswa-Sabuni, *et. al.* 2002) and corn cob ash (CCA) (Adesanya and Raheem, 2009a; 2009b; 2010; Raheem, et. al. 2010, Raheem and Adesanya, 2011).

Elinwa and Ejeh (2004) considered the effect of waste incineration fly ash (SWIFA) in cementing pastes and mortar. Cheah and Ramli (2011) investigated the implementation of wood waste ash as a partial replacement for cement in the production of structural grade concrete and mortar. Elinwa, et al. (2008) assessed the properties of fresh self-compacting concrete containing sawdust ash. Elinwa and Mahmood (2002) considered ash from timber waste as cement replacement material. One of the roles of a conventional filler material in a bituminous mix is to increase the viscosity of the binder, thereby lessening the risk of stripping. It is now well established that, if a small amount of hydrated lime or cement (say, 1 to 2 percent by mass of the aggregate in the mix) is included as a replacement for some of the conventional filler material, a chemical action will take place between either additive and the bitumen that results in the formation of compounds that are adsorbed on negatively charged aggregate surfaces, and this has the effect of improving adhesion and rendering the bitumen less vulnerable to stripping (Brennan and O'Flaherty, 2002). Addition of filler to asphalt is to make it harder and stiffer, which primarily depends on the amount of filler added. Thus, the use of saw dust

as filler in asphalt mixture will go a long way to remedy the situation of boycotting the use of mineral filler in asphalt mixture by some construction companies as well as reducing its environmental littering and pollution impact.

1.2 Statement of the Research Problem

Ordinary Portland cement and limestone dust are common materials used as mineral filler in asphalt production. However, increase in the cost of these materials in recent times has led to some construction companies boycotting their use as mineral filler. The importance of filler in asphalt cannot be ignored in that the general effect of adding it to asphalt mixture is to make it harder and stiffer and helps to produce a dense graded strong material. A situation where it is not used will affect the performance of the asphalt, such as toughness and the danger of stripping of binders.

Recent researches have focused on the use of locally available waste materials, rich in calcium oxide (CaO) as possible substitute for cement or limestone dust as mineral filler in asphalt mixture. This research is aimed at evaluating the suitability of saw dust ash as mineral filler in asphalt production.

1.3 Justification of the Study

Preparing asphalt without adding mineral filler or other additives affects the performance characteristics of the asphalt (Atkins, 1977). It is worthwhile to know that the general effect of adding filler to asphalt is to make it harder and stiffer and thus preventing the stripping of bitumen.

The use of saw dust ash as substitute for cement or limestone dust will ensure economy in the production of asphalt, and the use of mineral filler that is omitted by some construction companies. Environmental pollution associated with saw dust will also be overcome.

1.4 Aim and Objectives

1.4.1 Aim

The aim of this research work is to evaluate the suitability of saw dust ash, as partial replacement for cement, as mineral filler in asphalt production. The aim of the study will be achieved through the following objectives.

1.4.2 Objectives

i. To determine the chemical constituents of the material (saw dust ash).

ii. To determine its suitability as mineral filler in asphalt mixture as stipulated in AASHTO M17 and the Nigerian General Specification for Roads and Bridges (1997), volume II-Federal Ministry of Works.

iii. To subject its briquette to Marshall Test and compare result of tests with standards.

1.5 Scope of Study

There are different kinds of industrial wastes such as fly ash, silica fume, pulverized fuel ash, corn cob ash and volcanic ash. This research work focuses only on the use of saw dust ash as partial replacement for cement in asphalt production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Asphalt Concrete

Asphalt concrete (commonly called asphalt, blacktop, or pavement in North America, and tarmac in Great Britain) is a composite material used to form road surface, parking lots and runways. It consists of mineral aggregate bound together with bitumen, laid in layers, and compacted. The terms “asphalt (or asphaltic) concrete”, bituminous asphalt concrete and bituminous mixture are typically used in engineering and construction documents, to refer to asphalt. The different types of asphalt mixtures commonly used in pavement construction are hot-mix, hot-laid and cold-mix, cold laid. When used in the construction of highway pavements, it must resist deformation from imposed traffic loads, be skid resistant even when wet, and not affected easily by weathering forces. The degree to which an asphalt mixture achieves these characteristics mainly is dependent on the design of the mix used in producing the material (Garber and Hoel, 2010).

2.2 Composition of Asphalt

The main ingredients of asphalt mix are bitumen, and aggregates. Aggregates usually are categorized as coarse, fine, and fillers. Coarse aggregate ranging from 14 mm, 12 mm to 10 mm in sizes and fine aggregates are referred to as sand sizes, while the fines are the fillers (Atkins, 1997).

2.2.1 Bitumen

Bitumens used for road construction are viscous liquid or semi-solid materials consisting essentially of hydrocarbons and their derivatives, which are soluble in trichloroethylene (Brennan and O'Flaherty, 2002).

There are different types of bitumen such as native asphalt, rock asphalt, tars and petroleum asphalt. The native asphalt is obtained from asphalt in Trinidad and other Caribbean areas. These were used in some earliest pavements in North America. Rock asphalts are rock deposits containing bituminous materials, which have been used for road surfaces in localities, where they occur. Tar bituminous materials are obtained from the destructive distillation of coal (Garber and Hoel, 2010).

The petroleum asphalts are products of the distillationof crude oil. These asphalts are the most common bituminous paving materials in use today. Bitumen is knownby its penetration grades. Their grades and temperature relationships are extremely important in the design of asphalt concrete. Viscosity decreases as temperature increases (Atkins, 1997).

Bitumen used in road works occurs in three forms; penetration-grade or straight run bitumen, cut-back bitumen and bitumen-emulsion. Penetration-grade bitumen is obtained directly from the traditional distillation of the crude petroleum as residue without mixing or refluxing with any diluents or solvent. The fractional distillation processes involve the separation of the different materials in the crude petroleum without significant changes in the chemical composition of each material. Ten grades of bitumen, from 15 pen (Hardest) to 450 pen (softest) are used in pavement materials in the United Kingdom. The harder

grades (15 – 25pen) are used in mastic asphalts, the medium grades (35 – 70 pen) in hot rolled asphalts and the softer grades (100 – 450pen) in macadam. (Brennan and O'Flaherty, 2002).

Cut-back bituments are obtained from the penetration grade bitumen through the addition of suitable diluents in order to reduce its viscosity. The bitumen cut-backs are slow curing bitumen, medium-curing bitumen, and rapid-curing bitumen. They are used mainly in cold-laid plant mixes, road mixes (mixed-in-place), and as surface treatments. Slow-curing (SC) bitumen can be obtained directly as slow-curing straights run bitumen or as slow-curing cutback bitumen by 'cutting back' penetration grade bitumen with a heavy distillate, such as diesel oil. They have lower viscosities than the penetration grade bitumen and are very slow to harden. Slow-curing bitumen usually are designated as SC-70, SC-250, SC-800 or SC-3000, where the numbers relate to the approximate kinematic viscosity in centistokes at 60^{o}C (140^{0}F). They are used with dense-graded aggregate to provide a surface dressing in warm climate to act as a dust palliative (Garber and Hoel, 2010).

Medium-curing (MC) bitumen is produced by fluxing, or cutting back, the residual bitumen (usually 120 to 150 penetrations) with light fuel or kerosene. The term medium refers to the medium volatility of the kerosene-type diluter used. Medium curing cutback bitumen hardens faster than slow-curing liquid bitumen, although consistencies of the different grades are similar to those of slow-curing bitumen. However, the MC-30 is a unique grade in this series as it is very fluid and has no counterpart in the SC or RC series. The fluidity of the medium-curing bitumen depends on the amount of solvent in the material. MC-3000, for example, may have only 20 percent of the solvent by volume,

whereas MC-70 may have up to 45 percent. This medium-curing bitumen can be used for construction of pavement bases, surfaces, and surface treatments.

Rapid-curing cutback bitumens (RC) are produced by blending a penetration grade bitumen with a petroleum distillate that will evaporate easily, thereby facilitating a quick change from the liquid form at the time of application to the consistency of the original bitumen. Gasoline or naphtha generally is used as solvent for this series of bitumen. The grade of rapid-curing bitumen required dictates the amount of solvent to be added to the residual bitumen. For example, RC-300 requires about 15 percent of distillate, whereas RC-70 requires about 40 percent. The grades of bitumen can be used for jobs similar to those for which MC series is used (Garba and Hoel, 2010).

2.2.2 Aggregates

The main aggregates used in road pavements on their own or in combination with a cementitious material are either natural rock materials, gravels and sands, or slag aggregates (Brennan and O'Flaherty, 2002).

Aggregates for asphalt mixture are usually classified as coarse aggregate, fine aggregate and fines otherwise knownas fillers. The coarse aggregates are generally referred to as gravel sizes. They are aggregate particles mainly larger than 4.75mm (No.4) B.S sieve. The fine aggregates are generally referred to as sand sizes. They are aggregate particles mainly between 4.75 mm (No.4 sieve) and 75 μm (No.200 sieve) in size. Fines are generally referred to as fillers. They are silt, clay or dust particles smaller than 75 μm (No.200 sieve). They occupy the empty space between the aggregate and enhances the

wearing potential of the mix. It is fed in a dry condition into the mixture, during or may be after the addition of binder (Atkins, 1997).

The Nigerian General Specifications for Roads and Bridges (1997) specified the type of aggregates to be used in asphalt mixture. Clause 6371, part A (I) reads 'Coarse aggregate shall be the portion of the aggregate retained on the No.4 sieve and shall be hard, clean and durable crushed igneous rock from a source to be approved by the Engineer.

The crushed stone shall be free from dirt or any objectionable matter'.

For fine aggregate, part A (II) reads "Fine aggregate shall be the portion of the aggregate passing the No.4 sieve and shall be quarry fine produced from the crushing of igneous rock.

They shall be composed of clean, tough, rough surfaced and angular particles, free from lumps or ball of clay, loam and other deleterious substances"

For mineral filler, part A (III) reads "Mineral filler shall consist of finely ground particles of hydrated lime, Portland cement or non-plastic mineral matter approved by the Engineer. It shall be free from foreign or other objectionable material and shall meet the degree of fineness.

2.2.2.1 Coarse Aggregates

Geologists have classified rocks into three main groups, based on their mode of formation as;igneous, sedimentary and metamorphic. Igneous rocks were formed above (extrusive rocks) or below (intrusive rocks) the earth's surface by cooling of molten material, called magma, which erupted from, or was trapped beneath, the earth's crust. Extrusive magma

cooled rapidly and the rocks formed are very often glassy or vitreous (without crystals) or partly vitreous and partly crystalline with very small grain sizes (Brennan and O'Flaherty, 2002).

An extrusive rock may also contain cavities that give it a vesicular texture. By contract, the intrusive rocks are entirely crystalline, due to magma cooling slowly, and the crystals may be sufficiently large to be visible to the naked eyes. The best igneous road stones normally contain medium grain sizes. Particles with coarse grains (>1.250 mm) are liable to brittle and to break down under the crushing action of a compacting roller. If the grains are too fine (< 0.125mm), especially if the rock is vesicular, the aggregates are also liable to brittle and splintery (Brennan and O'Flaherty, 2002).

When igneous rock contains more than 66 per cent silica (SiO_2) it is described as 'acidic', and as 'basic' if it has less than 55 per cent. Rocks with 55-66 per cent total SiO_2 are termed 'intermediate'. Acidic rocks tend to be negatively charged and aggregates containing large amount of feldspar and quartz in large crystals do not bind well with bitumen (which also has a slight negative charge), whereas aggregates that are rich in ferromagnesian minerals, for example, basalt and gabbro, bind well with bitumen (Brennan and O'Flaherty, 2002).

Many rock aggregates differ from each other in respect of practical road-making abilities, it is convenient to combine them into groups with common characteristics, e.g. the important igneous rock aggregates belong to the basalt, gabbro, granite and porphyry groups. The main rocks in the basalt group are basalt, dolerite, basic porphyrite and andesite; they are mostly basic and intermediate rocks of medium and fine grain size. The gabbro group is composed primarily of basic igneous rocks, gabbro, basic diorite and

basic gneiss. Members of the granite group are mostly acidic and intermediate rocks of coarse grain size; the heavily used members of this group are granite, quartz-diorite, gneiss and syenite. Porphyry group members are acid or intermediate igneous of fine grain size; typical examples are porphyry, granophyres, microgranite and felsites (Brennan and O'Flaherty, 2002).

Basalt aggregates are strong and have a high resistance to polishing; however, those containing olivine which has decomposed to clay have high shrinkage characteristics that lead to problems in asphaltic concrete. Granites are strong and their resistance to polishing is usually good; however, being acidic, more attention may be paid to anti-stripping treatment if they are to be used with bitumen. The porphyries are generally considered to be good all-round roadstone (Brennan and O'Flaherty, 2002).

2.2.2.2 Fine Aggregates

The effect of aggregate properties on the fatigue behavior of the conventional and polymer modified bituminous mixtures using two types of sand as fine aggregate, as reported by Yasreem and Ibrahim (2011) shows that, fine aggregate is a primary constituent in asphalt mixtures. The properties of fine aggregate namely its physical, chemical and mechanical properties play a significant role in determining the characteristics of the resulting bituminous mixture. The use of crushed rock as fine aggregate in Hot Mixed Asphalt (HMA) wearing course results in mixture with higher resistance to deformation, compared to most naturally occurringsand used as fine aggregate. Ahirich, (1991)shows that the replacement of the rounded aggregate by

crushed fine aggregates improved mixture properties such as stability, rutting and water resistance.

The aggregate gradation (distribution of particle sizes) is another important factor that enhances asphalt resistance to pavement distress. The chemical composition of aggregate has a significant effect on the stripping behavior; indirectly its effect on the cracking because one of the distresses that might be caused by stripping is cracking.

The physical property of sand can be determined using fine aggregate angularity (FAA). The fine aggregate angularity is measured by determining the percentage of voids in the sand, since it is known that the more angular the particles of sand, the higher the percentage of voids. Quarry sand has more angularity compared to the mining sand. It was found that fine aggregate with higher values of FAA produce more angular particles and greater rough surface texture, resulting in a larger interlock between particles consequently resulting in higher shear strength, and this enhances fatigue resistance (Yasreem and Ibrahim, 2011).

The chemical composition of sand can be determined by the x-ray fluorescence (XRF) test by Yasreem and Ibrahim (2011) showed that mining sand has higher percentage of SiO_2 (80%), compared to the quarry sand (66.1%). It was found that large amount of SiO_2 can cause stripping of HMA pavements because silica reduces the bond strength between the aggregate and binder. Quarry sand has the higher total percentage of alumina (Al_2O_3) that is, 12.6% compared to mining sand which contains 8.98%. The Al_2O_3 content is related to the hardness of the material. Quarry sand also has the higher total percentage of haematite (Fe_2O_3) that is, 5.30% compared to mining sand which

contains 2.2% of the hematite. The hematite which has the smallest particle size compared to other elements increases the density of the bituminous mixture. The oil absorption property is needed to absorb the extensive oil in the bituminous mixtures; this property could decrease the pavement distress behaviour. Al_2O_3 also has the highest oil absorption value of 25-225g/100g followed by Fe_2O_3 and SiO_2 respectively. This indicates that quarry sand showed the highest ability to absorb the extensive oil in bituminous mixture, because it has got higher Al_2O_3 and Fe_2O_3, whilst mining sand exhibited the lower ability to absorb oil in bituminous mixture, (Yasreem and Ibrahim, 2011).

The mechanical property of sand can be determined using shear box test. The angle of internal friction (Ø) is an indication of particle interlocking and hence particle shape and surface texture. The direct shear test results showed that quarry sand has the higher Ø value of 45^0 compared to the mining sand which is 34.9^0. It was found that rounded smooth textured aggregate particles tend to slide past one another producing a HMA mixture with relatively low shear strength. These results explain why crushed aggregate like quarry sand has higher shear resistance compared to natural sand (mining sand). Natural sands has more rounded particles with smooth surface texture resulting in less interlock between particles. The higher shear resistance is an indication of resistance to mixture deformation or distress. Study confirmed that the higher internal friction angle of fine aggregate indicates better interlocking mechanism results in a more resistant granular structure, (Yasreem and Ibrahim, 2011).

Ahirich (1991) considered the effects of natural sands on asphalt concrete engineering properties. According to the research, soils having more than 50% of their particles

smaller than 75mm – that is, passed through the No. 4 (4.75mm) sieve – are sands. Natural sand material is generally considered to be an aggregate that has occurred naturally without any blasting or crushing. Natural sand is generally a siliceous material that has a smooth, rounded surface and is in the size range of the No.4 (4.75mm) and No. 200(0.075mm) sieves. Natural sands can be classified as a fine sand No. 40 (0.425mm) to No.200 (0.075mm), medium sand No. 10 (2.0mm) to No.40 (0.425mm) and coarse sand No.4 (4.75mm) to No.10 (2.0mm).

Natural sand materials, which are primarily uncrushed rounded particles, are often used in asphalt concrete mixtures because these materials are generally less expensive, readily available, and can be blended easily with other materials. Natural sand materials have a smooth, rounded surface texture that greatly reduces the interlocking properties of the asphalt concrete and reduces the strength properties. Low strength properties and stability values in asphalt concrete mixtures allow deformation to occur, which leads to rutting (Ahirich, 1991).

In numerous field evaluations by the Federal Highway Administration (FHWA) and U.S. Corps of Engineers of asphalt concrete pavements that exhibited rutting, it was found that many highway departments and military installations were allowing an excess of natural sand in their asphalt concrete mixtures. This excessive amount of uncrushed rounded particles had caused a reduction in pavement strength and stability and an increase in pavement deformation under traffic, (Ahirich, 1991).

Most agencies that construct flexible pavements have some guidance or have set limits on the use of natural sands. The Corps U.S of Engineers has set allowable limits for natural

sand content for asphalt concrete mixture, but these limits are not widely used outside major airfield pavement projects. Some state highway departments in the U.S. have also set limit for the amount of natural sand, but the maximum varies from 10 to 30 percent (Ahirich, 1991).

The natural sand limits established by the U.S Corps of Engineers are based on past observed behaviour and performance in the field. Since the widely specified Marshall Mix design procedure does not always reflect the detrimental effect of natural sand, many mix designs produced for state highway departments and military installations have excess amount of natural sand (Ahirich, 1991).

2.2.2.3 Filler

The earliest study on mineral filler dates back to 1931 when the Detroit Edison Company compared the physical properties of fly ash with those of limestone dust (Zimmer and Frank, 1970).

Filler acts as one of the major constituents in asphalt mixture. Fillers not only fill voids in the coarse and fine aggregates but also affect the ageing characteristics of the mix. Generally, the aggregate material that is finer than 75μm in size is referred to as filler. Filler is defined as consisting of finely divided mineral matter, such as rock dust, slag dust, hydrated lime, hydraulic lime, fly ash, loess, or other suitable mineral matter, (Rahman, 2013).

Filler as one of the components in an asphalt mixture plays a major role in determining the properties and the behavior of the mixture especially the binding and aggregate interlocking effects. The filler has the ability to increase the resistance of particle to move

within the matrix and or works as an active material when it interacts with the asphalt cement to change the properties of the mastic (Eltaher, *et al.,* 2013). Mineral fillers serve a dual purpose when added to asphalt mixes, the portion of the mineral filler that is finer than the thickness of the asphalt film blends with asphalt cement binder to form a mortar or mastic that contributes to improved stiffening to the mix. Particles larger than the thickness of the asphalt film behave as mineral aggregate and hence contribute to the contact points between individual aggregate particles (Puzinauskas, 1969).

Furthermore, fillers affect workability, moisture sensitivity, stiffness and ageing characteristics of the hot asphalt (Mogawer, *et al.,* 1996). Fillers vary in gradation, particle shape, surface area, voidscontent, mineral composition and Physio–chemical properties and therefore, their influence on the properties of Hot Mixed Asphalt (HMA) mixtures also varies and the maximum allowable amount different for various types of filler (Kandhal, 1981). In order to improve the pavement performance, it is necessary to ensure that adequate behavior of the bituminous mixtures is achieved, which depends especially on their composition. Therefore, selecting proper types of filler in asphalt mixtures would improve its properties and thus enhance the mixture performance.

According to Zimmer and Frank (1970), the general effect of adding filler to bitumen is to make it harder and stiffer and the extent of this hardening or stiffening effect depends on the amount of filler added and on its particle shape, size and grading.

Mineral fillers are often used in asphalt concrete mixtures to supply fines, as they are very important in producing dense–graded strong asphalt (Atkins, 1977). However, most

natural sands do not contain the amount of fines required to produce this type of dense – graded asphalt concrete.

2.2.2.3.1 Choice of Filler

The factors considered in selecting mineral fillers according to Kenth, G.O.(2012) are as follows:

(i) Fillers which absorb water such as clay and gypsum should not be used in situations where the mixture is in contact with water.

(ii) If bitumen is employed or used as an acid – resistant coating, acid resistance fillers such as silica or slate dust should be used.

(iii) When hydrated lime is used as mineral filler, it improves the adhesion of bitumen to mineral surfaces such as stone, glass and so on in the presence of water.

(iv) Asbestos fillers are not good for application in which the mixture is used as a sealant especially where it is in contact with liquid, in view of the fact that it acts with wick to transport liquid through bitumen.

2.2.2.3.2 Types of Filler

Limestone dust and cement are the most common mineral materials used as mineral filler (Atkins, 1977) but over the years, research has shown the performance characteristics of some materials as mineral filler in asphalt mixture. These materials are as follows:

Coal Fly Ash: The use of fly ash as filler in asphalt production was reported by Zimmer and Frank (1970), coal fly ash was used as mineral filler in hot mix asphalt paving applications. Asphalt mixtures containing low addition levels (approximately 5 percent by dry weight of aggregate) of fly ash as a mineral fillers exhibit mix design properties

that are usually comparable to asphalt mixtures containing natural filler such as hydrated lime or stone dust.

Further research into the beneficial anti – stripping characteristics of fly ash mineral fillers was revealed from an investigation of two western coal fly ashes (one class C and other class F) in combination with, or replacement for Portland cement or hydrated lime. All mixes that contained fly ash – exhibited comparable or improved retained strengths in the immersion – compression test when the two different sources of aggregate were used (Rosener, *et al.*, 1982).

Table 2.1: AASHTO M17 Specification Requirements for Mineral Filler used in asphalt paving mixtures

Particles Sizing			
Sieve size	Percent Passing	Organic Impurities	Plasticity index
0.006mm (No. 30)	100	mineral filler must be free from any organic impurities	Mineral filler must have plasticity index not greater than 4
0.003mm (No. 50)	95 – 100		
0.075mm (No.200	70 – 100		

Source: Federal Ministry of works General Specifications (Roads and Bridges) Lagos, Nigeria, Vol.11, 1997.

2.2.2.3.3 Kiln Dust

Kiln dusts are fine by-products of Portland cement and lime high temperature rotary kiln production operations that are captured in the air pollution control dust collection system (for example, cyclones, electrostatic precipitators and bag houses). Kraszewski, *et al.*, (1981) observed that Cement Kiln Dust (CKD) and Lime Kiln Dust (LKD) have been

used as mineral filler in asphalt concrete mixes. The blending of cement kiln dust (CKD) into the asphalt cement binder prior to incorporation with the hot mix aggregate results in a binder (mastic) that can significantly reduce asphalt cement requirements (between 15 and 25 percent by volume). Furthermore, the lime components of the cement kiln dust (CKD) can assist in promoting stripping resistance preventing moisture related damage resulting from the separation of the bitumen film from aggregate at its interface in the presence of moisture that is common in siliceous aggregate (Ciesielski *et al*., 1994).

The use of low addition levels of both fresh cement kiln dust (CKD) and lime kiln dust (LKD) as mineral filler in hot mix asphalt surface course mixes (approximately 5 percent by weight of aggregate) reportedly exhibit mix properties comparable to that of natural fillers such as hydrated lime and stone dust. LKD can assist in promoting stripping resistance. In this application, these dust can be used to replace hydrated lime or liquid anti stripping agents (Ciesielski, *et al*., 1994).

Research work carried out by Deddy (2002) aimed at studying and evaluating the performance of hot rolled asphalt and sawdust filler when compared with standard filler (stone ash). In his work, the composition of each filler used in the mixture were 100% stone dust, 50% stone dust, 50 % saw dust and 100% sawdust. The mixture of bitumen and filler of 100% sawdust really has the worst mixing characteristics. The best result was achieved when the mixture of bitumen and filler of stone dust and saw dust had content of 50% each at an optimum bitumen content of 6.65% which gave characteristics value approaching to the mixture of bitumen and 100% stone dust filler.

Deddey, (2002), the mixture using 100% sawdust filler is not recommended for heavy traffic because bleeding could be experienced. The mixture using filler of 50% stone dust and 50% saw dust has to be further studied to find the best composition, since its structural values nearly approach the standard mixture (filler of 100% stone dust).

Danjuma (2000) carried out a research on the effect of various fillers on the properties of asphaltic concrete. The research was aimed at studying and evaluating three different filler types and their effect on asphaltic concrete. The filler types are quarry dust, collector dust and saw dust with Portland cement as the control. The various fillers, binder and graded mineral aggregates were subjected to physical property/quantity assurance tests in order to determine whether they conform to standard specifications. The specimens were prepared with mixture proportion such that the percentage of graded mineral aggregates, (70% coarse aggregate and 20% fine aggregate) in the mix remained constant throughout, while filler content (3 to 7 percent) and bitumen content 7 down to 3 percent were varied. The method adopted for preparing specimen and Marshall Test procedure is the same with the one recommended by the Asphalt Institute (1984).

The maximum stability of 10.192kN was achieved by saw dust at 4 percent filler content and 6 percent bitumen content, a maximum tensile strength 0.439N/mm^2 was attained and an average flow of 5.2mm was obtained. According to the research, saw dust was found to be the least among these fillers in terms of maximum stability and tensile strength.

Kenth, G.O. (2012) aimed at studying and evaluating the suitability of Periwinkle Shell Dust (PSD) as mineral filler in asphalt mixture. He recommended the use of 100% Periwinkle Shell Dust as complete replacement for quarry dust as mineral filler in asphalt mixture which is very reliable in terms of strength, flow and other void parameters.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Materials

The main materials that are required for preparing asphalt mixes are bitumen, aggregate and fines (filler).

The aggregate consists of coarse and fine aggregates. The following are the materials used for this research work.

(i) Bitumen 60/70 pen grade

(ii) Coarse aggregate (12mm and 10mm)

(iii) Fine aggregate (Quarry fine)

(iv) Ordinary Portland Cement (filler)-control

(v) Saw dust ash (filler)-investigation

3.1.1 Bitumen

Bitumen was sourced from NNPC refinery, Kaduna through EKSIOGULARRI Construction Company, Sabon Tasha, Kaduna.

Below are the main laboratory tests carried out on the bitumen:

(i) Penetration Test (BS2000, 1983)

Bitumen penetration test is to determine the grade of the bitumen. Samples of bitumen were prepared and cured at a temperature of 25^{o}C for about 45 minutes. Penetration was measured in millimeters where one unit equals 0.1mm. Three

penetration tests were conducted and an average was taken to arrive at the penetration of the bitumen. The penetration test gives an empirical measurement of the consistency of a material in terms of the distance a standard needle sinks into the material under a prescribed loading and time. It is also used to indicate the viscosity of asphalt cements to ensure the exclusion of materials with very low penetration value at 25^{o}C (77^{o}F).

Practical Significance: Penetration values below 20 has been associated with bad cracking of the road surfacing while cracking rarely occurs when the penetration exceeds 30 for normal road work. The result of penetration test is presented in Table 3.1a.

Table 3.1a – Result of standard penetration test for asphalt cement (BS2000-49)

TEST	CONTAINER 1 Penetration (mm)	CONTAINER 2 Penetration (mm)
Test point 1	61.0	61.1
Test point 2	63.0	63.0
Test point 3	60.0	62.0
Average	**61.3**	**62.0**

(ii) Ductility Test (ASTMD113, 1995)

Ductility test was carried out on the bitumen to evaluate the susceptibility characteristics of asphalt materials to changes in temperature and other atmospheric factors. Samples of the bitumen were cast in moulds consisting of two jaws and were placed successively in the ductility machine to measure the

elongation of the bitumen. Sample elongation was measured as 105cm, which is an average of the samples.

Practical Significance: The ductility test is a measure of the internal cohesion of bitumen. Bitumen possessing high ductility is normally cementitious and adheres well to aggregates. The test is used as a measure of ductility in the material.

iii. Specific Gravity Test (Pycnometer Method)

The specific gravity of asphalt materials is used mainly to determine the weight of a given volume of material (or vice versa) to determine the amount of Voidsin compacted mixes and to correct volumes measured at high temperatures. The samples were prepared and poured into the pycnometer and were allowed to cool to a temperature of 25^{o}C before adding distill water at 4^{o}C and the temperatures were taken. The results are given in the Table 3.1b.

Table 3.1b – Result of Specific Gravity of Bitumen using Pycnometer

S/NO	DESCRIPTION OF SAMPLE	TEST 1 (g)	TEST 2 (g)	TEST 3 (g)
A	Weight of pycnometer + water (full)	1420	1420	1420
B	Weight of pycnometer	495	495	495
C	Volume of pycnometer = (a-b)=925cm^3=925g	925	925	925
D	Weight of pycnometer +sample	655	655	655
E	Weight of sample (d - b)	160	160	160
F	Weight of pycnometer + sample + water	1425	1425	1425
G	Weight of water added = (f-d)	770	770	770
H	Weight of water displaced = (c-g)	155	155	155
I	Specific Gravity = (e/h)	1.03	1.03	1.03

Practical Significance: When designing a paving mixture with a given aggregate, the maximum specific gravity at each bitumen content is needed to calculate the percent of air voids for each bitumen content.

3.1.2 Coarse Aggregates

Coarse aggregates of 12mm and 10mm were obtained from Malari Quarry, Kaduna.

3.1.2.1 Laboratory Test on Coarse Aggregates

The following tests were performed on the 12mm and 10mm size aggregates.

i. Sieve Analysis (BS 1377, 1990)

Gradation tests are used by aggregate producers for quality control purposes and by users for checking compliance with specifications. They provide the quantities, expressed in percentages by mass, of the various sizes of which a sample of aggregate is composed.

Sampling of materials was done and sieve analysis was carried out in accordance with BS 1377, 1990 part [1.2] in A.B.U soil laboratory. The results of sieve analysis tests are given in the Tables 3.1.2a and 3.1.2b.

Table 3.1.2a – Result of Sieve Analysis (12mm Coarse Aggregate)

Sieve sizes (mm)	Mass Retained (g)	Percentage retained (%)	Percentage passing (%)
25.4mm	0	0	100
12.7mm	275	53.9	46.1
9.52mm	225	44.1	2.0
6.30mm	10	2.0	0
Pan	0	0	
Total	**510g**	**100 %**	

Table 3.1.2b – Result of Sieve Analysis (10mm Coarse Aggregate)

Sieve Sizes (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)
25.4mm	0	0	100
12.7mm	20	3.2	96.8
9.52mm	140	22.6	74.2
6.30mm	290	46.8	27.4
2.36mm	170	27.4	0
Pan	0	0	0
TOTAL	**620g**	**100%**	

ii. Aggregate Crushing Value Test (BS 812, 1990)

The Aggregate Crushing Value (ACV) test, which is a measure of the resistance of aggregate to crushing under a gradually applied compressive load. Aggregate crushing value test was carried out on 12mm and 10mm aggregates in A.B.U concrete laboratory in accordance with B.S 812, 1990. The calculations are as shown in appendix A.

Table 3.1.2.1a: Result of Aggregate Crushing Value Test (12mm Aggregate)

S/No.	DESCRIPTION	1st Test	2nd Test	3rd Test
1.	Weight of Sample (g)	5000	5000	5000
2.	Wt of Sample remaining after compaction (g)	1300	1350	1350
3.	Wt of Crushed Sample passing sieve 2.36mm (g)	819	850	844
4.	ACV (%)	22.14	23.29	23.12
	Average ACV%		**22.85%**	

Table 3.1.2.1b: Result of Aggregate Crushing Value Test (10mm Aggregate)

S/NO.	DESCRIPTION	1st Test	2nd Test	3rd Test
1.	Weight of Sample (g)	5000	5000	5000
2.	Wt. of Sample remaining after compaction(g)	1180	1200	1200
3.	Wt. of Crushed Sample passing Sieve 2.36mm(g)	925	895	892
4.	ACV (%)	24.21	23.55	23.47
	Average ACV%		**23.74%**	

iii. Aggregate Impact Value Test (BS 812, 1990)

The AIV test provides a relative measure of resistance of an aggregate to sudden shock for example as might occur under a vibratory roller. Aggregate impact value for 12mm aggregate and 10mm aggregate were conducted in ABU concrete laboratory in accordance to (BS 812, 1990). The tables of results of impact value tests of 12mm and 10mm aggregates are shown in tables 3.1.2.1a_1 and 3.1.2.1b_1.

Table 3.1.2.1a_1: Result of Aggregate Impact Value Test (12mm Aggregate)

S/NO	DESCRIPTION	1ST Test	2nd Test	3rd Test
1.	Weight of samples (g)	500	500	500
2.	Wt of sample remaining after compaction (g)	145	150	148
3.	Wt of impact sample passing sieve 2.36mm (g)	76	68	75
4.	AIV (%)	21.41	19.43	21.31
	Average AIV%		**20.72%**	

Table 3.1.2.1b$_1$: Result of Impact Value Test (10mm Aggregate)

S/NO	DESCRIPTION	1ST Test	2nd	3rd Test
1.	Wt of Sample (g)	500	500	500
2.	Wt of Sample remaining after Compaction (g)	128	129	130
3.	Wt of Impact sample passing Sieve 2.36mm (g)	89	89	79
4.	AIV (%)	23.92	23.99	21.35
	Average AIV%		**23.09%**	

iv. Specific Gravity Test

When designing a pavement mixture with a given aggregate, the specific gravity at each bitumen content is needed to calculate the percent of air voids for each bitumen content. Specific gravity test was conducted for 12mm and 10mm aggregates using pycnometer method. The results are presented in the Tables 3.1.2e and 3.1.2f respectively.

Table 3.1.2e – Result of Specific Gravity of 12mm Coarse Aggregate using Pycnometer.

S/NO.	DESCRIPTION OF SAMPLE	TEST 1 (g)	TEST 2 (g)	TEST 3 (g)
A	Weight of Pycnometer + Water (full)	1420	1420	1420
B	Weight of Pycnometer	495	495	495
C	Volume of Pycnometer (a-b) = 925cm^3	925	925	925
D	Weight of Pycnometer + Sample	1150	1150	1150
E	Weight of Sample = (d-b)	655	655	655
F	Weight of Pycnometer + Sample + Water	1328	1328	1328
G	Weight of Water added = (f-d)	673	673	673
H	Weight of Water displaced = (c-g)	252	252	252
I	Specific Gravity = (e/h)	2.60	2.60	2.60

Table 3.1.2f – Result of Specific Gravity of 10mm Coarse Aggregate using Pycnometer.

S/NO.	DESCRIPTION OF SAMPLE	TEST 1 (g)	TEST 2 (g)	TEST 3 (g)
A	Weight of Pycnometer + Water (full)	1420	1420	1420
B	Weight of Pycnometer	495	495	495
C	Volume of Pycnometer=(a-b)=925cm^3=925g	925	925	925
D	Weight of Pycnometer + Sample	1060	1060	1060
E	Weight of Sample = (d-b)	565	565	565
F	Weight of Pycnometer + Sample + Water	1770	1770	1770
G	Weight of Water added = (f-g)	710	710	710
H	Weight of Water displaced = (c-g)	215	215	215
I	Specific Gravity = (e/h)	2.63	2.63	2.63

3.1.3 Fine Aggregate

Fine aggregate of crushed rock was obtained from Malari Quarry, Kaduna. Fine aggregates range mainly from 4.75mm (sieve No.4) to 75μm (sieve No.200). The aggregates are referred to as sand sizes.

3.1.3.1 Laboratory Test on Fine Aggregate

The following tests were carried out on fine aggregate:

i. Sieve analysis (BS 1377, 1990)

The sieve analysis was conducted in accordance with BS 1377 – 2, (1990).

The result is shown in Table 3.1.3.

Table 3.1.3 – Result of Sieve Analysis (Quarry fine)

Sieve Sizes (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)
6.30mm	0	0	100
2.36mm	140	14.0	86.0
2.0mm	365	36.5	49.5
No.25 (600μm)	135	13.5	36.0
No.52 (300μm)	150	15.0	21.0
No.100 (150μm)	90	9.0	12.0
No.200 (75μm)	40	4.0	8.0
Pan	80	8.0	0
TOTAL	**1000g**	**100%**	

3.1.4 Ordinary Portland Cement – OPC (Control)

The Portland cement was obtained from a cement depot Kaduna. It was used in this research as a control, as this is the common material used as filler in asphalt mixture.

3.1.4.1 Laboratory Test on Portland Cement

Below are the necessary laboratory tests carried out on the Portland cement.

i. Sieve Analysis

Sieve analysis was carried out in accordance with BS 1377 – 2, (1990). See Table 3.1.4a and 3.1.4b.

Table 3.1.4a – Result of Sieve Analysis (Cement) – Control

Sieve Sizes (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)
No.52 (300μm)	0	0	100
No.100 (150μm)	10	9.5	90.5
No.200 (75μm)	20	19.0	71.5
Pan	75	71.5	0
TOTAL	**105g**	**100%**	

Table 3.1.4b – Result of Specific Gravity of Cement (Gravity Bottle Method)

S/NO.	DESCRIPTION OF SAMPLE	TEST 1 (g)	TEST 2 (g)	TEST 3 (g)
a	Weight of bottle + Water (full)	81.81	81.81	81.81
b	Weight of bottle	29.90	29.90	29.90
c	Volume of bottle=(a-b)=51.91cm^3=51.91g	51.91	51.51	51.51
d	Weight of bottle + Sample	40.75	40.75	40.75
e	Weight of Sample = (d-b)	10.85	10.85	10.85
f	Weight of bottle + Sample + Water	89.22	89.22	89.22
g	Weight of Water added = (f-d)	48.47	48.47	48.75
h	Weight of Water displaced = (c-g)	3.44	3.44	3.44
i	Specific Gravity = (e/h)	3.15	3.15	3.15

ii. Specific Gravity Test

Specific gravity of the cement was carried out using the gravity bottle method and the result is presented in Table 3.1.4b.

3.1.5 Saw Dust Ash (SDA) - Investigation

The saw dust for this research workwas obtained from a saw mill at Panteka in Kaduna, Kaduna State, Nigeria. The sample was carefully collected to avoid being mixed with sand. The saw dust was burnt into ashes by open fire in a metal container. The saw dust ash was ground after cooling using a grinding machine to the degree of fineness required to be used as mineral filler as stipulated by the Nigerian General Specifications for Roads and Bridges (1997) and as also specified by (AASTHO M17, 1986).

3.1.5.1 Laboratory Tests on Saw Dust Ash (SDA)

Below are the necessary laboratory tests carried out on saw dust ash.

(i) Sieve Analysis

Sieve analysis was carried in accordance to BS 1377 – 2, (1990) and the result is presented in table 3.1.5a.

Table 3.1.5a – Result of Sieve Analysis (Saw Dust Ash) – Investigation

Sieve Sizes (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)
No.100 (150μm)	0	0	100
No.200 (75μm)	20	22.2	77.8
Pan	70	77.8	0
TOTAL	**90g**	**100%**	

(ii) Specific Gravity Test

Specific gravity test was carried out on the sample in accordance with BS 1377 – 2, (1990) using the Gravity Bottle Method. The result is presented in Table 3.1.5b.

Table 3.1.5b – Specific Gravity of Saw Dust Ash (Gravity Bottle Method)

Bottle No.	N2	N2	N2
Weight of bottle + Water (full) (W_4)	45.80	45.80	45.80
Weight of bottle + SDA + Water (W_3)	47.00	47.00	47.00
Weight of bottle + SDA (W_2)	23.20	23.20	23.20
Weight of bottle (W_1)	21.00	21.00	21.00
Weight of addition of Water ($W_4 – W_1$)	24.80	24.80	24.80
Weight of Water added to SDA ($W_3 – W_2$)	23.80	23.80	23.80
Weight of SDA ($W_2 – W_1$)	2.20	2.20	2.20
Weight of Water displaced by SDA ($W_4 – W_1$) - ($W_3 – W_2$) = W	1.00	1.00	1.00
Specific Gravity of saw dust ash ($W_2 – W_1$)/W	2.20	2.20	2.20

(iii) Atterberg Limit Determination (Casagrande Method)

Atterberg limit was conducted in the A.B.U soil laboratory using Casagrande apparatus. The result is given in Table 3.1.5c.

Table 3.1.5c: Atterberg Limit Test

	LL	LL	LL	LL	LL	PL	PL
Number of blows	48	39	26	18	12		
Container No.	91	J7	66	F7	Z	189	26
Mass of Wet Soil + Container	16.40	16.30	18.50	19.20	21.30	10.8	10.8
Mass of dried soil + Container	13.00	12.80	13.80	14.40	15.30	9.90	9.90
Mass of Container	9.30	8.60	8.80	9.40	9.00	8.90	8.90
Mass of Moisture	3.40	3.50	4.70	4.80	6.00	0.90	0.90
Mass of dry soil	3.70	4.20	5.00	5.00	6.30	1.00	1.00
Moisture Content	91.89	83.33	94.00	96.00	95.24	90.00	90.00

LL	94
PL	90
PL	4

Table 3.1.5c_1: Atterberg Limit Test

(iv) Chemical Analysis of Saw Dust Ash

About 2.0grammes of the sample of saw dust ash was analyzed for oxide composition at the Centre for Energy Research, Zaria using X-Ray Fluorescent (XRF) Method.

(v) Procedure for Analysis of Sample (XRF Method)

Mini Pal is a compact energy dispersive X-ray spectrometer designed for the elemental analysis of a wide range of samples.

The Mini Pal 4 version in use is PW 4030 X-ray Spectrometer, which is an energy dispersive microprocessor controlled analytical instrument designed for the detection and

measurement of elements in sample (solids, powders and liquids) from sodium to uranium.

The sample for analysis was weighed and grounded in a mortar in an agate mortar (this is to prevent contamination) and a binder Polyvinylchloride (PVC) dissolved in Toluene is added to the sample, carefully mixed and pressed in a hydraulic press into a pellet.

The pellet is loaded in the sample chamber of the spectrometer and voltage (30KV maximum) and a current (1μA maximum) is applied to produce the X-rays to excite the sample for a preset time (10minutes in this case). The spectrum for the sample is now analyzed to determine the concentration of the elements in the sample. The result is given in Table 3.1.5d.

Table 3.1.5d Result of Chemical Oxide Composition of Saw Dust Ash

Compound in Sample	**Concentration (Percent)%**
SiO_2	6.4
P_2O_5	1.9
SO_3	3.45
K_2O	25.53
CaO	29.8
TiO_2	0.56
V_2O_5	0.01
MnO_2	0.26
Fe_2O_3	29.84
CuO	0.28
ZnO	1.29
BaO	0.44
EU_2O_3	0.26

3.2 Aggregate Gradation (Blending Method)

Saw dust ash was used to replace Portland cement at 0% to 100% at an interval of 10% by weight of cement.

The aggregate gradation is as follows: 100% Portland cement, 0% saw dust ash; Portland cement 90%, 10% saw dust ash; 80% Portland cement, 20% saw dust ash; 70% Portland cement, 30% saw dust ash; 60% Portland cement, 40% saw dust ash; 50% Portland cement, 50% saw dust ash; 40% Portland cement, 60% saw dust ash; 40% Portland cement, 60% saw dust ash; 30% Portland cement, 70% saw dust ash; 20% Portland cement, 80% saw dust ash; 10% Portland cement, 90% saw dust ash; and 0% Portland cement, 100% saw dust ash; All aggregates were blended using the trial and error method for both control and investigation.

3.2.1 Asphalt Concrete Mix Design

The design of an asphalt concrete mixture include the selection of the best blend of the aggregates and the optimum bitumen content to provide a material that meets the required specifications as economically as possible. There are two most common traditional methods for making and evaluating trial mixes. These are Marshall and Hveem methods. Currently, the super-pave method developed by the Strategic Highway Research Program (SHRP) is being introduced (Atkins, 1997).

The mix design aims to determine the proportion of bitumen, filler, fine aggregates and coarse aggregates that will produce a mix that is workable, durable and economical.

According to Atkins (1997), asphalt concrete mix design involves the following steps:

(i) Selection of aggregate proportion to meet the specification requirement.

(ii) Conducting trial mixes at a range of bitumen contents

(iii)Analyzing the results to obtain optimum bitumen content.

Most private laboratories use the Marshall method because it is a proven method and requires relatively light, portable and inexpensive equipment. Like the Hveem and super-pave methods, the Marshall method has been proven to produce quality HMA from which long lasting pavements have been constructed. The Marshall method of mix design is adopted in this study.

3.2.2 The Marshall Method

The Marshall method of asphalt mix design according to ASTM D 1559, (1989) consists of the following major steps:

(i) Aggregates are blended in proportions that meet the specification.

(ii) The mixing and compacting temperature for the asphalt cement being used are obtained from the temperature–viscosity graph. These temperatures are those required to produce viscosities of 1.7 ± 0.2cm^2/s (170 ± 20 centistokes) for mixing and 2.8± 0.3cm^2/s (280± 30 centistokes) for compacting.

(iii)Thetotal number of briquettes cast were 32, its diameter is 100mm and its height is 65mm using 1200g of aggregates and asphalt content at various percentages both above and below the expected optimum bitumen content. For surface courses with 12.5mm

aggregate, the expected optimum content may be about 6.5%. Therefore, briquettes were made at 5.0%, 5.5%, 6.0%, 6.5% and 7.0% asphalt cement.

(iv) Density of the briquettes is measured to allow calculation of voids properties.Briquettes were cured at a temperature of 60^0C. Stability and flow values were obtained usingthe Marshall apparatus to measure strength and flexibility. The stability is the maximum load that the briquettes can carry. The flow is the compression (measured in units of hundredths of an inch or in millimeter) that the sample undergoes between no load and maximum load in the compression test.

CHAPTER FOUR

ANALYSIS, RESULTS AND DISCUSSION

4.1 Results

The results of the various laboratory tests conducted in this study are presented and discussed in this section. The specific gravity, aggregate crushing value and aggregate impact value test results of coarse and fine aggregates are presented in Table 4.1.

Table 4.1: Specific Gravity, Aggregate Crushing Value, (ACV) and Aggregate Impact Value, (AIV) of Coarse and Fine Aggregates used.

Type of Aggregate	Bulk Specific Gravity	ACV Percent (%)	AIV Percent (%)
Coarse 12mm	2.60	22.85	20.72
Coarse 10mm	2.63	23.74	23.09
Fine Aggregate	2.65		

The values of specific gravities of coarse aggregates with sizes of 12mm, 10mm and fine aggregate presented in Table 4.1 are within the acceptable values recommended by Mageswari *et al*., (2009). The aggregate crushing values of 12mm aggregate and 10mm aggregate which are 22.85% and 23.74% are within the acceptable limits. Aggregate crushing values above 30 are rarely used in road pavements (Nigerian General Specifications for Roads and Bridges, 1997). The aggregate impact values of 12mm aggregate and 10mm aggregate which are 20.72% and 23.09% are also within acceptable limits specified by the Nigerian General Specifications for Roads and Bridges, 1997.

Aggregates with AIV greater than 30 are normally regarded as being too weak and brittle for use in pavements. These values are within the acceptable limits specified by the Nigerian Specifications for Roads and Bridges, 1997.

The results of physical properties of mineral fillers are presented in Table 4.2.

Table 4.2: Physical Properties of Mineral Fillers

Sieve sizes (μm)	**Portland Cement**	**Saw Dust Ash**	**AASHTO M17**
No.52 (300μm)	100	100	100
No.100 (150μm)	90.5	100	95 – 100
No.200 (75μm)	71.5	77.8	70 – 100
Plasticity Index	0	4	≤4
Specific Gravity	3.15	2.20	-

The percentages of Portland cement passing through sieve size, 300μm, 150μm and 75μm are 100, 90.5 and 71.5. The values of 100% and 71.5% are within acceptable limits specified in AASHTO M17, (1986). Furthermore, the percentages of saw dust ash passing through sieve size, 300μm, 150μm and 75μm are 100, 100 and 77.8 which are also within the specifications stipulated in AASHTO M17. Portland cement has a plasticity index of zero, while that of saw dust ash is 4. Mineral fillers must have plasticity index not greater than 4 as stipulated in AASHTO M17 specifications. Requirements for mineral fillers in asphalt paving mixtures are contained in the Federal Ministry of Works General Specifications Roads and Bridges (1997). The specific gravity of cement which is 3.15 is within the limit stipulated in General specifications (Roads and Bridges), 1997. The specific gravity of saw dust ash which is 2.20 is within a range of 2.0 to 2.8 as specified for non-conventional mineral filler such as fly ash (Zimmer and

Frank, 1970). Furthermore, the specific gravity of saw dust ash which is 2.20 is also very close to the value of 2.5 obtained as specific gravity of saw dust ash by (Mageswari *et al.,* 2009).

The results of different tests performed on bitumen are presented in Table 4.3.

Table 4.3: Physical Properties of Bitumen

Test	**Unit**	**NGSRB (1994)**	**Result (60/70)**
Penetration, 100gm, 25^{o}C	0.1mm	60 – 70	61.65
Ductility, 5cm/min, 25^{o}C	Cm	$\geq$ 100	105
Specific Gravity at 25^{o}C	-	1.01 – 1.05	1.03

The result of the physical properties of bitumen as presented in Table 4.3 shows that the penetration grade bitumen is within 60mm minimum to 70mm maximum penetration `grade. Hence, the bitumen is 60/70 type. Elongation of bitumen in the ductility machine is 105cm. This result shows that the elongation of the bitumen is higher than 100cm minimum for 60/70 penetration grade bitumen as stipulated and acceptable for asphalt mixture. The specific gravity of bitumen which is 1.03 shows that it belongs to the grade of 60/70 bitumen. The test values are within the range specified in the Nigerian General Specifications for Roads and Bridges (1997).

The oxide composition analysis result performed on SDA is presented in Table 3.1.5d.

Referring to Table 3.1.5d (oxide composition) of saw dust ash, it shows that the material is free from any organic impurity. The test shows that haematic or ferric oxide (Fe_3O_2) has the highest percentage (29.84%) in the oxide composition of saw dust ash. The ferric oxide which has small particle size compared to other elements increases the density of bituminous mixture. Ferric oxide also aids in absorption of excess oil in bituminous mixture (Ahirich, 1991). It has the highest oil absorption value in saw dust ash. This property could decrease the pavement distress behavior by the absorption of excess oil in the bituminous mixture. Silicon oxide (SiO_2) which has a percentage of 6.4% also has oil absorption property in the bituminous mixture. Calcium oxide has 29.8% in oxide composition in saw dust ash. When just sufficient water is added to calcium oxide to satisfy its chemical affinity for moisture under the hydration conditions, all of the calcium oxide will be converted to calcium hydroxide, $Ca(OH)_2$, which is a good Pozzolanic material in accordance with the requirements in ASTMC 618 (1991) with evolution of heat as shown in Equation (4.1)

$$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca\ (OH)_{2(aq)} \qquad (4.1)$$

From the result of chemical analysis, it shows that the saw dust ash satisfies the requirement of the Nigerian General Specifications for Roads and Bridges (1997).

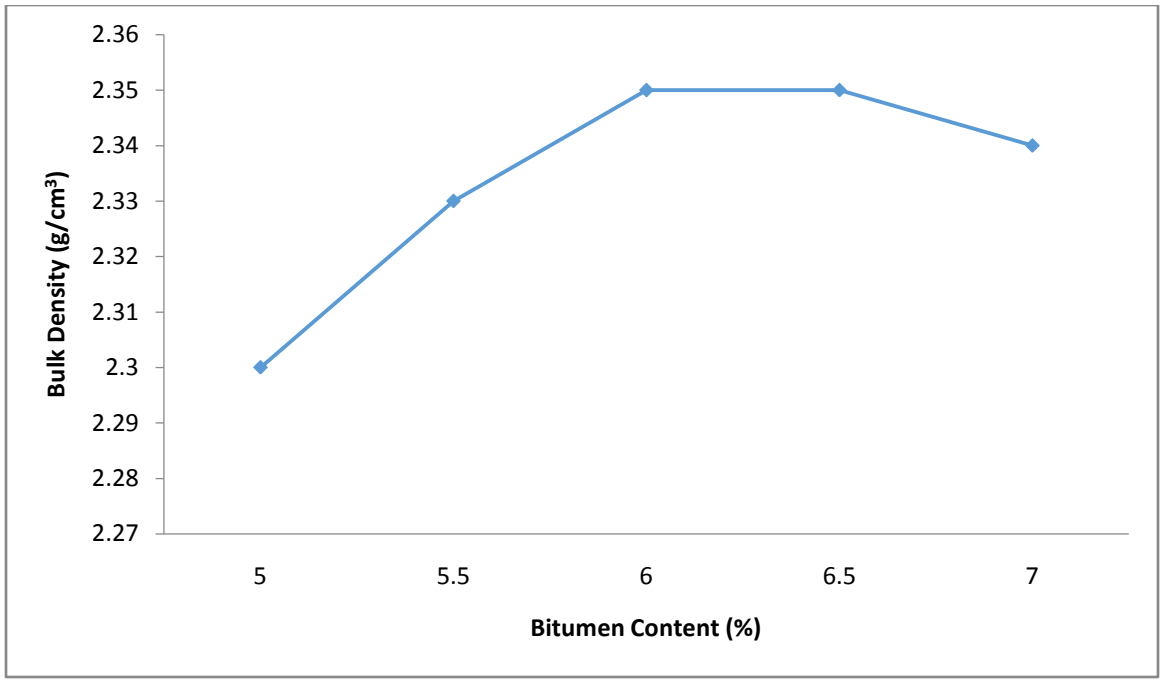


Figure 4.8: Relationship of Bulk Density (g/cm^3) to Bitumen content (%) - Mix with Cement – Control

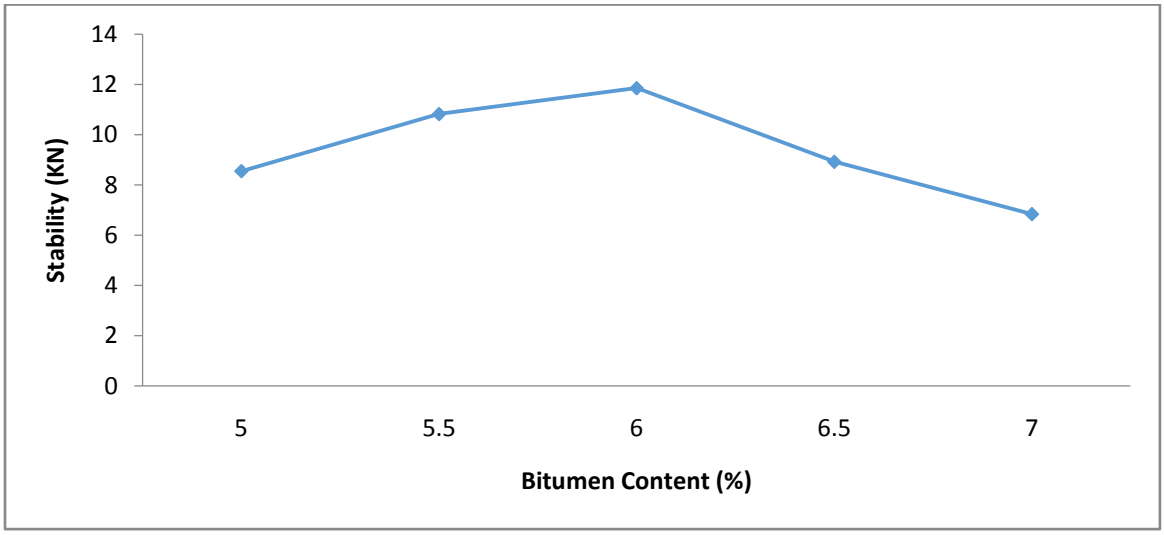


Figure 4.9: Relationship of Stability (kN) to Bitumen content (%)-Mix with Cement – Control

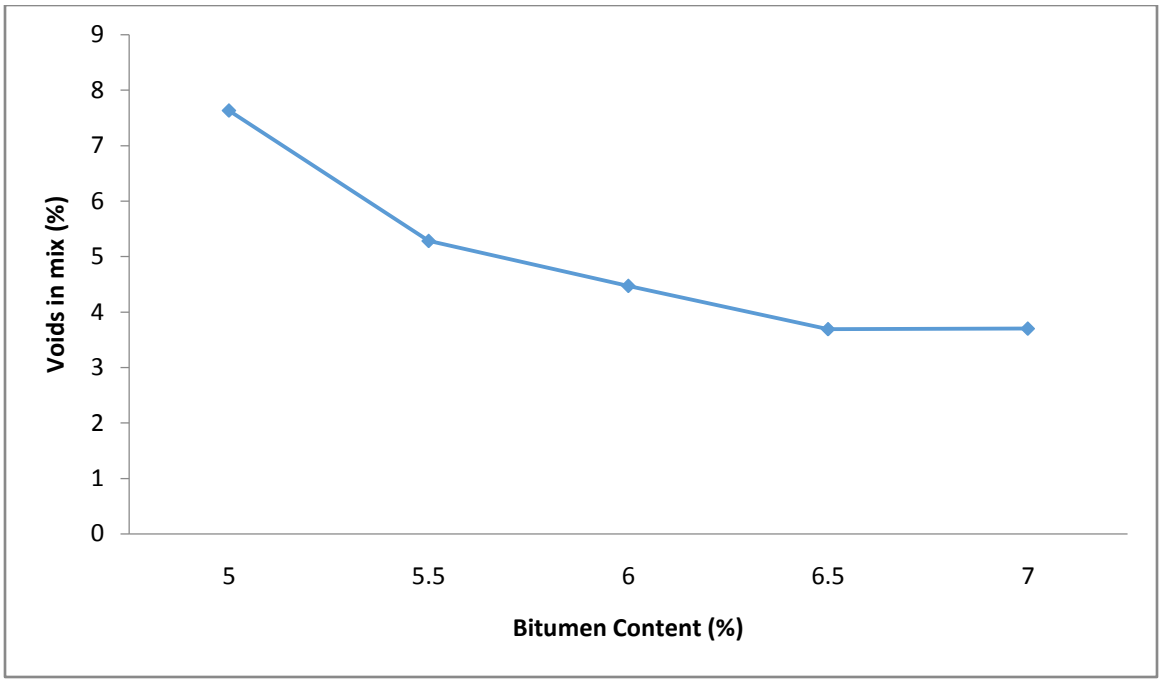


Figure 4.10: Relationship of Voids in Mix (%) to Bitumen Content (%) - Mix with Cement – Control

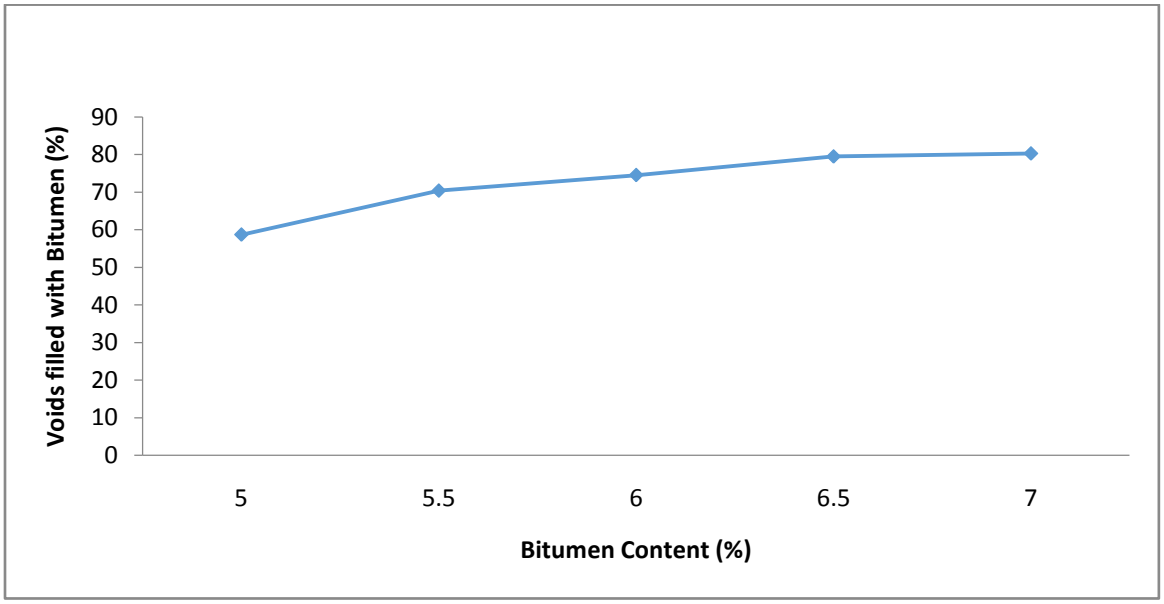


Figure 4.11: Relationship of Voids Filled with Bitumen (%) to Bitumen Content (%) - Mix with Cement – Control

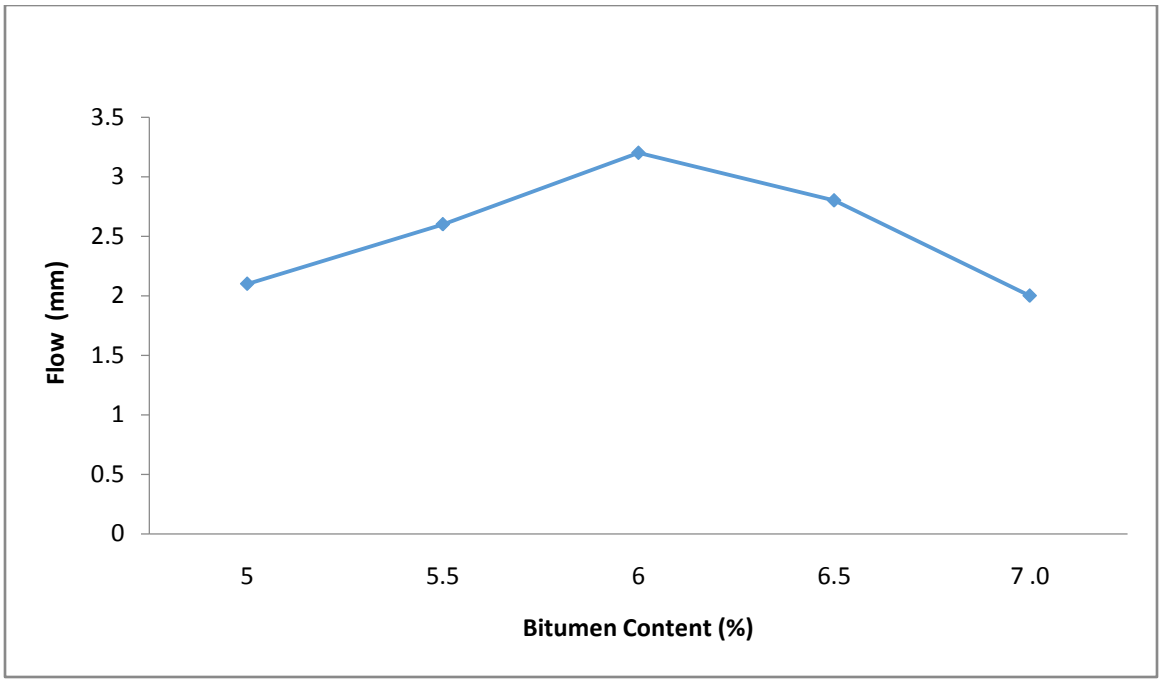


Figure 4.12: Relationship of Flow (mm) to Bitumen Content (%) – Mix with Cement – Control

4.2 Marshall Stability Test Results

The complete replacement of the conventional mineral filler (Portland cement) with saw dust ash was experimented to ascertain its possibility to totally replace Portland cement, which is the conventional filler. The result in Table 4.5bin the Appendix obtained with the use of SDA without Portland cement shows that the stability value of 3.29kN was obtained which is below 3.5kN specified for wearing courses, flow value of 1.00mm was obtained and is not within the range of 2mm – 4mm, while the voids in total mix value was 15.06% and the percentage of voids filled with bitumen was 42.78% for wearing course. All these

values obtained from the laboratory tests indicate that saw dust ash cannot totally replace Portland cement, which is the conventional filler material in asphalt production.

4.3 Effect of Saw Dust Ash on flow

Increase in flow value was noticed when Portland cement was replaced with 10% saw dust ash content which resulted in a flow value of 2.90mm and is the highest here. The flow value is within the limit specified by the Nigerian General specifications for Roads and Bridges (1997) which lies between 2mm – 4mm. At 100% saw dust ash content, the value of flow corresponding to it is 1.00mm which does not satisfy the requirement of the Nigerian General Specifications for Roads and Bridges (1997). As the percentage of saw dust ash content increased from 20% to 100% there was corresponding reduction in the percentage of flow. The flow decreased as a result of increase in the percentage of saw dust ash content thereby filling the voids in the asphalt mix.

The variation of saw dust ash content with flow is shown in Figure 4.1.

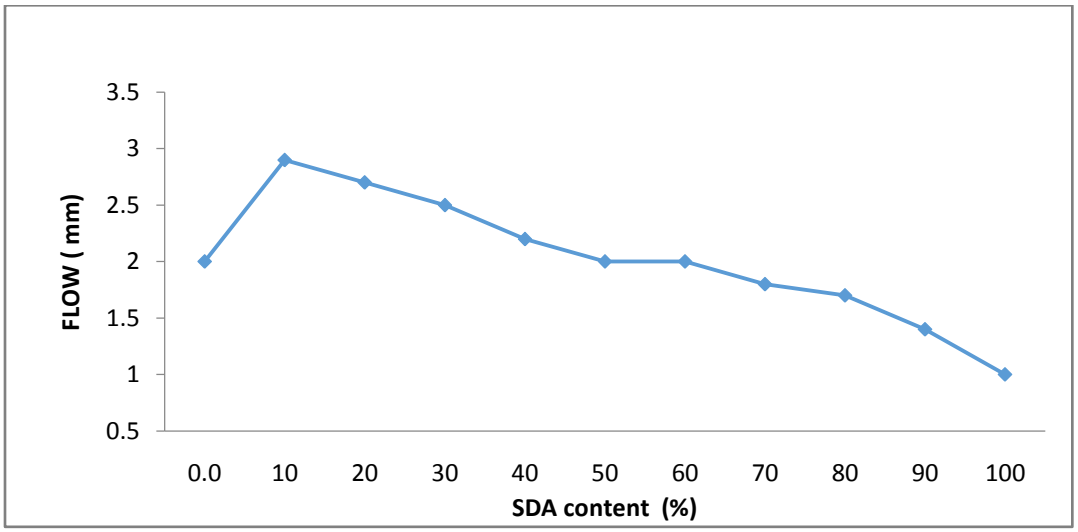


Figure. 4.1: Variation of Saw Dust Ash Content (%) with flow (mm)

4.4 Effect of Saw Dust Ash on Bulk Density

The relationship between saw dust ash and bulk density is presented in Figure 4.2.

Figure 4.2 indicates that at 10% saw dust ash content, the value of bulk density is 2.32g/cm^3 which is higher than the other values of bulk density apart from 0% saw dust ash content. At 100% saw dust ash content, the value of bulk density is 2.03g/cm$^{3.}$ This shows that as the percentage of saw dust ash increased, there was a corresponding reduction in the value of bulk density. The reason for the reduction in bulk density is in view of the fact that saw dust ash has low specific gravity.

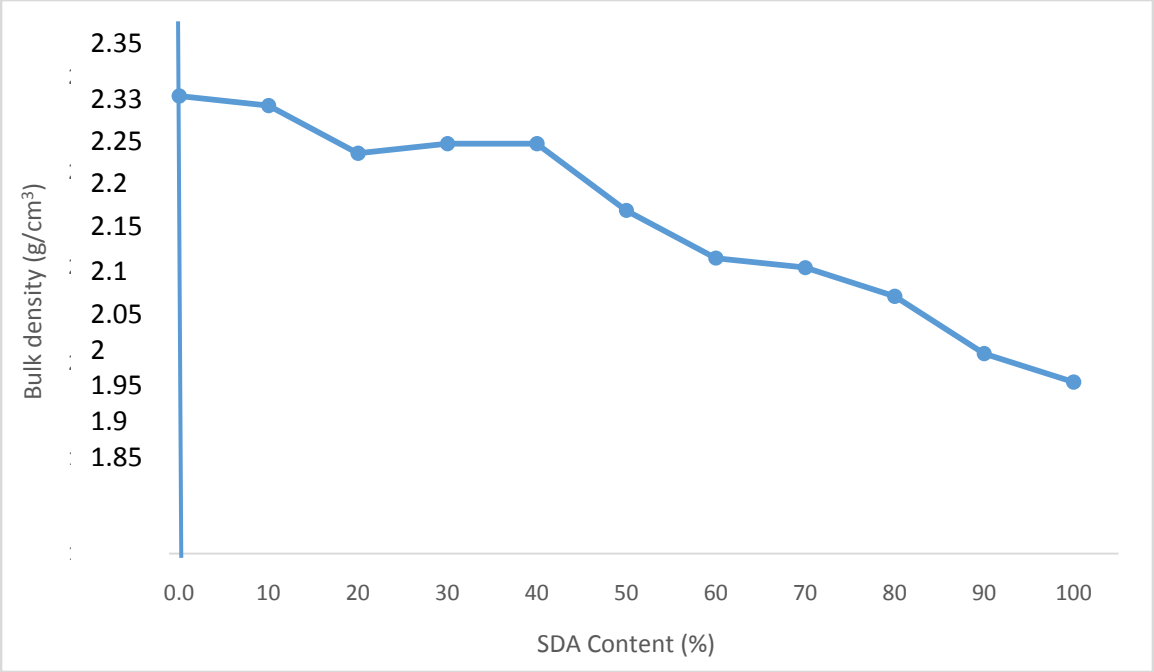


Figure. 4.2: Variation of Saw Dust Ash Content (%) with Bulk density (g/cm^3)

4.5 Effect of Saw Dust Ash on Voids in Mineral Aggregate

Figure 4.3 shows that as the percentage of saw dust ash content increases, there is also a corresponding increase in percentage of voids in mineral aggregate. The increase in voids in mineral aggregates is as a result of low specific gravity of saw dust ash. Thus, a given percentage weight of saw dust ash will occupy a greater volume than that of Portland cement, the conventional filler (Asmael, 2010).

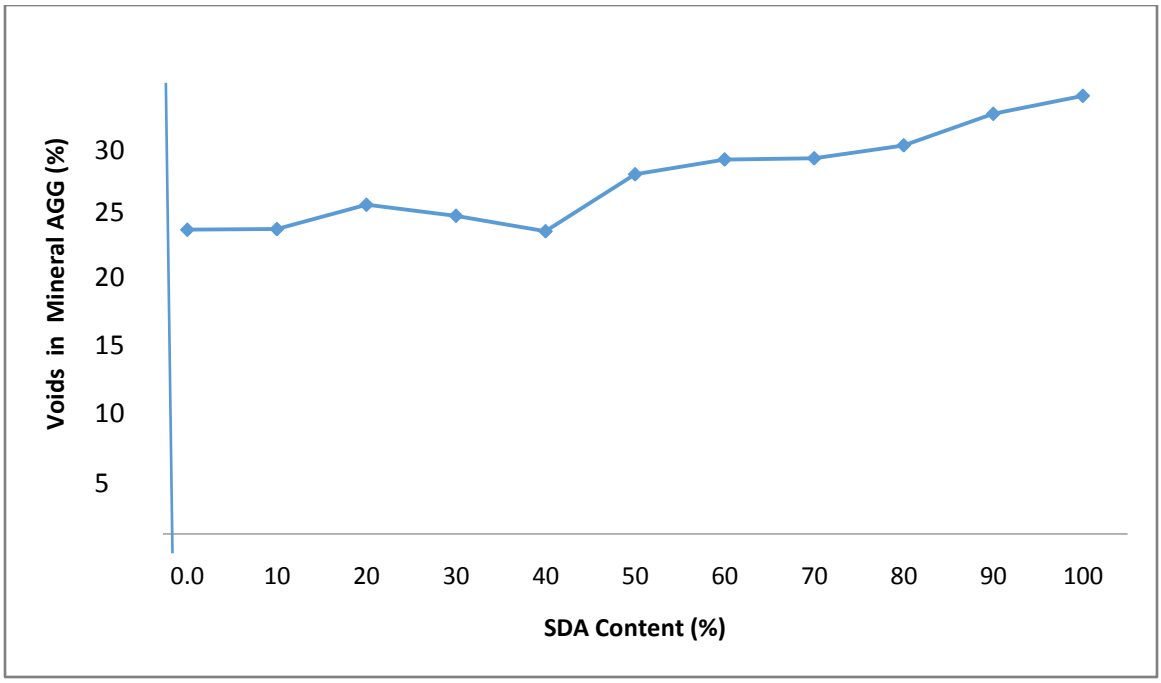


Figure. 4.3: Variation of Saw Dust Ash Content (%) with Voids in Mineral Aggregate (%)

4.6 Effect of Saw Dust Ash on Stability

Figure 4.4 shows that as percentage of saw dust ash content increases, there is a corresponding decrease in the value of stability. At 10% saw dust ash content, the corresponding value of stability is 7.78kN which is the highest.

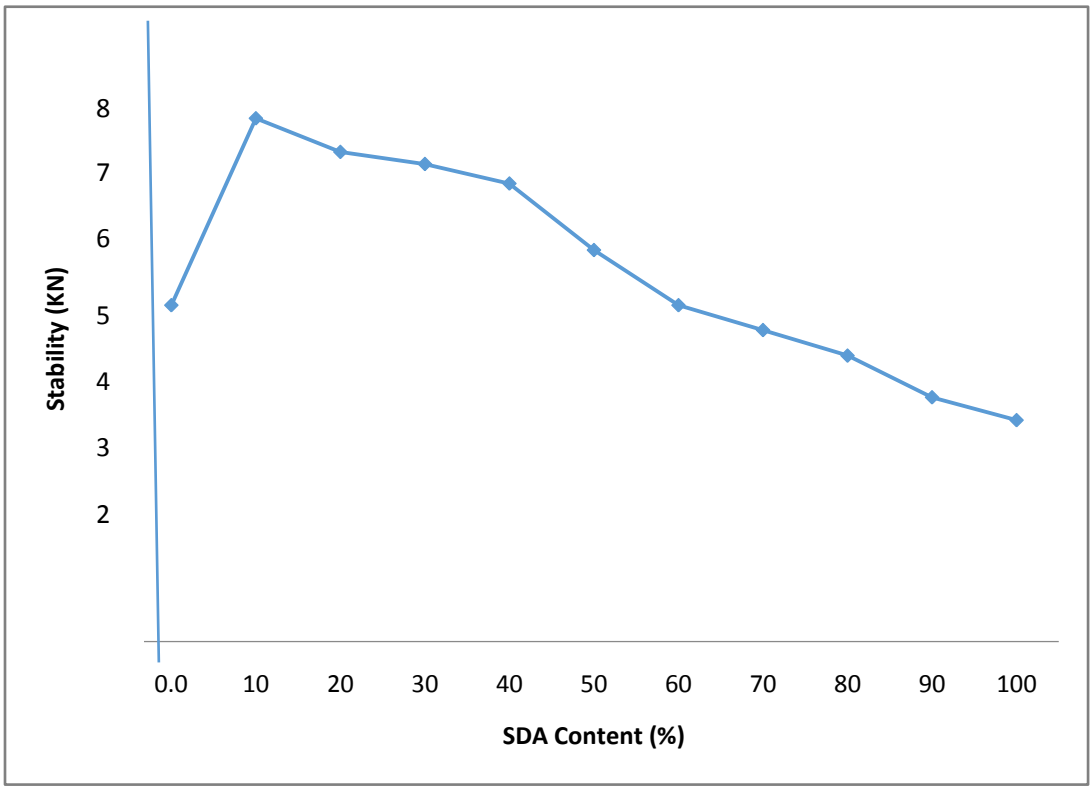


Figure 4.4: Variation of Saw Dust Ash Content (%) with Stability (KN)

4.7 Effect of Saw Dust Ash on Voids in Total Mix

Figure 4.5 shows that as the percentage of saw dust ash content increases, there is a corresponding increase in the percentage of voids in the total mix. More voids are created in the asphalt mix as the percentage of saw dust ash increases, thus increasing the volume of voids in the total mix. At 30% and 40% saw dust ash contents, the behavior of saw dust is not consistent in view of the fact that the values of voids in total mix remain constant at those two points. Furthermore, at 70% saw dust ash, the corresponding value of voids in total mix reduces to 5.29%. At 80% to 100% saw dust ash contents, there is increase in percentage of voids in total mix. This is due to low specific gravity of saw dust ash (Asmael, 2010).

Figure 4.5: Variation of Saw Dust Ash Content (%) with Voids in Total Mix (%)

4.8 Effect of Saw Dust Ash on Voids Filled with Bitumen

Figure 4.6 shows that at 0% saw dust ash content, the percentage of voids filled with bitumen has the highest value of 71.12%. The relationship is not consistent in view of the fact that at 30% saw dust ash content, the corresponding value of voids filled with bitumen is 67.73% while at 70% saw dust ash content, the corresponding percentage voids filled with bitumen is 67.85%. At 100% saw dust ash content, the corresponding percentage of voids filled with bitumen is 42.78% which is the least value. This implies that saw dust ash which has low specific gravity has filled theinter- granular void space between the aggregate particles (Brennan and O'Flaherty, 2002).

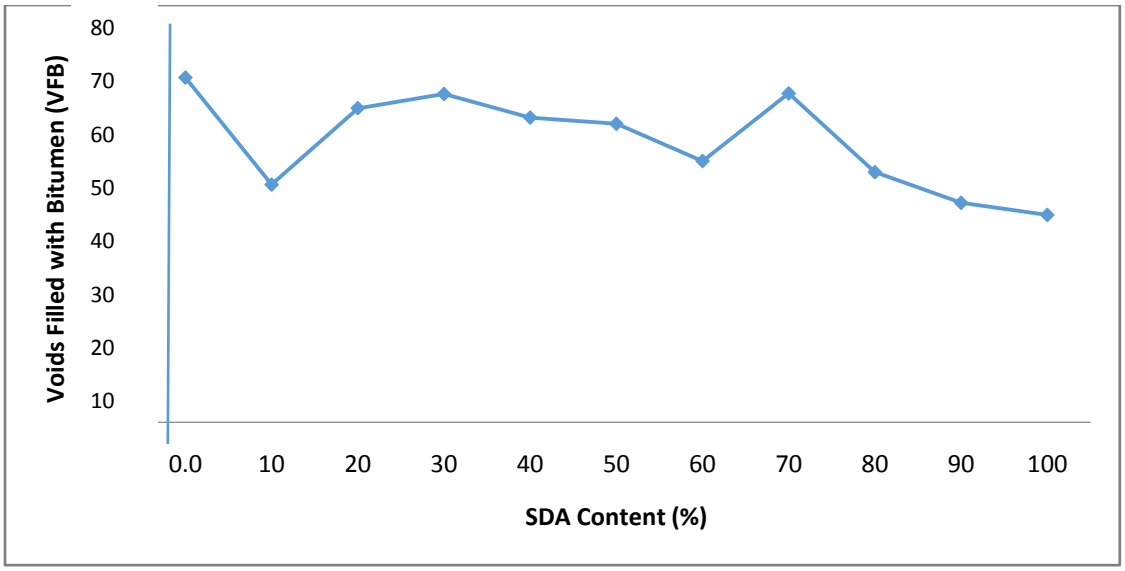


Figure. 4.6: Variation of Saw Dust Ash Content (%) with Voids Filled with Bitumen (VFB) (%)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Results of tests carried out on saw dust ash to determine its suitability for use as mineral filler show that it has a specific gravity value of 2.20, plasticity index value of 4 with 77.8% passing sieve No.200. These values are within the limit specified in the AASHTO M17, (1986) for mineral filler used in asphalt paving mixture.

Asphalt briquettes were prepared using 100% Portland cement as control. Saw dust ash was used to replace Portland cement at 0% to 100% with an increase of 10% respectively by weight of cement. For 100% Portland cement used as control in the research, 6.0% optimum bitumen content was obtained, maximum bulk density of 2.35g/cm^3 was obtained, maximum stability of 11.85kN was attained, voids in total mix was 4.47%, voids filled with bitumen was 75.00% and the value of flow was 3.20mm. These values obtained are in accordance with the Nigerian General Specifications for Roads and Bridges (1997) and the AASHTO M17, (1986) specifications.

At the variation of percentages of Portland cement and saw dust ash at optimum bitumen content of 6.0% as contained in Table 4.5b, as percentage of saw dust ash increases, the value of bulk density of the mixture sample also decreases. At 100% Portland cement and 0% saw dust ash, the stability obtained was 5.00kN. At 10% saw dust ash, the stability value was 7.78kN which satisfies the Nigerian General Specifications for Roads and Bridges (1997) of not less than 3.5kN. Flow value of 2.90mm at 10% saw dust ash satisfies the Nigerian General Specifications for Roads and Bridges (1997). Flow values reduced from 2.90mm to a minimum value of 1.00mm when Portland cement was replaced with 100% saw dust ash. The bulk density generally reduces from 2.33g/cm^3 at 100% cement to a minimum value of 2.03g/cm^3 at 100%

saw dust ash content. Voids in mix increases from 5.28% at 100% Portland cement to 15.06% maximum at 100% saw dust ash. The value of voids in total mix at 100% saw dust ash does not conform to the standard of Nigerian General Specifications for Roads and Bridges (1997). Voids in mineral aggregate also increased from 18.28% at 100% Portland cement to 26.32% at 100% saw dust ash. This value conforms with FMWH (2013) standard of not less than 15%. Voids filled with bitumen decreased from 71.12% at 100% Portland cement to a minimum value of 42.78% at 100% saw dust ash content. The value of voids filled with bitumen at 100% saw dust ash does not satisfy the requirement of the Nigerian General Specifications for Roads and Bridges (1997). The investigated saw dust ash can perform satisfactorily as mineral filler in asphalt mixture at 10%. Hence, it is generally suitable as mineral filler in asphalt mixture.

5.2 Recommendations

Based o+n results of the findings from the research, the partial replacement of Portland cement with 10% saw dust ash for use in asphalt production is recommended for use in Nigeria and any other part of the tropics.

From the chemical analysis of the saw dust ash, it was found out that it is a good pozzolanic material in accordance with the requirements in ASTMC 618 (1991).

Saw dust ash has a specific gravity value of 2.20, plasticity index of 4 with 77.8% passing sieve No. 200. These values show that saw dust ash is suitable as mineral filler in asphalt mixture in accordance with AASHTO M17 (1986).

At 10% saw dust ash content, the highest value of stability obtained is 7.78kN, its bulk density is 2.32g/cm^3, the voids in total mix is 2.90mm and voids in mineral aggregate is 18.32%. These

values are within the limits specified by the Nigerian General Specifications for Roads and Bridges (1997).

The percentage of cement replaced at 10% saw dust ash for asphalt production could be used for pedestrian walkways, out-door paving and Motorcycle Park.

REFERENCES

Adesanya, D.A., and Raheem, A.A, (2009a). A Study of the Workability and Compressive Strength Characteristics of Corn Cob Ash Blended Cement Concrete. Construction and Building Materials, Vol. 23, pp. 311-317.

Adesanya, D. A. and Raheem, A.A. (2009b), "Development of corn cob ash blended cement", Construction and Building Materials; vol. 23, pp. 347 – 352.

Ahmed, Y.A. Ayman, M.O. and Afaf, A. M. (2006). Effect of Using Waste Cement Dust as Mineral filler on the Mechanical properties of Hot Mix Asphlat. Ass. Uni. Bull Environ. Res. Vol. 9 No. 1 pp. 55-59.

Antiohos, S.; Maganari, K.; Tsimas, S. (2005), "Evaluation of blends of high and low calcium fly ashes for use as supplementary cementing materials", Cement & Concrete Composites, Vol. 27, pp. 349-356.

America

Association of State Highway and Transportation Officials (1986). Standard method of test, Mineral filler for bituminous paving mixtures" AASHTO designation: M17-83 Part I specifications 14 edition.

Ahirich, R.C. (1991). The Effects of Natural Sands on Asphalt Concrete Engineering Properties. Department of the Army, Waterways Experiment Station, Corps of Engineers. 3909 Hall Ferry Road, Vicksburg, Mississippi 39180-6199.

Asmael, N.M. (2010), Effect of mineral Filler type and content on properties of Asphalt Concrete Mixes. Journal of Engineering, Vol. 16issue 3, PP. 5352-5362.

Asphalt Institute (1984). "Mix Design Methods for Asphalt Concrete (MS-2) and Other Hot-Mix Types" Maryland, U.S.A.

ASTM (1986): American Association of State Highway and Transportation Officials (1986).

"Standard Method of Test, Mineral Filler for Bituminous Paving Mixtures". AASHTO Designation: T153-86, Part II Tests, 14th Edition.

ASTM C 618 (1991).Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Portland Cement Concrete. Annual Book of ASTM Standards, Philadelphia, USA.

Atkins, H.N. (1997). Highway materials, soils and concretes. Prentice Hall, Upper Saddle River New Jersey.

Balendran, R. V. and Martin-Buades, W. H. (2000), "The influence of high temperature curing on the compressive, tensile and flexural strength of pulverized fuel ash concrete", Building and Environment, Vol. 35 No.5, pp.415-423.

Brennan, M.J. and O'Flaherty, C.A. (2002). Highways, the location, design, construction and maintenance of road pavements. Butterworth-Heinemann. USA.

Cheah, C. B., and Ramli, M. (2011) The Implementation of Wood Ash as a Partial Cement Replacement Material in the Production of Structural Grade Concrete and Mortar: an overview Review Article, Resources, Conservation and Recycling, Vol. 55 Issue 1, pp.69-685.

Cook, (1981). Rationale for the compilation of international guidelines for low-cost sustainable road surfacing. Low Cost Road Surfacing Project, Working Paper No. 1. Intech Associates - DFID.

Ciesielski S.K and Collins, R. J. (1994). Recycling and Use of Waste materials and By-products in Highway Construction. National Cooperative Highway Research Program.

Danjum, J. U. (2000).The Effect of Various Fillers on Properties of Asphaltic concrete. Unpublished M. Tech Thesis, Department of Civil Engineering, University of Science and Technology, Port Harcourt.

Deddy, M., Roeswan, S. and Djoko, P.(2002) The performance Evaluation of Hot Rolled Asphalt Mixed with Saw Dust Ash as a Filler. UNDIP Institutional Respiratory.

Elinwa, A. U. and Mahmooodb, Y. A. (2002).Ash from Timber Waste as Cement Replacement Materials, Cement and Concrete Composites. Vol. 24 Issue 2, pp. 219-222.

Elinwa, A. U. and Ejeh, S. P. (2004), "Effects of the incorporation of sawdust waste incineration fly ash in cement pastes and mortars", Journal of Asian Architecture and Building Engineering, Vol. 3 No.1, pp.1-7.

Elinwa, A. U.; Ejeh, S. P. and Mamuda, A. M. (2008) "Assessing of the fresh concrete properties of self-compacting concrete containing sawdust ash, Construction and Building Materials, Vol. 22 Issue 6, pp. 1178-1182.

Eltaher, A. Lamy, M.J. and Ratnasamy, M. (2013). Effect of Mineral Filler Type and Particle Size on Asphalt-Filler Mastic and stone Mastic Asphalt Laboratory measured properties. Australian Journal of Basic and Applied Sciences. Vol. 7 No. 1 pp. 475-2013.

Federal Ministry of works (2013), Highway Manual part 2: Maintenance Works, Abuja, Nigeria.

Federal Ministry of Works (1997). General Specifications (Roads and Bridges) Lagos, Nigeria, Vol. 11.

Garber, N. J. and Hoel, L. A. (2010). Traffic and Highway Engineering, fourth edition. University of Virginia. Publisher Raju Sarkar, Delhi engineering college, India.

Grosse, F. (2010). Is Recycling Part of the Solution? The role of recycling in an expanding society and a world of finite resources.

Hossain, K. M. A. (2003), "Blended Cement using Volcanic Ash and Pumice", Cement and Concrete Research, Vol. 33, pp. 1601-1605.

Kandhal, P.S. (1981). "Evaluation of Baghouse Fines in Bituminous Paving Mixtures" Proceedings Association of Asphalt Paving Technologists, 50:150-210.

Keneth, G.O. (2012). The Use of Periwinkle Shell Dust as Mineral Filler in Asphalt Mixture. Unpublished M.Sc. Thesis, Department of Civil Engineering, Ahmadu Bello University, Zaria.

Kraszewski, L.P. and Emery, J.J. (1981). Use o Cement kiln Dust as Filler in Asphalt Mixes. Symposium on Mineral Fillers. Ontario Research Foundation, ORF/CANMET, Toronto.

Mageswari, M. and Vidivelli, B. (2009). The Use of Saw Dust Ash as Fine Aggregates Replacement in Concrete. Journal of Environmental Research and Development, Vol. 3 No. 3, pp. 720-726.

Mogawer, W.S. and K.D. Stuart, 1996. Effects of Mineral Fillers on Properties of Stone Matrix AsphaltMixtures. Transportation Research Record 1530, Transportation Research Board, National Research Council,Washington, DC, TBR: 86-94.

Puzinauskas, V. P (1969). Filler in Asphalt Mixtures. *Research Report 69-2.* The Asphalt Institute. College Park, Maryland.

Raheem, A. A.; Oyebisi, S. O.; Akintayo, S. O. and Oyeniran, M. I. (2010), "Effects of admixtures on the properties of corn cob ash cement concrete", Leonardo Electronic Journal of Practices and Technologies, Vol. 16, pp.13 – 20.

Rahman, N.M. (2013). Use of Non-Conventional Fillers on Asphalt-Concrete Mixture. International Journal of Innovation and Applied Sciences. Vol. 3 No. 4, pp. 1101-1109.

Rosner, J.C and Gene, R.M. (1982). Fly Ash as a Mineral Filler and Anti-Strip Agent for Asphalt Concrete. *Proceedings of the Sixth International Ash Utilization Symposium.* U.S. Department of Energy, Report No. DOE/METC/82/52, Volume 1, Washington. DC.

Siddique, R. (2004), "Performance characteristics of high-volume Class F fly ash concrete", Cement and Concrete Research, Vol. 34 No.3, pp. 487-493.

Wang, S. and Baxter, L. (2007), "Comprehensive study of biomass fly ash in concrete: Strength, microscopy, kinetics and durability", Fuel Processing Technology, Vol. 88, pp. 1165-1170.

Waswa-Sabuni, B.; Syagga, P. M.; Dulo, S. O. and Kamau, G, N. (2002), "Rice Husk Ash Cement – An Alternative Pozzolana Cement for Kenyan Building Industry", Journal of Civil Engineering, JKUAT, Vol. 8, pp. 13-26.

Yasreem, S.G., Madzlan, N.B. and Ibrahim, K. (2011). The Effect of Fine Aggregate Properties on the Fatigue Behaviour of the Conventional and Polymer Modified Bituminous Mixtures using Two Types of Sand as Fine Aggregate. Journal of World Academy of Science, Engineer and Technology Vol. 5, pp. 417 – 422.

Zimmer, Frank V. (1970). Fly Ash as a Bituminous Filler, Proceedings of the Second Ash utilization Symposium. U.S. Bureau of Mines, Information Circular No. 8488, Pittshurgh, Pennsylvania.

APPENDIX A

Appendix A1: Aggregate Crushing Value (ACV)

$$ACV = \frac{Weight\ of\ crushed\ sample\ \ (g)}{Weight\ of\ sample\ \ (g) - Weight\ of\ sample\ \ remaining\ \ (g)} \times 100 \quad \text{.....3.1}$$

For 12mm aggregate,

$$ACV\ (1) = \frac{C}{A-B} \times 100$$

$$+ \quad = \frac{819}{5000-1300} \times 100$$

$$= \frac{819}{3700} \times 100$$

$$= 22.14\%.$$

$$ACV\ (2) = \frac{850}{5000-1350} \times 100$$

$$= \frac{850}{3650} \times 100$$

$$= 23.29\%$$

$$ACV\ (3) = \frac{844}{5000-1350} \times 100$$

$$= \frac{844}{3650} \times 100$$

$= 23.12\%$

Average (ACV) $= \frac{22.14+23.29+23.12}{3}$

$= 22.85$

For 10mm aggregate,

ACV (1) $= \frac{925}{5000-1180} \times 100$

$= \frac{925}{3820} \times 100$

$= 24.21\%$

ACV (2) $= \frac{895}{5000-1200} \times 100$

$= \frac{895}{3800} \times 100 \quad = 23.55\%$

ACV (3) $= \frac{892}{5000-1200} \times 100$

$= \frac{892}{3800} \times 100 \quad = 23.47\%$

Average (ACV) $= \frac{24.21+23.55+23.47}{3}$

$= 23.74\%$

(II) Aggregate Impact Value (AIV)

$$\text{AIV} = \frac{Wt\ of\ Impacted\ \ Sample\ \ (g)}{Wtofsample\ \ (g) - Wt\ ofsample\ \ remaining\ \ (g)} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

$$\text{AIV} = \frac{C}{A-B} \times 100$$

For 12mm aggregate,

$$\text{AIV (1)} = \frac{76}{500-145} \times 100$$

$$= \frac{76}{355} \times 100$$

$$= 21.41\%$$

$$\text{AIV (2)} = \frac{68}{500-150} \times 100$$

$$= \frac{68}{350} \times 100$$

$$= 19.43\%$$

$$\text{AIV (3)} = \frac{75}{500-148} \times 100$$

$$= \frac{75}{352} \times 100$$

$$= 21.31\%$$

$$\text{Average (AIV)} = \frac{21.41+19.43+21.31}{3}$$

$$= 20.72\%$$

For 10mm aggregate,

AIV (1) = $\frac{89}{500-128} \times 100$

$= \frac{89}{372} \times 100$

= 23.92%

AIV (2) = $\frac{89}{500-129} \times 100$

$= \frac{89}{371} \times 100$

= 23.99

AIV (3) = $\frac{79}{500-130} \times 100$

$= \frac{79}{370} \times 100$

= 21.35%

Average (AIV) = $\frac{23.92+23.99+21.35}{3}$

= 23.09%

APPENDIX B

Appendix B1: Table 3.1.3.1b – Result of Specific Gravity of Quarry Fine using Pycnometer

S/NO	DESCRIPTION OF SAMPLE	TEST 1 (g)	TEST 2 (g)	TEST 3 (g)
a	Weight of Pycnometer + Water (full)	1420	1420	1420
b	Weight of Pycnometer	495	495	495
c	Volume of Pycnometer (a-b)=925cm^3=925g	925	925	925
d	Weight of Pycnometer + Sample	1115	1115	1115
e	Weight of Sample = (d-b)	620	620	620
f	Weight of Pycnometer +Sample + Water	1806	1806	1806
g	Weight of Water added = (f-d)	691	691	691
H	Weight of Water displaced = (c-g)	234	234	234
I	Specific Gravity = (e/h)	2.65	2.65	2.65

APPENDIX C **DESIGN MIX FORMULAE**

DATE: 11/08/2015 **LOCATION: Civil Engineering Department (ABU)**

Laboratory: Civil Engineering Lab (ABU) **SAMPLE: Wearing Course** **DESIGN MIX: 15%: 20%:55%:10%**

Table 3.2a: Aggregate Blending Mix (with 10% Cement)

B.S Sieves (mm)	**% PASSING**							**% GRADATION**								Combined Gradation	Average Specification	Specification
								12mm		10mm		Quarry Fine		Cement				
	12mm		10mm		Fine		Cement	15%		20%		55%		10%				
19.05mm	100		100					15		20		55		10		100	100	100
12.7mm	46.1		96.8					6.9		19.4		55		10		91.3	92.5	85-100
9.52mm	2.0		74.2					0.3		14.8		55		10		80.1	83.5	75-92
6.30mm	-		27.4		100			-		5.5		55		10		70.5	73.5	65-82
2.36mm			-		86 .0							47.3		10		57.3	57.5	50-65
2.0mm					49.5							27.2		10		37.2	43.5	36-51
600µm					36.0							19.8		10		29.8	33.0	26-40
300µm					21.0		100					11.6		10		26.6	24.0	18-30
150µm					12.0		90.5					6.6		9.1		15.7	18.4	13-24
75µm					8.0		71.5					4.4		7.2		11.6	10.5	7-14

Design with 10% Cement - Control

APPENDIX D

Appendix D1: Table 3.2b – PRACTICAL COMBINATION OF DESIGN MIX (Sieve Analysis).Selected mix design of 15% (12mm aggregate), 20% (10mm aggregate), 55% (Quarry fine), 10% (Cement), was practically combined and sieve analysis carried out.

Sieve Sizes (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)	Specification limits
$\frac{3''}{4}$ (19.05mm)	-	-	100	100
$\frac{1''}{2}$ (12.7mm)	120	12.0	88.0	85 – 100
$\frac{3''}{8}$ (9.52mm)	100	10.0	78.0	75 – 92
$\frac{1''}{4}$ (6.3mm)	95	9.5	68.5	65 – 82
2.36mm	115	11.5	57.0	50 – 65
2.00mm	190	19.0	38.0	36 – 51
No.25 (600μm)	80	8.0	30.0	26 – 40
No.52 (300μm)	90	9.0	21.0	18 – 30
No.100 (150μm)	75	7.5	13.5	13 – 24
No.200 (75μm)	30	3.0	10.5	7 – 14
Pan	105	10.5	0	
TOTAL	**1000**	**100%**		

APPENDIX E

Appendix E1: Table 3.2c – Practical Combination of design mix (Sieve Analysis). Selected mix design 15% (12mm aggregate), 20% (10mm aggregate), 55% (Quarry fine), and 100% Saw Dust Ash.

Sieve Sizes (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)	Specification limits
$\frac{3''}{4}$ (19.05mm)	-	-	100	100
$\frac{1''}{2}$ (12.7mm)	135	13.5	86.5	85 – 100
$\frac{3''}{8}$ (9.52mm)	55	5.5	81	75 – 92
$\frac{1''}{4}$ (6.3mm)	112	11.2	69.8	65 – 82
2.36mm	196	19.6	50.2	50 – 65
2.00mm	93	9.3	40.9	36 – 51
No.25 (600μm)	70	7.0	33.9	26 – 40
No.52 (300μm)	146	14.6	19.3	18 – 30
No.100 (150μm)	55	5.5	13.8	13 – 24
No.200 (75μm)	24	2.4	11.4	7 – 14
Pan	114	11.4	0	
TOTAL	**1000**	**100%**		

APPENDIX F

Appendix F1: Table 3.2d – Practical combination of design mix (Sieve Analysis). Selected mix design of 15% (12mm aggregate), 20% (10mm aggregate), 55% (Quarry fine), 50% Saw Dust Ash: 50% Cement.

Sieve Sizes (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)	Specification limits
$\frac{3''}{4}$ (19.05mm)	-	-	100	100
$\frac{1''}{2}$ (12.7mm)	143	14.3	85.7	85 – 100
$\frac{3''}{8}$ (9.52mm)	79	7.9	77.8	75 – 92
$\frac{1''}{4}$ (6.3mm)	79	7.9	69.9	65 – 82
2.36mm	185	18.5	51.4	50 – 65
2.00mm	108	10.8	40.6	36 – 51
No.25 (600μm)	73	7.3	33.3	26 – 40
No.52 (300μm)	134	13.4	19.9	18 – 30
No.100 (150μm)	75	7.5	12.4	13 – 24
No.200 (75μm)	26	2.6	9.8	7 – 14
Pan	98	9.8	0	
TOTAL	**1000**	**100%**		

APPENDIX G

Appendix G1: Asphalt Hot Mix Design

Aggregates were blended using the adopted design of 15% (12mm), 20% (10mm), 55% (quarry fine) and 10% (cement)-Control.

Total weight of sample = 1200g

At Bitumen content of 5.0%,

Weight of Bitumen	= 5.0% of 1200g	= 60g
Accumulated weight of aggregate	= 1200-60(g)	= 1140g

By design data,

Weight of 12mm aggregate	= 15% of 1140g	= 171g
Weight of 10mm aggregate	= 20% of 1140g	= 228g
Weight of quarry fine	= 55%of 1140g	= 627g
Weight of cement	= 10% of 1140g	= 114g

At Bitumen content of 5.5%,

Weight of Bitumen	= 5.5% of 1200g	= 66g
Accumulated weight of aggregate	= 1200-66(g)	= 1134g

By design data,

Weight of 12mm aggregate	= 15%of 1134g	= 170.10g
Weight of 10mm aggregate	= 20% of 1134g	= 226.80g
Weight of quarry fine	= 55%of 1134	= 623.70g
Weight of cement	= 10% of 1134g	= 113.40g

At Bitumen content of 6.0%,

Weight of Bitumen	= 6.0% of 1200g	= 72g
Accumulated weight of aggregate	= 1200-72 (g)	=1128g

By design data,

Weight of 12mm aggregate	= 15% of 1128(g)	= 169.20g
Weight of 10mm aggregate	= 20% 0f 1128(g)	= 225.60g
Weight of quarry fine	= 55% of 1128(g)	= 620.40g
Weight of cement	= 10%of 1128(g)	= 112.80g

At Bitumen content of 6.5%,

Weight of Bitumen	= 6.5% of 1200(g)	= 78g
Accumulated weight of aggregate	= 1200-78(g)	= 1122g
Weight of 12mm aggregate	= 15% of 1122(g)	= 168.30g
Weight of 10mm aggregate	= 20% of 1122(g)	= 224.40g
Weight of quarry fine	= 55% of 1122(g)	= 617.10g
Weight of cement	= 10% of 1122(g)	= 112.20g

At Bitumen content of 7.0%,

Weight of Bitumen	= 7.0% of 1200(g)	= 84g
Accumulated weight of aggregate	= 1200-84(g)	= 1116g

By design data,

Weight of 12mm aggregate	= 15%of 1116(g)	= 167.40g
Weight of 10mm aggregate	= 20% of 1116(g)	= 223.20g
Weight of quarry fine	= 55% of 1116(g)	= 613.80g
Weight of cement	= 10% of 1116(g)	= 111.60g

APPENDIX H

Weight of mixture samples of Cement and saw Dust Ash at various Percentages at optimum Bitumen content of 6.0%-INVESTIGATION.

At 0% saw dust ash, 100% cement has weight of 112.80g

	Wt. of SDA	Wt. of cement
0% saw dust ash: 100% Cement	0.00g	112.80g
10% saw dust ash:90% Cement	11.28g	101.52g
20% saw dust ash: 80% Cement	22.56g	90.24g
30% saw dust ash: 70%Cement	33.84g	78.96g
40% saw dust ash: 60% Cement	45.12g	67.68g
50% saw dust ash: 50% Cement	56.40g	56.40g
60% saw dust ash:40% Cement	67.68g	45.12g
70% saw dust ash: 30% Cement	78.96g	33.84g
80% saw dust ash: 20% Cement	90.24g	22.56g
90% saw dust ash: 10% Cement	101.52g	11.28g
100% saw dust ash: 0% Cement	112.80g	0.00g

APPENDIX I

ASPHALT HOT MIX DESIGN DATA (With Cement)

Appendix II: Table 4.4 Aggregate by proportion in design mix (with Cement as control)

S/No	Material	Job mix design	Aggregate by weight (g) at Bitumen Content 5.0%	Aggregate by weight (g) at Bitumen Content 5.5%	Aggregate by weight (g) at Bitumen Content 6.0%	Aggregate by weight (g) at Bitumen Content 6.5%	Aggregate by weight (g) at Bitumen Content 7.0%
1	12mm	15%	171.00	170.10	169.20	168.30	167.40
2	10mm	20%	228.00	226.80	225.60	224.40	223.20
3	Quarry fine	55%	627.00	623.70	620.40	617.10	613.80
4	Cement	10%	114.00	113.40	112.80	112.20	111.60
Total		100%	1140	1134	1128	1122	1116

Appendix I2: Bitumen/Aggregate data

S/No.	BITUMEN CONTENT (%)	INDIVIDUAL BITUMEN WEIGHT (g)	ACCUMULATED AGG WEIGHT(g)	ACCUMULATED SPECIMEN WT(g)
1	5.0	60	1140	1200
2	5.5	66	1134	1200
3	6.0	72	1128	1200
4	6.5	78	1122	1200
5	7.0	84	1116	1200

APPENDIX J

Appendix J1: Marshall Computation

Steps to calculate bulk volume, bulk density, maximum theoretical density and specific gravity of total aggregate are given below.

(a) Weight of compacted asphalt

(i) Weight in air (g) was measured = D

(ii) Weight in water (g) was measured = E

Then, bulk volume – weight in air (g) – Weight in water = F

(b) Density of compacted asphalt

(i) Bulk density = $\frac{weigt\ \ in\ air}{apparent\ \ \ volume} = G$

(ii) Maximum theoretical Density = $\frac{100}{\frac{\%\ Bit}{S.G\ Bit} + \frac{\%\ Agg}{S.G\ M.A\ (agg\ )}}$ 4.2

Where S.G.M.A is Bulk Specific Gravity of Total Aggregate.

$P_{1,}$+P_2,..P_4 = individual percentages by mass of aggregate; and

$S.G_1$, $S.G_2$… $S.G_4$ = Individual bulk specific gravities of aggregate.

Hence, S.G.M.A (Control) = $\frac{P_1+P_2+P_3+P_4}{\frac{P_1}{S.G_1}+\frac{P_2}{S.G_2}+\frac{P_3}{S.G_3}+\frac{P_4}{S.G_4}}$ 4.3

$$= \frac{15 + 20 + 55 + 10}{\frac{15}{2.60}+\frac{20}{2.63}+\frac{55}{2.65}+\frac{10}{3.15}}$$

$$= \frac{15 + 20 + 55 + 10}{5.77+ 7.60+20.75+3.17} = \frac{100}{37.29} = 2.68$$

P_1 = Design percentage of 12mm aggregate

P_2 = Design percentage of 10mm aggregate

P_3 = Design percentage of quarry fine

P_4 = Design percentage of cement

$S.G_1$ = Specific Gravity of 12mm aggregate

$S.G_2$ = Specific Gravity of 10mm aggregate

$S.G_3$ = Specific gravity of quarry fine

$S.G_4$ = Specific Gravity of cement/SDA

S.G. M.A (Investigation) = $\frac{P_1 + P_2 + P_3 + P_4}{\frac{P1}{S.G_1} + \frac{P2}{S.G_2} + \frac{P3}{S.G_3} + \frac{P4}{S.G_4}}$

$$= \frac{15 + 20 + 55 + 10}{\frac{15}{2.60} + \frac{20}{2.63} + \frac{55}{2.65} + \frac{10}{2.2}}$$

$$= \frac{15 + 20 + 55 + 10}{5.77 + 7.60 + 20.75 + 4.55}$$

$$= \frac{100}{38.69}$$

$$= 2.59$$

At 90% cement/10% SDA,

$$\text{S.G.M.A} = \frac{15 + 20 + 55 + 10}{\frac{15}{2.60}+\frac{20}{2.63}+\frac{55}{2.65}+\frac{9}{3.15}+\frac{1}{2.20}}$$

$$= \frac{100}{5.77+7.60+20.75+2.68+0.45}$$

$$= \frac{100}{37.43}$$

$$= 2.67$$

At 80% cement/20% SDA,

$$\text{S.G.M.A} = \frac{15 + 20 + 55 + 10}{\frac{15}{2.60}+\frac{20}{2.63}+\frac{55}{2.65}+\frac{8}{3.15}+\frac{2}{2.20}}$$

$$= \frac{100}{5.77+7.60+20.75+2.54+0.91}$$

$$= \frac{100}{37.57}$$

$$= 2.66$$

At 70% cement/30% SDA,

$$\text{S.G.M.A} = \frac{15 + 20 + 55 + 10}{\frac{15}{2.60}+\frac{20}{2.63}+\frac{55}{2.65}+\frac{7}{3.15}+\frac{3}{2.20}}$$

$$= \frac{100}{5.77+7.60+20.75+2.22+1.36}$$

$$= \frac{100}{37.7} = 2.65$$

At 60% Cement/40% SDA

$$\text{S.G.M.A} = \frac{15 + 20 + 55 + 10}{\frac{15}{2.60} + \frac{20}{2.63} + \frac{55}{2.65} + \frac{6}{3.15} + \frac{4}{2.20}}$$

$$= \frac{100}{5.77+7.60+20.75+1.90+1.82}$$

$$= \frac{100}{37.84} = 2.64$$

At 50% Cement/50% SDA,

$$\text{S.G.M .A} = \frac{15 + 20 + 55 + 10}{\frac{15}{2.60}+\frac{20}{2.63}+\frac{55}{2.65}+\frac{4}{3.15}+\frac{6}{2.20}}$$

$$= \frac{100}{5.77+7.60+20.75+1.59+2.27}$$

$$= \frac{100}{37.98} = 2.63$$

At 40% cement/60% SDA,

$$\text{S.G.M.A} = \frac{15+20+55+10}{\frac{15}{2.60}+\frac{20}{2.63}+\frac{55}{2.65}+\frac{4}{3.15}+\frac{6}{2.20}}$$

$$= \frac{100}{5.77+7.60+20.75+1.27+2.73}$$

$$= \frac{100}{38.12} = 2.62$$

At 30% Cement/70% SDA,

$$S.G.M.A = \frac{15+20+55+10}{\frac{15}{2.60}+\frac{20}{2.63}+\frac{55}{2.65}+\frac{3}{3.15}+\frac{7}{2.20}}$$

$$= \frac{100}{5.77+7.60+20.75+0.95+3.18}$$

$$= \frac{100}{38.25} = 2.61$$

At 20% Cement/80% SDA,

$$S.G.M.A = \frac{15 + 20 + 55 + 10}{\frac{15}{2.60} + \frac{20}{2.63} + \frac{55}{2.65} + \frac{2}{3.15} + \frac{8}{2.20}}$$

$$= \frac{100}{5.77+7.60+20.75+0.63+3.64}$$

$$= \frac{100}{38.39} = 2.60$$

At 10% Cement/90% SDA,

$$S.G.M.A = \frac{15 + 20 + 55 + 10}{\frac{15}{2.60} + \frac{20}{2.63} + \frac{55}{2.65} + \frac{1}{3.15} + \frac{9}{2.20}}$$

$$= \frac{100}{5.77+7.60+20.75+0.33+4.09}$$

$$= \frac{100}{38.53} = 2.95$$

Volume, V = Weight in air – Weight in water

Compacted Density, Dp = $\frac{Mass}{Volume}$……..……..4.4

Theoretical Density, D_T = $\frac{100+B_p}{\frac{100}{S.G_{agg}}+\frac{B_p}{G_b}}$……..……4.5

Where B_p = Percentage by mass of bitumen

G_b = Specific gravity of bitumen

$S.G_{agg}$ = combined specific gravity of aggregate

Voids in Mix, V_H = $\frac{D_T-D_P}{D_T} \times 100$……4.6

Voids in Mineral Aggregate, VMA = 100 - $\left[\frac{(100-B_P)\times D_P}{S.G_{Agg}}\right]$……4.7

Voids filled with bitumen, V_F = $\frac{VMA-V_H}{VMA} \times 100$……..…..4.8

At Bitumen content of 5.0%

Volume, V = weight in air – weight in water

= 1187 – 670

= 517cm^3

Compacted Density, D_p = $\frac{Mass\ in\ Air}{Volume}$

$$= \frac{1187}{517} = 2.30 g/cm^3$$

Theoretical density, $D_T = \frac{100+B_p}{\frac{100}{S.G_{agg}} + \frac{B_p}{G_b}}$

$$= \frac{100+5}{\frac{100}{2.68} + \frac{5}{1.03}} = \frac{105}{37.31+4.85} = \frac{105}{42.16} = 2.49 g/cm^3$$

Voids in Mix, $V_H = \frac{D_T - D_P}{D_T} \times 100$

$$= \frac{2.49-2.30}{2.49} \times 100 = \frac{0.19}{2.49} \times 100 = 7.63\%$$

Voids in Mineral Aggregate,

$$V_{MA} = 100 - \left[\frac{(100 - B_P) \times D_P}{SG_{agg}}\right]$$

$$= 100 - \left[\frac{(100-5) \times 2.30}{2.68}\right] = 100 - 81.53 = 18.47\%$$

Voids filled with bitumen, $V_F = \frac{VMA - V_H}{VMA} \times 100$

$$= \frac{18.47 - 7.63}{18.47} \times 100 = \frac{10.84}{18.47} \times 100 = 58.69\%$$

At 5.5% Bitumen content

Volume = 1160-662

$= 498 cm^3$

Compacted density, $D_p = \frac{1160}{498} = 2.33 g/cm^3$

Theoretical density, $D_T = \frac{100 + 5.5}{\frac{100}{2.68} + \frac{5.5}{1.03}}$

$$= \frac{105}{37.31+5.34} = \frac{105}{42.65} = 2.46 g/cm^3$$

Voids in Mix, $V_H = \frac{2.46-2.33}{2.46} \times 100 = \frac{0.13}{2.46} \times 100 = 5.28\%$

Voids in Mineral aggregate,

VMA = $100-\left[\frac{(100-5.5)\times 2.33}{2.68}\right] = 100-82.16 = 17.84\%$

Voids filled bitumen, $V_F = \frac{17.84-5.28}{17.84} \times 100 = \frac{12.56}{17.84} \times 100 = 70.40\%$

At 6.0% bitumen content,

Volume, V = 1166 – 669

$= 497 cm^3$

Compacted density, Dp = $\frac{1166}{497} = 2.35 g/cm^3$

Theoretical density, $D_T = \frac{100 + 6.0}{\frac{100}{2.68} + \frac{6}{1.03}}$

$$= \frac{106}{37.31+5.83} = 106/43.14 = 2.46 g/cm^3$$

Voids in Mix $V_H = \frac{2.46-2.35}{2.46} \times 100$

$= \frac{0.11}{2.46} \times 100 \quad = 4.47\%$

Voids in mineral Aggregate,

$VMA = 100-\left[\frac{(100-6) \times 2.35}{2.68}\right] = 100-82.43$

$= 17.57\%$

Voids filled with bitumen, $V_F = \frac{17.57-4.47}{17.57} \times 100$

$= \frac{13.1}{17.57} \times 100 = 75.00\%$

At bitumen content of 6.5%

Volume, V = 1181 - 678

$= 503 cm^3$

Compacted density, $D_P = \frac{1181}{503} = 2.35 g/cm^3$

Theoretical density, $D_T = \frac{100 + 6.5}{\frac{100}{2.68}+\frac{6.5}{1.03}}$

$= \frac{106.5}{43.62} = 2.44 g/cm^3$

Voids in Mix $V_H = \frac{2.44-2.35}{2.44} \times 100$

$$= \frac{0.9}{2.44} \times 100 \quad = 3.69\%$$

Voids in mineral Aggregate,

$$VMA = 100-\left[\frac{(100-6.5) \times 2.35}{2.68}\right]$$

$$= 100 - 81.99$$

$$= 18.01\%$$

Voids filled with bitumen, $V_F = \frac{18.01-3.69}{18.01} \times 100$

$$= \frac{14.32}{18.01} \times 100 = 79.51\%$$

At bitumen content of 7.0%

Volume, V = 1167 - 669

$$= 498cm^3$$

Compacted density, $D_P = \frac{1167}{498}$

$$= 2.34g/cm^3$$

Theoretical density, $D_T = \frac{100 + 7.0}{\frac{100}{2.68} + \frac{7}{1.03}} = \frac{107}{44.11}$

$$= 2.43g/cm^3$$

Voids in Mix, $V_H = \frac{2.43-2.34}{2.43} \times 100 = \frac{0.9}{2.43} \times 100$

$= 3.70\%$

Voids in Mineral Aggregate,

$VMA = 100 - \left[\frac{(100-7)\times 2.34}{2.68}\right]$

$= 100 - 81.20 = 18.8\%$

Voids filled with bitumen,

$V_F = \frac{18.8-3.70}{18.8} \times 100 = 80.31\%$

Mixture sample: Variation of percentages of cement and Saw Dust Ash at optimum bitumen content of 6.0%

Preferring to table 4.5b

Variation: 100% cement and 0% Saw Dust Ash 60%

Volume = 1187 – 678

$=509cm^3$

Compacted Density, $Dp = \frac{1187}{509} = 2.33g/cm^3$

Theoretical Density, $D_T = \frac{100 + 106}{\frac{100}{2.68} + \frac{6}{1.03}} = \frac{106}{43.14} = 2.46g/cm^3$

Voids in Mix, $V_H = \frac{2.46-2.33}{2.46} \times 100$

$= 5.28\%$

Voids in Mineral Aggregate

$$VMA = 100 - \left[\frac{(100-6)\times 2.33}{2.68}\right]$$

$$= 100 - 81.72$$

$$= 18.28\%$$

Voids filled with bitumen, $V_F = \frac{18.28-5.28}{18.28} \times 100$

$$= 71.12\%$$

At 90% cement /10% Saw Dust Ash

Volume, V = 1188 – 675

$$=513cm^3$$

Compacted Density, Dp = $\frac{1188}{513} = 2.32g/cm^3$

Theoretical Density, $D_T = \frac{100+6}{\frac{100}{2.67}+\frac{6}{1.03}} = \frac{106}{37.45+5.83} = \frac{106}{43.28} = 2.45g/cm^3$

Voids in Mix, $V_H = \frac{2.45-2.32}{2.32} \times 100 = \frac{0.13}{2.32} \times 100$

$$= 5.60\%$$

Voids in Mineral Aggregate,

$$VMA = 100 - \left[\frac{(100-6)\times 2.32}{2.67}\right]$$

$$= 100 - 81.68$$

$$= 18.32\%$$

Voids filled with bitumen, $V_F = \frac{10.99-5.60}{10.99} \times 100$

$$= \frac{5.39}{10.99} \times 100 = 49.04\%$$

At 80% cement/20% Saw Dust Ash

Volume, V = 1173 – 657

= 516cm^3

Compacted Density, Dp = $\frac{1173}{516}$ = 2.27g/cm^3

Theoretical Density, D_T = = $\frac{100+6}{\frac{100}{2.66}+\frac{6}{1.03}} = \frac{106}{43.42}$ = 2.44g/cm^3

Voids in Mix, V_H= $\frac{2.44-2.27}{2.44}\times 100$ = 6.96%

Voids in Mineral Aggregate,

VMA = 100 $\left[\frac{(100-6)\times 2.27}{2.66}\right]$

= 100 – 80.22

= 19.78%

Voids filled with bitumen, V_F = $\frac{19.78-6.96}{19.78}\times 100$

= 64.81%

At 70% cement /30% Saw Dust Ash

Volume, V= 1179 – 662

= 517cm^3

Compacted Density, Dp = $\frac{1179}{517}$= 2.28g/cm^3

Theoretical Density, D_T = $\frac{100+6}{\frac{100}{2.65}+\frac{6}{1.03}}$ = $\frac{106}{43.57}$ =2.43g/cm^3

Voids in Mix V_H =$\frac{2.43-2.28}{2.43}\times 100$ = 6.17%

Voids in Mineral Aggregate,

$$VMA = 100 - \left[\frac{(100-6)\times 2.28}{2.65}\right]$$

$$= 100 - 80.88$$

$$= 19.12\%$$

Voids filled with bitumen, $V_F = \frac{19.12 - 6.17}{19.12} \times 100$

$$= 67.73\%$$

At 60% Cement /40% Saw Dust Ash

Volume, V = 1177 – 661

$$= 516 cm^3$$

Compacted Density, $Dp = \frac{1177}{516}$

$$= 2.28 g/cm^3$$

Theoretical Density, $D_T = \frac{100 + 6}{\frac{100}{2.64} + \frac{6}{1.03}} = \frac{106}{43.71} = 2.43 g/cm^3$

Voids in Mix, $V_F \frac{2.43 - 2.28}{2.43} \times 100 = 6.17\%$

Voids in Mineral Aggregate,

$$VMA = 100 - \left[\frac{(100-6)\times 2.28}{2.64}\right] = 100 - 81.81$$

$$= 18.19\%$$

Voids filled with bitumen, $V_F = \frac{18.19 - 6.17}{19.12} \times 100$

$$= 62.87\%$$

At 50% Cement /50% Saw Dust Ash

Volume, V = 1152 – 631

= 521cm^3

Compacted Density, $D_p = \frac{1152}{521}$ = 2.21g/cm^3

Theoretical Density, $D_T = \frac{100+6}{\frac{100}{2.63}+\frac{6}{1.03}} = \frac{106}{43.85} = 2.41g/\text{cm}^3$

Voids in Mix, $V_H \frac{2.41-2.21}{2.41} \times 100 = 8.30\%$

Voids in Mineral Aggregate,

VMA = 100 - $\left[\frac{(100-6)\times 2.21}{2.65}\right]$

= 100 – 78.39

= 21.61%

Voids filled with bitumen

$V_F = \frac{21.61-8.30}{21.61} \times 100$

= 61.59%

At 40% Cement /60% Saw Dust Ash

Volume, V = 1187 – 637

= 550cm^3

Compacted Density, $D_p = \frac{1187}{550}$ = 2.16g/cm^3

Theoretical Density, $D_T = \frac{100+6}{\frac{100}{2.62}+\frac{6}{1.03}} = \frac{106}{44} = 2.41g/\text{cm}^3$

Voids in Mix, $V_H = \frac{2.41-2.16}{2.41} \times 100$

= 10.37%

Voids in Mineral Aggregate,

VMA =100 - $\left[\frac{(100-6)\times 2.16}{2.62}\right]$= 100 – 77.50

= 22.50%

Voids filled with bitumen,

$V_F = \frac{22.50-10.37}{22.50} \times 100$

= 53.91%

At 30% Cement /70% Saw Dust Ash

Volume, V = 1182 – 633

= 549cm^3

Compacted Density, Dp = $\frac{1182}{549}$ = 2.15g/cm^3

Theoretical Density, $D_T = \frac{100+6}{\frac{100}{2.61}+\frac{6}{1.03}} = \frac{106}{44.14} = 2.27 g/\text{cm}^3$

Voids in Mix, $V_H = \frac{2.27-2.15}{2.27} \times 100 = 5.29\%$

Voids in Mineral Aggregate,

VMA = 100 - $\left[\frac{(100-6)\times 2.15}{2.61}\right]$

= 100 – 77.43

= 22.57%

Voids filled with bitumen,

$V_F = \frac{25.57-5.29}{25.57} \times 100$

= 67.58%

At 20% Cement /80% Saw Dust Ash

Volume, V = 1177 – 623

= 554cm^3

Compacted Density, Dp = $\frac{1177}{554}$ = 2.12g/cm^3

Theoretical Density, $D_T = \frac{100+6}{\frac{100}{2.60}+\frac{6}{1.03}} = \frac{106}{44.29} = 2.39 g/\text{cm}^3$

Voids in Mix, $V_H = \frac{2.39-2.12}{2.39} \times 100 = 11.30\%$

Voids in Mineral Aggregate,

$VMA = 100 - \left[\frac{(100-6)\times 2.12}{2.60}\right]$

= 100 – 76.65

= 23.35%

Voids filled with bitumen,

$V_F = \frac{23.35-11.30}{23.35} \times 100$

= 51.61%

At 10% Cement /90% Saw Dust Ash

Volume, V = 1175 – 605

= 570cm^3

Compacted Density, $D_p = \frac{1175}{570}$ = 2.06g/cm^3

Theoretical Density, $D_T = \frac{100+6}{\frac{100}{2.59}+\frac{6}{1.03}} = \frac{106}{44.44} = 2.39g/\text{cm}^3$

Voids in Mix, $V_H = \frac{2.39-2.06}{2.39} \times 100 = 13.81\%$

Voids in Mineral Aggregate,

$VMA = 100 - \left[\frac{(100-6)\times 2.06}{2.59}\right]$

= 100 – 74.76

= 25.24%

Voids filled with bitumen,

$V_F = \frac{25.24-13.81}{25.24} \times 100$

= 45.29%

At 0% Cement /100% Saw Dust Ash

Volume, V = 1147 – 581

= 566cm^3

Compacted Density, $D_p = \frac{1147}{566}$ = 2.03g/cm^3

Theoretical Density, $D_T = \frac{100+6}{\frac{100}{2.59}+\frac{6}{1.03}} = \frac{106}{44.44} = 2.39g/\text{cm}^3$

Voids in Mix, $V_H = \frac{2.39-2.03}{2.39} \times 100 = 15.06\%$

Voids in Mineral Aggregate,

$$VMA = 100 - \left[\frac{(100-6)\times 2.03}{2.59}\right]$$

$$= 100 - 73.68$$

$$= 26.32\%$$

Voids filled with bitumen,

$$V_F = \frac{26.32-15.06}{26.32} \times 100$$

$$= 42.78\%$$

APPENDIX K
MARSHALL STABILITY TABLE
HOT MIX DESIGN METHOD

Appendix K1: TABLE 4.5a: DESCRIPTION: WEARING COURSE (HEAVY TRAFFIC ASPHALT) No. of Blows: 75

Sample: Mix with Cement – Control DESIGN MIX: 15:20:55:10

Laboratory: ABU Transportation Lab.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Specimen number	Bitumen by weight of aggregate	Bitumen by weight of total mix	Weight		Bulk Volume D-E	**Density**		Voids in mix	Voids in Mineral Agg. (VMA)	Voids filled with Bitumen	Specimen height	Stability	Correlation ratio	Corrected stability	Flow
				Air	water		Bulk D/F	Theoretical								
Unit	4	%	%	(g)	(g)	(cm^3)	(g/cm^3)	(g/cm^3)	%	%	%	(mm)	(KN)		KN	(mm)
	1/1	5.3	5.0	1185	667							65.1	8.50	1.00	8.55	2.00
	2/1	5.3	5.0	1189	672							65.1	8.60	1.00	8.55	2.10
	Average			1187	670	517	2.30	2.49	7.63	18.47	58.69	65.1	8.55	1.00	8.55	2.10
	1/2	5.8	5.5	1160	660							65.0	10.40	1.04	10.82	2.60
	2/2	5.8	5.5	1160	663							65.0	10.30	1.04	10.82	2.60
	Average			1160	662	498	2.33	2.46	5.28	17.84	70.40	65.0	10.40	1.04	10.82	2.60
	1/3	6.4	6.0	1165	670							65.0	11.40	1.04	11.85	3.20
	2/3	6.4	6.0	1167	667							65.1	11.37	1.04	11.85	3.18
	Average			1166	669	497	2.35	2.46	4.47	17.57	75.00	65.1	11.39	1.04	11.85	3.20
	1/4	7.0	6.5	1183	677							65.0	8.60	1.04	8.92	2.80`
	2/4	7.0	6.5	1179	674							65.0	8.55	1.04	8.92	2.77
	Average			1181	678	503	2.35	2.44	3.69	18.01	79.51	65.0	11.39	1.04	11.85	2.80
	1/5	7.5	7.0	1168	671							65.1	6.60	1.04	6.84	2.00
	2/5	7.5	7.0	1165	666							65.0	6.56	1.04	6.84	2.00
	Average			1167	669	498	2.34	2.43	3.70	18.8	80.31	65.1	6.58	1.04	6.84	2.00

APPENDIX L

Appendix L1: Table 4.5b Mixture Sample: Variation of Percentages of Cement and Saw Dust Ash at optimum bitumen Content of 6.0%

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Specimen number	Bitumen by weight of aggregate	Bitumen by weight of total mix	Weight		Bulk Volume D-E	**Density**		Voids in mix	Voids in Mineral Agg. (VMA)	Voids filled with Bitumen	Specimen height	Stability	Correlation ratio	Corrected stability	Flow
				Air	water		Bulk D/F	Theoretical								
Mixture Sample (Variation: 100% Cement and 0% Saw Dust Ash)																
Unit		%	%	(g)	(g)	(cm^3)	(g/cm^3)	(g/cm^3)	%	%	%	(mm)	(KN)		KN	(mm)
	1/1	6.4	6.0	1185	676							65.1	5.60	0.89	5.00	2.00
	2/1	6.4	6.0	1189	679							65.1	5.64	0.89	5.00	1.98
	Average			1187	678	509	2.33	2.46	5.28	18.28	71.12	65.1	5.62	0.89	5.00	2.00
Mixture Sample (Variation: 90% Cement and 10% Saw Dust Ash)																
	1/2	6.4	6.0	1190	677							65.0	7.80	1.00	7.78	2.90
	2/2	6.4	6.0	1186	673							65.0	7.75	1.00	7.78	2.90
	Average			1188	675	513	2.32	2.45	5.60	18.32	49.04	65.0	7.78	1.00	7.78	2.90
Mixture Sample (Variation: 80% Cement and 20% Saw Dust Ash)																
	1/3	6.4	6.0	1175	659							65.1	7.30	1.00	7.28	2.70
	2/3	6.4	6.0	1170	655	516	2.27	2.44	6.96	19.78	64.81	65.1	7.25	1.00	7.28	2.70
	Average			1173	657							65.1	7.28	1.00	7.28	2.70
Mixture Sample (Variation: 70% Cement and 30% Saw Dust Ash)																
	1/4	6.4	6.0	1180	663							65.1	7.00	1.00	7.10	2.50
	2/4	6.4	6.0	1177	660							65.0	7.10	1.00	7.10	2.49
	Average			1179	662	517	2.28	2.43	6.17	19.12	67.73	65.1	7.10	1.00	7.10	2.50
Mixture Sample (Variation: 60% Cement and 40% Saw Dust Ash)																
	1/5	6.4	6.0	1178	663							65.0	6.80	1.00	6.81	2.20
	2/5	6.4	6.0	1175	658							65.0	6.82	1.00	6.81	2.18
	Average			1177	661	516	2.28	2.43	6.17	18.19	62.87	65.0	6.81	1.00	6.81	2.20
Mixture Sample (Variation: 50% Cement and 50% Saw Dust Ash)																
	1/6	6.4	6.0	1150	627							65.1	5.80	1.00	5.82	2.00
	2/6	6.4	6.0	1154	635							65.1	5.84	1.00	5.82	1.99
	Average			1152	631	521	2.21	2.41	8.30	21.61	61.59	65.1	5.82	1.00	5.82	2.00
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P

	Specimen number	Bitumen by weight of aggregate	Bitumen by weight of total mix	Weight		Bulk Volume D-E	Density		Voids in mix	Voids in Mineral Agg. (VMA)	Voids filled with Bitumen	Specimen height	Stability	Correlation ratio	Corrected stability	Flow
				Air	water		Bulk D/F	Theoretical								
Mixture Sample (Variation: 40% Cement and 60% Saw Dust Ash)																
	1/7	6.4	6.0	1189	639							65.0	5.60	0.89	5.00	2.00
	2/7	6.4	6.0	1185	635							65.0	5.64	0.89	5.00	1.98
	Average			1187	637	550	2.16	2.41	10.37	22.50	53.91	65.0	5.62	0.89	5.00	2.00
Mixture Sample (Variation: 30% Cement and 70% Saw Dust Ash)																
	1/8	6.4	6.0	1180	634							65.1	5.20	0.89	4.63	1.80
	2/8	6.4	6.0	1183	631							65.1	5.22	0.89	4.63	1.80
	Average			1182	633	549	2.15	2.27	5.29	22.57	67.85	65.1	5.21	0.89	4.63	1.80
Mixture Sample (Variation: 20% Cement and 80% Saw Dust Ash)																
	1/9	6.4	6.0	1180	634							65.0	4.80	0.89	4.25	1.70
	2/9	6.4	6.0	1183	631							65.1	4.75	0.89	4.25	1.70
	Average			1182	633	554	2.12	2.39	11.30	23.35	51.61	65.1	4.78	0.89	4.25	1.70
Mixture Sample (Variation: 10% Cement and 90% Saw Dust Ash)																
	1/10	6.4	6.0	1176	607							65.0	4.20	0.86	3.63	1.40
	2/10	6.4	6.0	1174	603							65.0	4.24	0.86	3.63	1.40
	Average			1175	605	570	2.06	2.39	13.81	25.24	45.29	65.0	4.22	0.86	3.63	1.40
Mixture Sample (Variation: 0% Cement and 100% Saw Dust Ash)																
	1/11	6.4	6.0	1145	579							65.1	3.80	0.86	3.29	1.00
	2/11	6.4	6.0	1148	583							65.1	3.84	0.86	3.29	1.00
	Average			1147	581	566	2.03	2.39	15.06	26.32	42.78	65.1	3.82	0.86	3.29	1.00

APPENDIX M

Appendix M1: Table 4.6a Variation of Saw Dust Ash Content (%) with Flow (mm)

Flow (mm)	SDA Content (%)
2.00	0
2.90	10
2.70	20
2.50	30
3.20	40
2.00	50
1.80	70
1.70	80
1.40	90
1.00	100

Appendix M2: Table 4.6b Variation of Saw Dust Ash Content (%) with Bulk Density (g/cm^3)

Bulk Density (g/cm^3)	SDA Content (%)
2.33	0
2.32	10
2.27	20
2.28	30
2.28	40
2.21	50
2.16	60
2.15	70
2.12	80
2.06	90
2.03	100

APPENDIX N

Appendix N1: Table 4.6c Variation of Saw Dust Ash Content (%) with Voids in mineral Aggregate (%)

Bulk Density (g/cm^3)	SDA Content (%)
18.28	0
18.32	10
19.78	20
19.12	30
18.19	40
21.61	50
22.50	60
22.57	70
23.35	80
25.24	90
26.32	100

Appendix N2: Table 4.6d Variation of Saw Dust Ash Content (%) with Stability (kN)

Bulk Density (g/cm^3)	SDA Content (%)
5.00	0
7.78	10
7.28	20
7.10	30
6.81	40
5.82	50
5.00	60
4.63	70
4.25	80
3.63	90
3.29	100

APPENDIX O

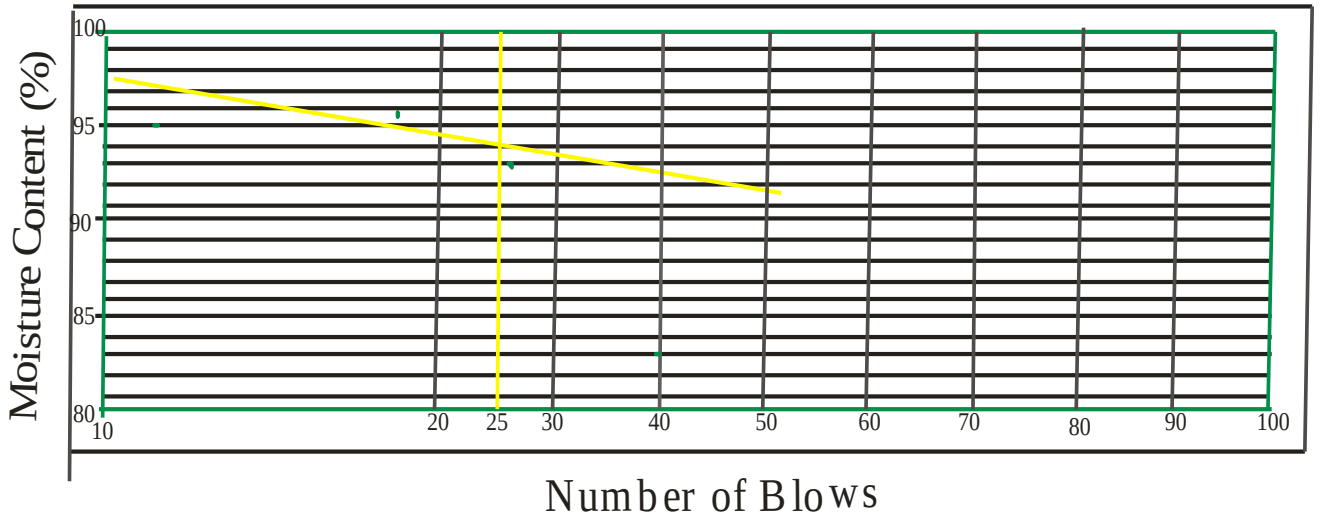
Appendix O1: Table 4.6e Variation of Saw Dust Ash Content (%) with Voids in Total Mix (%)

Bulk Density (g/cm^3)	SDA Content (%)
5.28	0
5.60	10
6.96	20
6.17	30
6.17	40
8.30	50
10.37	60
5.29	70
11.30	80
13.81	90
15.06	100

Appendix O2: Table 4.6f Variation of Saw Dust Ash Content (%) with Voids Filled with Bitumen, VFB (%)

Bulk Density (g/cm^3)	SDA Content (%)
71.12	0
49.04	10
64.81	20
67.73	30
62.87	40
61.59	50
53.91	60
67.85	70
51.61	80
45.29	90
42.78	100

APPENDIX P



Appendix P1: Figure 4.7: Relationship of Moisture Content to Number of Blows

Rr4

11