INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

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A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

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UGANDA CHRISTIAN UNIVERSITY
A Centre of Excellence in the Heart of Africa

FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY

DEPARTMENT OF ENGINEERING AND ENVIRONMENT

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Research and Design Report

ON

Investigating the Use of Lime Kiln Dust as a Filler in Asphalt Concrete for Durable Flexible Pavements

BY

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ABSTRACT

Flexible pavements, primarily used in Uganda, are roadways composed of a blend of bitumen, mineral filler, and aggregates. The main aim of this study was to investigate the use of lime kiln dust as a mineral filler in asphalt concrete for durable flexible pavements, in proportions by mass of the active filler. The main methods used were the Marshall test, determination of engineering properties of the mineral filler, bitumen, and aggregates, as well as Indirect Tensile Strength (ITS) testing on the asphalt mixtures. During the study, various factors were evaluated, encompassing Marshall stability, flow characteristics, unit weight, air voids (Va), voids filled with asphalt (VFA), and voids in the mineral aggregate (VMA).

The results showed that the use of lime kiln dust led to a reduction in air voids from 5.7% to 4.9%, an increase in Marshall stability from 14.8 to 17.1, increased Indirect Tensile Strength Wet Strength from 81% to 90%. This implied that the incorporation of 4% lime kiln dust filler improved the rutting resistance of asphalt mixtures by enhancing the stability and stiffness of the mix.

However, further studies should consider a batch total mass of the mix of 18,000g, with proportions of 882g of bitumen, 856g of 14/20, 1198g of 10/14, 2568g of 6/10, 11,811g of 0/6 aggregates, and 685g of LKD filler in the mix design. Additionally, the effect of temperature on the storage of filler material should be investigated to assess fatigue response, as it affects the filler composition and, in turn, the strength performance properties of asphalt.

DECLARATION

I, MOHAMMED MBARAK, hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for an award

Name: MOHAMMED MBARAK

Signature: ....

Date ....

APPROVAL

This research and design project report has been submitted for examination with my Approval as the university supervisor.

Signature:.................................... Date: ....

MS JOSEPINE AGUTI

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

ADT	Average Daily Traffic
LKD	Lime Kiln Dust
AADT	Annual Average Daily Traffic
GHG	Greenhouse gas
PSD	Particle Size Distribution
FI	Flakiness Index
OPC	Ordinary Portland Cement
RD	Rock dust
ESA	Equivalence Standard Axle
HMA	Hot mix asphalt
AASHTO	American Association of the State Highway and Transportation Officials
VMA	Voids in Mineral Aggregate
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
XRF	X-Ray Fluorescence
Gmm	Theoretical Maximum Specific Gravity
PCFA	Portland Cement Filler Asphalts
LOI	Loss of Ignition
SD	Stone Dust
SSD	Saturated Surface Dry
OBC	Optimum Bitumen Content

DEFINITIONS OF TERMS

Air voids	The percentage of void space or air pockets present in the compacted AC mixture. As a requisite in all dense-graded highway mixes, a specific proportion of air voids is essential to facilitate adequate compaction and flexibility under traffic loads. loading (Zaltuom, 2018).
Workability	Ease with which pavement mixtures can be compacted and laid down. The workability of a mixture is determined by the final air void content after compaction, as less workable mixes tend to compact less under consistent compaction efforts (Zaumanis, Poulikakos and Partl, 2018).
Rutting	A type of deformation when pavement becomes more depressed, deformed or worn down in the wheel tracks, resulting into displacement the asphalt road layer (Liley, 2018).
Bitumen	A viscous, black, and complex mixture of hydrocarbons, characterized by its highly sticky nature. It is obtained from the refining of crude oil and is commonly used in the formation of asphalt concrete (Porto *et al.*, 2022).
Pavement	A hard or firm surface designed for foot or vehicle activity, typically constructed by placing courses of asphalt and aggregate in layers over an upgraded subgrade (Mahajan, 2020).

Lime Kiln Dust	A by product generated during the manufacturing of lime, composed of calcium oxide, calcium carbonate, and calcium hydroxide hence useful as mineral filler (Moser, 2015).
Durability of asphalt	A gauge of the asphalt's endurance under various mechanical and environmental stresses over time (Lesueur, 2013).
Mineral filler	A finely divided mineral product that passes through a No. 200 or (0.075 mm) screen, typically comprising at least 50% of particles of this size. It serves to enhance adhesion between the aggregates and the bitumen in asphalt concrete (Chen *et al.*, 2022).
Flexibility of asphalt	The ability of a structure covered with asphalt liquid to accommodate foundation settling is known as its rutting resistance, which is augmented by a high asphalt content. This characteristic also serves as an index parameter or indicator for characterizing load-displacement curves (Yurt, 2020).
Design period	The duration or number of years between the initial work significant resurfacing or overlay and the commencement of traffic is referred to as pavement life. This lifespan can be prolonged indefinitely through the application of hot mix asphalt overlays as needed, or until geometric factors render the pavement obsolete (Francisco, 2020).

Stability of an asphalt	The resilience of an asphalt paving mixture against deformation caused by applied loads relies on its permeability, cohesiveness, and internal friction, which are crucial factors for ensuring the firmness of the asphalt mix (Akhtar *et al.*, 2021).
Concrete	This refers to composite material formed by blending a binding medium e.g. cement with aggregates (such as sand, gravel, or stone) and water in precise proportions (Rahman, 2019).

CHAPTER ONE: INTRODUCTION

1.1 Background

Uganda's road network has improved significantly due to the increased funding and the road sector reforms of the 1990s, as evidenced by the development of road infrastructure and construction of road pavements (Kagina, 2021). The two major types of road pavement are flexible pavements, consisting of asphalt concrete, and rigid pavements that consist of concrete (Mahajan, 2020).

Roads constructed with asphalt concrete are primarily used in Uganda due to their ability to flexibly deform and move slightly under heavy traffic loads and environmental changes. However, flexible pavements with asphalt concrete can experience several types of distresses or failure over time that leads to challenges such as cracking, shoving, thermal fatigue, rutting (Tasnim, 2021).

Pavement failures can be caused by number of factors, including poorly designed mixes, inadequate compaction, weak subgrade soil, and large axle loads in high traffic volumes. Rutting occurs as the pavement surface gradually becomes deformed and develops a depression that collects water accelerating the deterioration of the pavement and also a decrease in the bitumen's adherence to the aggregates (Su, 2020).

In order to enhance the characteristics of asphalt concrete mixtures, finely divided mineral materials known as mineral fillers are used as they increase the mixture's stiffness and resistance to deformation or rutting in flexible pavements. A case study of this problem is along a section in Mbambire along Masaka road that experiences pavement distresses of rutting, with a poor pavement condition Index of 46.8 with increased in traffic loading.

However, Lime kiln dust (LKD) can bridge the gap as a filler material in asphalt concrete and improve resistance to road defect of rutting (Ghasemi, 2015).

1.2 Problem Statement

Rutting is one of the major bituminous deteriorations observed in asphalt concrete pavements in Uganda. It occurs when permanent deformation or consolidation accumulates on surface overtime, resulting in the wheel path being engraved in the road. This is caused by a variety of factors, including poorly designed mixes with higher voids greater than 5% reducing contact surface area, inadequate compaction and large axle loads in high traffic volumes with current estimates at 54 MESA compared to the projected 44.1 MESA (Moses, 2022).

Studies carried out by Jitsanigam on the performance of Lime Kiln Dust under hot conditions showed that a 50% LKD composition in hot mix asphalt mixture provided superior viscoelasticity properties. Additionally, Lime Kiln dust GHG emissions and embodied energy consumption may potentially be decreased by 18.5% and 2.4% from inception to the production life cycle assessment of asphalt than other fillers (Jitsanigam, 2018).

Another study carried out by Nitin Tiwari on the strength properties of asphalt presented experimental findings regarding air voids and Marshall stability. The mixture with LKD exhibited a better adhesion with lower voids of about 70%, reduced mixture porosity and bitumen hardening (Type-169). This resulted into slightly better strength compared to Ordinary Portland Cement of 15% stiffness in design period of 15 years (Tiwari, 2023).

In a study conducted by James on the wet conditioning of asphalt specimens with Lime Kiln Dust and Rock Dust, subjected to numerous freeze-thaw cycles and prolonged soak times to assess their reactions under harsh conditions. The findings revealed that the LKD utilized in this investigation outperformed the rock dust mineral filler, exhibiting a 25.4% reduction in voids in mineral aggregates (James, 2006). Therefore, this study aimed at investigating the use of Lime kiln Dust as a mineral filler in asphalt concrete for durable flexible pavements.

1.3 Objectives of the Study

1.3.1 Main Objective

To Investigate the Use of Lime Kiln Dust as a Filler in asphalt concrete for Durable Flexible Pavements.

1.3.2 Specific Objectives

1. To determine the engineering properties of Lime Kiln Dust, Bitumen and Aggregates.
2. To determine the Optimum Bitumen Content for Asphalt Concrete with Lime Kiln Dust.
3. To determine the strength performance properties of Asphalt Concrete with and without Lime Kiln Dust.

1.4 Research Questions

1. What are the engineering properties of Lime Kiln Dust, Bitumen and Aggregates?
2. What is the optimum bitumen content for asphalt concrete with LKD?
3. What is the strength performance properties of Asphalt Concrete with and withoutLime Kiln Dust?

1.5 Justification of the Study

Lime Kiln Dust (LKD) is a by-product generated in the production of lime, comprising of, calcium oxide, silicon dioxide and calcium hydroxide that has been shown to improve adhesion of aggregates with bitumen. Furthermore, on addition of Si02, it has shown an increase in fatigue life and resistance to rutting of asphalt mixtures as LKD can function as a mineral filler, aiding in reducing the temperature susceptibility of the asphalt binder by 18.5% and 2.4% compared to other common fillers (Gholam, 2020).

Furthermore, Lime Kiln dust possesses the properties of a mineral filler and has a higher specific surface area compared to other common fillers, which allows more effective interaction with the asphalt binder and aggregate particles (Moser, 2015).

1.6 Significance of the Study

Lime Kiln Dust is readily available from Cement Manufacturing Industries, offering a practical, viable and effective solution to high costs associated with road maintenance caused by premature flexible pavement deterioration (Christopher, 2019). Its primary significance lied in enhancing adhesion and stiffness properties, thereby mitigating possibility of rutting and cracking.

1.7 Scope

1.7.1 **Content Scope**

This study aimed at investigating the use of Lime Kiln Dust as a filler in asphalt concrete for durable flexible pavement

1.7.2 **Geographical Scope**

The scope of this study was a section in Mbamire along Kampala Masaka Road

1.7.3 **Time Scope**

The project took a duration of eight months

CHAPTER TWO: LITERATURE REVIEW

2. Pavements

A pavement is a firm surface or hard surface that is intended for foot or vehicle activity (Mahajan, 2019).In Uganda, a significant amount of investment is directed towards the construction of Asphalt pavement roads. Frequent failures such as rutting, fatigueand thermal cracking are attributed to many causes such as increase in traffic volumes, poor mix designs, poor drainage, poor adhesion and bonding of binder, just to mention a few. To accommodate the ever-increasing traffic load in varyingclimatic environments and to resist to such failures, major emphasis has been puton improving the performance of road pavements which are made of two types; rigid and flexible pavements (Yurt, 2020).

2.1 Rigid Pavements

Rigid pavements refer to firm surfaces made of concrete and due to their strong flexural strength, rigid pavements are ideal for transferring wheel load to a larger surface. Unlike flexible pavements, rigid pavements have fewer material layers and are rigidly set either on top of a single layer of stabilized or granular material or a well-compacted subgrade.

Between the concrete and the subgrade, there is just one layer, which is referred to as the sub-base course. Furthermore, rigid roads function like an elastic plate lying on a viscous liquid, transferring the load of automobile traffic through slab action (Mahajan, 2020).

2.2 Flexible Pavements

Flexible pavements are a type of road surface made of asphalt concrete and designed to be flexible and durable under varying traffic loads and weather conditions. The base course, often composed of multiple layers of materials like asphalt concrete, is chosen and positioned according to its stiffness and strength (Association, 2021).

2.2.1 Design and Performance Requirements of Flexible Pavements

Flexible pavements transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure as seen in Figure 2.1. They should provide adequate skid resistance, good reflecting characteristics, riding quality and low noise pollution to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the subgrade (Flarherty, 2020).

As depth increases, the wheel weight pushing on the pavement disperses across a larger area decreasing stress. Flexible pavements typically consist of multiple layers to capitalize on this stress distribution feature. This layered system concept means that multiple layers of flexible pavement may be built, with the top layer designed to withstand wear and tear and the largest amount of compressive stress, reducing stress on lower layers where inferior materials may be used (Zaltuom, 2018).

Bituminous materials, such as asphalt concrete surface courses, which are typically utilized on high volume roads like national highways, or surface treatments such as bituminous surface treatments, which are typically seen on low volume roads improve the flexible pavement performance.

Pavement layers that are flexible mirror the deformation of the lower layers onto the surface layer. For example, any undulation in the subgrade will be reflected onto the surface layer. In flexible pavement, the design is determined by the material's total performance under heavy traffic loads ensuring that the stresses generated must be maintained considerably below the maximum amounts permitted by each layer of pavement such as the wearing course (Flarherty, 2020).

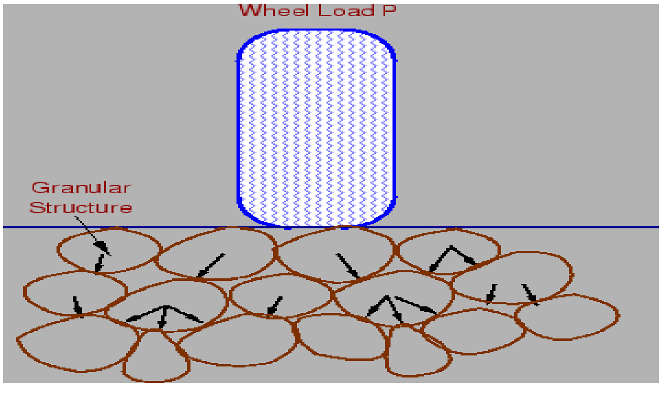

Figure 2. 1:Load transfer in granular structure

Factors to consider in the Design and Performance of Flexible Pavement.

Table 2. 1:Design and Performance Requirements of Flexible Pavement (AASHTO AND FHWA)

Traffic loads	Considering the type, volume, and weight of traffic that the pavement is anticipated to accommodate involves adopting appropriate design traffic loads, often expressed in terms of axle loads and repetitions.
Subgrade soil characteristics	Assessing the bearing capacity and resilience of the subgrade soil involves evaluating its soil classification and determining soil properties, such as the California Bearing Ratio (CBR).

Climate and Environmental conditions	Adjusting the pavement design to suit the local climate encompasses considerations of temperature fluctuations, rainfall patterns, and freeze-thaw cycles. This adaptation involves integrating drainage systems to alleviate the adverse effects of water on pavement.
Materials Selection	Choosing appropriate materials for various layers of the pavement structure, such as the surface course, base course, and subbase, involves considering their properties, including stiffness, fatigue resistance, and durability as seen in Table 2.2.
Pavement Structure:	Identifying the suitable pavement structure relies on factors such as the design traffic, subgrade strength, and material properties.
Load-Bearing Capacity	Ensuring that the pavement can withstand the imposed traffic loads without experiencing excessive deformation or rutting.
Durability and Fatigue Resistance	Designing the pavement to endure repeated loading cycles without developing fatigue cracks or enduring permanent deformation.
Resistance to Environmental Distress	Capacity to withstand distresses such as cracking, rutting, and surface deterioration induced by environmental factors such as moisture, temperature and chemical exposure.

Table 2. 2:Design Requirements for Asphalt Concrete

Property of mixture and laboratory test method			**Asphalt Concrete, continuously graded, (AC20, AC14, AC10)**
Marshall flow (mm)			2 – 4
Marshall stability (Newton), all severely loaded areas*)			Minimum 9000
Marshall stability (Newton)	Traffic Loads	> 10 x 10^6 Esa's	8000 – 18000
		1 - 10 x 10^6 Esa's	7000 – 15000
		< 1 x 10^6 Esa's	6000 – 10000
Air voids (%)			3 – 5
Voids in mineral Aggregatee (%)	Asphalt Mix	AC 20	min. 14
		AC 14	min. 15
		AC 10	min. 16
Voids Filled with Bitumen (%)	Traffic Loads	> 10 x 10^6 Esa's	65 – 75
		1 - 10 x 10^6 Esa's	65 – 78
		< 1 x 10^6 Esa's	70 -80
Requirement after refusal laboratory compaction BS-594 - Part 598 (severely loaded areas only) *)			Air voids shall be minimum3%
Indirect tensile strength (KPa) AASHTO T 283			Minimum 800Tested at 25 °C
Indirect wet tensile strength (KPa) AASHTO T 283			80 % of dry strength

2.2.2 Layers of Flexible Pavements

Subgrade- The compacted subgrade serves as base of all pavement layers, as all the stress is transferred to this layer and so proper compaction to desired density aids to reduces the stress.

Subbase- The subbase is a layer of material below the base course, consisting of high quality and wellgraded material aggregates. Its role is to provide structural support, improve drainage, and reduce the intrusion of fines from the subgrade.

Base- This is a layer of material just below the surface of the binder course. It provides additional load distribution and contributes to subsurface drain

Wearing course - The primary layer of flexible pavement, known as the surface course or top layer, is what gives a good road its smooth, resilient, and abrasion-resistant qualities. It bears the direct traffic while retaining adequate friction for road safety. Typically, it is made from bitumen bound aggregate known as asphalt concrete (Mahajan, 2020)

Components of the Wearing Course

Seal Coat: A thin layer of surface treatment is applied to provide skid resistance and water resistance. This layer, often referred to as a "tack coat," involves applying a very thin layer of asphalt, typically diluted asphalt emulsion with water. The tack coat ensures proper joining of the two layers of binder course. It needs to be thin, evenly covering the whole surface, and setting quickly to facilitate proper adhesion.

Prime Coat: Prior to the application of the binder layer, an absorbent surface, such as granular bases, is primed with a low viscosity cutback bitumen mixture. This primer facilitates the bonding of two layers by filling in the gaps, providing a watertight surface, and penetrating the layer beneath tack coat (Mathew, 2009)

Figure 2. 2:Road layers

2.2.4 Failures in Flexible Pavements

Asphalt flexible pavements are typically resilient and can endure diverse traffic loads and weather conditions. However, they are susceptible to failure due to various factors, including the passage of time. Processes like aging and oxidation can weaken the pavement layer. Some common types of failures in flexible pavement layers include;

a) Cracking

Cracks may occur in the surface, binder, or base courses due to thermal expansion and contraction, traffic loads, or aging of the pavement. Cracking can lead to water infiltration and accelerated pavement deterioration.

b) Raveling

Raveling is a type of surface defect that occurs when the aggregate particles become dislodged from the surface of the pavement due to poor bonding between the bitumen and the aggregates. It can be caused by poor compaction during construction, poor quality asphalt binder, or insufficient asphalt content.

c) Bleeding

Bleeding is a type of surface distress that occurs when excess asphaltbinder rises to the surface of the pavement due to high temperatures. This can result in a slippery surface that can cause safety concerns for drivers.

d) Shoving

Shoving is a type of deformation that occurs in the wheel path of the pavement due to high lateral stresses caused by heavy braking or turning movements. Shoving can cause the pavement to become rough and can result inloss of skid resistance.

e) Rutting

This is a type of depression that occurs in the wheel path of the pavement due to the prolonged accumulation of traffic loads over time as shown in Figure 2.3. Rutting can occur in the surface, binder, or base courses attributed to factors such as inadequate thickness, poor mix design, or inadequate compaction (Liley, 2018).

Rutting can be classified into two types; shallow rutting and deep rutting. Shallow rutting occurs within the asphalt concrete (AC) layer and typically has a depth of less than one point five cm. Some of requirements of constructing a high-quality road with reduced likelihood of rutting includes, quality control monitoring of the pavement and requires sticking to a stronger, stiffer subbase because it supplies the foundation upon which roads are built which is crucial to road networks (Chance, 2018).

The loading of weight and the number of passes made by the roller over a section of asphalt are crucial for ensuring the quality of the asphalt surface. To ensure adequate compaction of the road, a roller typically needs to traverse over a hot mix asphalt (HMA) stretch 3 to 4 times within a short timeframe while the asphalt cools down. However, achieving this can be challenging. As the temperature of the HMA drops, the aggregate's capacity to compact diminishes (Smith, 2018).

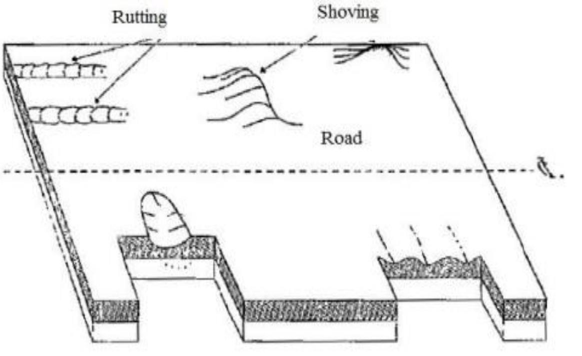

Figure 2. 3:Rutting image

2.2.5 Materials used in the Construction of Flexible Pavements.

i.Bitumen

Bitumen is a viscous, black, and highly sticky material that is obtained from the refining of crude oil. It is a complex mixture of hydrocarbons (Porto *et al.*, 2022). Examples of Bitumen grades include 60/70, 80/100 to mention a few. Bitumen is usually characterized in the following two types of grades;

Viscosity Grades

The bituminous material's fluid property is defined by its viscosity, which is the resistance to flow. The basis for viscosity grading is a fundamental, scientific viscosity test that is carried out with 60 °C which is close to the maximum temperature experienced by pavements during summer. The measuring for viscosity unit is the poise.

Penetration Grades

The penetration test is utilized to assess the hardness and characterize bitumen. The fundamental premise of penetration grading is that, under specific temperature, load, and loading time circumstances, the needle will penetrate the specimen of material more deeply indicating that the asphalt is less viscous but has to meet standards as seen in Table 2.3.

Table 2. 3:Bitumen ASTM standards

TEST	SPECIFICATION
PENETRATION	60-70
SOFTENING POINT	(49-56) C
SPECIFIC GRAVITY	1.01-1.06

ii.Aggregates

Aggregates are granular materials such as sand, gravel, crushed stone, and recycled concrete that are used in the construction. Some types of aggregates used in Asphalt concrete include Limestone and Granite and their sizes ofaggregates used in an asphalt mixture in Table 2.4.

Table 2. 4:Sieve size analysis

SIEVE SIZE	Description
>2.36mm	Coarse
>0.075mm	Fine

Tests carried out include Aggregate Crushing Value (ACV), Aggregate ImpactValue (AIV), Ten Percent Fines Value (TFV), Sieve Analysis, Flakiness Index with the required standards and specifications as seen in Table 2.5 according to the (MoWT 2010).

Table 2. 5: Aggregates BS AND ASTM standards

TEST	UNIT	SPECIFICATION
AIV	%	<25
ACV	%	<45
TFV (DRY)	KN	
TFV (WET)	KN	>110
WET/DRY	%	>75%
FLAKINESS INDEX	%	Max 25
COMBINED SPECIFIC GRAVITY		2.5-2.9

2.2.6 Materials used to Improve Asphalt Performance.

Filler

Mineral filler naturally present in or manufactured and added to aggregates play a significant role on the performance of asphalt mixtures. It is defined as material having particle sizes less than 0.075mm, which may originate from fines in the aggregate or be added in the form of cement, lime (Gabriel S, 2022).

Filler characteristics encompass particle shape, plasticity, texture, particle size, gradation, particle-size distribution, density and specific surface area which refers to the total surface area for a unit mass, and finer particles or lower specific density typically have a beneficial effect on the filler-asphalt system.

Specific Surface Area is one of the main factors affecting the interfacial interaction between asphalt binder and mineral filler.

Use of Mineral Fillers

By filling the voids in the aggregate skeleton, a denser mixture is created enhancing the cohesion of the asphalt binder and the stability of the mixture. This also improves the grading of aggregates, thereby enhancing the resistance of the asphalt mixture pavement to water and frost, pavement deformations, fatigue cracks, and low-temperature cracks (Abdullah *et al.*, 2017).

Examples of Fillers include; Slaked lime, Hydrated lime, Cement Kiln Dust, Fly Ash, lime, Ordinary Portland Cement, Lime Kiln Dust to mention a few.

i. Ordinary Portland Cement

The utilization of Ordinary Portland Cement (OPC) as a substitute filler aims to enhance the stiffness of asphalt concrete mixes, particularly when incorporating low-quality aggregates and bitumen 60/70.

The study employs four different percentages of OPC (0%, 2%, 4%, and 6%) as filler alternatives across three distinct mixes to evaluate the impact of OPC on the performance of asphalt mixtures in hot climates. The findings indicate that mixes containing higher percentages of OPC as filler exhibit significantly greater resistance to rutting.

This enhanced resistance is attributed to the resultant increase in modulus of stiffness. Consequently, these experimental results suggest that Portland Cement Filler Asphalts (PCFA) offer a more stable alternative to traditional asphalt while also reducing thickness requirements (Assaf, 2020).

ii. Hydrated Lime

When dissolved in pure water at room temperature, hydrated lime forms an alkaline solution with a pH of approximately 12.4, despite its limited solubility in water. Limewater, an aqueous solution of hydrated lime acts as a moderately strong base. It has the ability to react with acids thereby attacking certain metals such as aluminum while passivating the surfaces of other metals like iron to prevent corrosion. Additionally, hydrated lime adopts a polymeric structure, and its commercial production involves processing lime with water (Tom, 2021).

One of the numerous possible bitumen additives used to enhance the characteristics and functionality of asphalt mixtures is hydrated lime. The use of hydrated lime in hot mix asphalt (HMA) offers several advantages, including its ability to control water sensitivity and its widely recognized anti-stripping properties, which help prevent moisture damage.

Asphalt mixtures have long benefited from the addition of hydrated lime, although the precise mechanisms underlying its effects are not entirely understood. Hydrated lime may demonstrate distinctive effects on the damage mechanics and rheology of asphalt mastics due to its unique characteristics.

To regulate oxidative hardness and ageing in asphalt pavements, additional effective treatments or additives still need to be developed. Achieving this requires thorough investigation to improve the understanding of the ageing processes and the factors influencing bitumen ageing in the presence of various fillers, particularly hydrated lime. Therefore, exploring how various fillers and hydrated lime affect the ageing of asphalt mixtures is of significant interest (M.ALfaqawi, 2022).

iii. Bagasse Ash

According to the results of the current experiments, the traditional Ordinary Portland Cement (OPC) filler in Stone Matrix Asphalt (SMA) Mix is replaced by sugarcane bagasse ash (SBA). When the dense-graded mix was filled with SBA, the Marshall Stability value, flow value, and resilience modulus increased by 0.6%, 4.9%, and 17.4%, respectively.

Furthermore, considering its particle size, shape, specific surface area, and chemical makeup, SBA appears to be a superior substitute for traditional OPC filler. Since road construction requires a significant quantity of raw materials, using inexpensive alternatives like sugarcane bagasse ash can be beneficial (P.K.Akarsh, 2022).

iv. Lime Kiln Dust

Lime Kiln dust (LKD) is a byproduct of the lime production process which is generated during the manufacture of quicklime in a lime kiln. It is a fine-grained material that is mainly composed of calciumoxide (Cao) and other minerals and is often used as a supplementary cementitious material in asphalt concrete mixtures. LKD has been shown to improve the adhesion between aggregates and bitumen in asphalt mixtures.

Bala and Albrka (2019) investigated the impact of LKD on the rheological properties of asphalt binders. The authors reported that LKD improved the high-temperature performance and reduced the low-temperature susceptibility of asphalt binders. They suggested that LKD could be used as a sustainable modifier for asphalt.

Stone Matrix Asphalt (SMA) has a limited history of using lime kiln dust (LKD) as a mineral filler. Although LKD satisfies the mineral filler criteria of the majority of agency specifications, some lime kiln dusts with high percentages of accessible lime have been linked to a few instances of early pavement breakdown. Using fundamental tests for the construction of an asphalt mix, this study compared lime kiln dust to a typical rock dust mineral filler (Eyada, 2018).

Since the issue with SMA having LKD with a high accessible lime concentration only arises when the pavement is wet, specimens were treated with a number of freeze-thaw cycles and prolonged soak times to test possible reactions under extreme circumstances. The outcomes demonstrate that the rock dust mineral filler worked equally well or better than the LKD utilized in this investigation (James, 2006).

Several studies have investigated the effect of Lime Kiln Dust on the adhesion between aggregates and bitumen. For example, a study by Al-Abdul-Wahhab et al. (2013) found that the addition of LKD to asphalt mixtures increased the adhesion between the aggregates and bitumen by up to 47%. Another study by Choudhary et al. (2019) found that LKD improved the adhesion between aggregates and bitumen by up to 50%.

2.2.7 Methods used in Quality Control of a Flexible Pavement Design

I. Marshall Mix Design

Bituminous paving mixes are designed and assessed using the Marshall Method of Mix Design, which was developed by Bruce Marshall in the late 1930s for the Mississippi highway department in the United States. A common laboratory technique called Marshall Mix design is utilized worldwide to measure and record the strength and flow properties of bituminous pavement mixes (White, 1985).

This method was used to determine the Optimum Binder Content (OBC) of the mixes and in preparation of a mix design, binder and aggregate are blended together in precise proportions. The relative proportions of these materials determine the physical properties of the asphalt mixture and ultimately how the asphalt mixture performs as a finished pavement.

Mix design can be defined as the process of determining the relative proportions of components in a mixture. Subsequently, various Marshall Characteristics such as Marshall stability (ASTM D6927), flow value, and air voids are studied. Flexibility is assessed in terms of the 'flow value,' which is measured by the change in diameter of the sample in the direction of load application between the start of loading and at the time of maximum load. During loading, a dial gauge measures the specimen's deformation (plastic flow) due to the loading (Parsons T, 2016).

Gradation of Aggregates

Aggregate gradation is a fundamental aspect in the design of asphalt mixtures, influencing crucial characteristics such as stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and moisture susceptibility. The sieve analysis, mixing process, and defined boundaries of the mixture significantly impact gradation, making it the primary concern in mix design (Roberts, 1996).

II. Volumetric Mix Properties

Volumetrics in asphalt mixtures is a vital component of mix design because they greatly influence the performance of the pavement. Mix design aims to determine the volume of bitumen binder and aggregates required to produce a mixture with the desired properties.

Weights are commonly measured due to their ease of measurement and then converted to volume using specific gravities.

Key volumetric properties of bituminous mixtures include the theoretical maximum specific gravity (Gmm), the bulk specific gravity of the mix (Gmb), the percentage of air voids (Va), and the percentage volume of bitumen (Vb).

- **Theoretical Maximum Specific Gravity**

The Theoretical Maximum Specific Gravity (Gmm) was determined following the standardized procedure outlined in ASTM D204. This test enables the calculation of Gmm using Equation 2.1. Additionally, the voids in the mix were determined using Equation 2.2. These parameters provide crucial insights into the compactness and density of the asphalt mixture, essential for evaluating its performance characteristics and ensuring compliance with relevant standards.

$$G_{mm}=\frac{W_a}{W_a-W_w} \qquad \text{Equation 2.1}$$

$$\text{VIM} = 100\frac{G_{mm}-G_{mb}}{G_{mm}} \qquad \text{Equation 2.2}$$

Where; G_{mm} is the theoretical maximum specific gravity (g/cm^3)

Wa is the weight of dry sample in air (g)& Ww is the weight of the sample in water (g), Gmb is the bulk density of the compacted specimen (g/cm^3)

- **Bulk Specific Gravity**

Bulk specific gravity (Gmb) is a crucial parameter obtained by measuring both the total weight and volume of the asphalt mix. It explains why there are air gaps in the mixture, providing a comprehensive representation of its density. Gmb is calculated using Equation 2.3, taking into consideration the weight of the mix and the volume occupied by both the solid aggregates and the voids within the mixture.

$$G_{mb} = \frac{W_{mix}}{\text{Bulk volume of the mix}} \quad \text{Equation 2.3}$$

- **Air Voids**

The small airspaces or pockets of air that exist between the coated aggregate particles in the final compacted asphalt mixture are crucial and closely tied to the mix's performance criteria. The percentage of air voids is determined using Equation 2.4, which quantifies the volume of air within the compacted mixture relative to its total volume. This parameter is essential for assessing the density, durability, and permeability of the asphalt pavement, ensuring its long-term performance and functionality.

$$\%\ \text{Air Voids} = \frac{(G_{mm} - G_{mb}) * 100}{G_{mm}} \quad \text{Equation 2.4}$$

- **Bulk Density**

The determination of bulk density was conducted following the guidelines outlined in ASTM D2726-96. The weight of the compacted specimen was measured after being removed from the mold under three conditions: in air, in water, and at saturated surface dry condition.

Subsequently, the bulk density was calculated using Equation 2.5. This procedure provides valuable information regarding the density and compaction characteristics of the asphalt mixture, aiding in its performance evaluation and quality assurance.

$$G_{mb} = \frac{W_a}{W_{ssd} - W_w} \quad \text{Equation 2.5}$$

Where; G_{mb} is the bulk density of the compacted specimen (g/cm^3)

W_a is the weight of specimen in air (g)

W_{ssd} is the weight of the saturated surface dry specimen (g)

W_w is the weight of the specimen submerged in water (g)

- **Voids in Mineral Aggregate (VMA) and Voids Filled with Bitumen (VFB)**

VMA, or Voids in Mineral Aggregate, represents the volume of air space between the coated aggregate particles in the asphalt mixture. VFB, or Voids Filled with Bitumen, denotes the volume occupied by the effective bitumen within the mixture. Both VMA and VFB are expressed as a percentage by weight of the total mix and were calculated using Equations 2.6 and 2.7 respectively. These parameters are vital for assessing the compactness, durability, and performance of the asphalt mixture, aiding in its design and quality control processes (Sulyman, 2019).

$$VMA = 100 - \frac{G_{mb} P_s}{G_{sb}} \quad \text{Equation 2.6}$$

$$VFB = 100 \frac{VMA - VIM}{VMA} \quad \text{Equation 2.7}$$

Where; G_{sb} is the Bulk specific gravity of the total aggregates

P_s is the Aggregate content by weight of mix

2.2.7 Design for the traffic loading

The number of load cycles, pavement structural capacity, and performance as assessed by serviceability are all correlated according to the AASHTO standards. Some designs require annual traffic loading for example the road for this study of Kampala Masaka road with high traffic volumes with current estimates at 54 MESA compared to the projected 44.1 MESA (Moses, 2022).

Therefore, by multiplying the total daily traffic loading (ESA/ day) values by 365, the annual traffic loading for each direction is obtained. This figure is normally presented as millions of equivalent standard axles per year (MESA/year) for each direction.

The larger of the two directional values should be used for pavement design purposes (MoWT, 2010).

Table 2. 6: Traffic data of kampala-Masaka section

Vehicle type	Average EF per vehicle
Light Single Unit Truck/Large Bus/Medium Single Unit Truck	3.0 MESA
Medium- Large Single Unit Trucks – 3 and 4 axles	17.1 MESA
Heavy Trucks & Trailer or Heavy Truck & Semi Trailer (More than 5 axles)	33.9 MESA
Total Cumulative ESA	54.0 MESA

$$\text{Equivalence factor, EF} = \left[\frac{\text{axle load (in tonnes)}}{8.16}\right]^{4.5} \qquad \text{Equation 2.8}$$

From the study and analysis of traffic data for the section of Kampala – Masaka road, the total traffic (AADT) on the road was 6226 representing an increase from the design AADT hence the need for improvement in the design parameters as regards to strength performance and fatigue response of the asphalt pavement (Moses, 2022).

CHAPTER THREE: METHODOLOGY

3.1 Research Design

The research design involved qualitative, quantitative and majorly experimental methods that aided to investigate to use of Lime Kiln Dust as a mineral filler in asphalt concrete through sample collection, laboratory tests and analysis which can be seen in Figure 3.1.

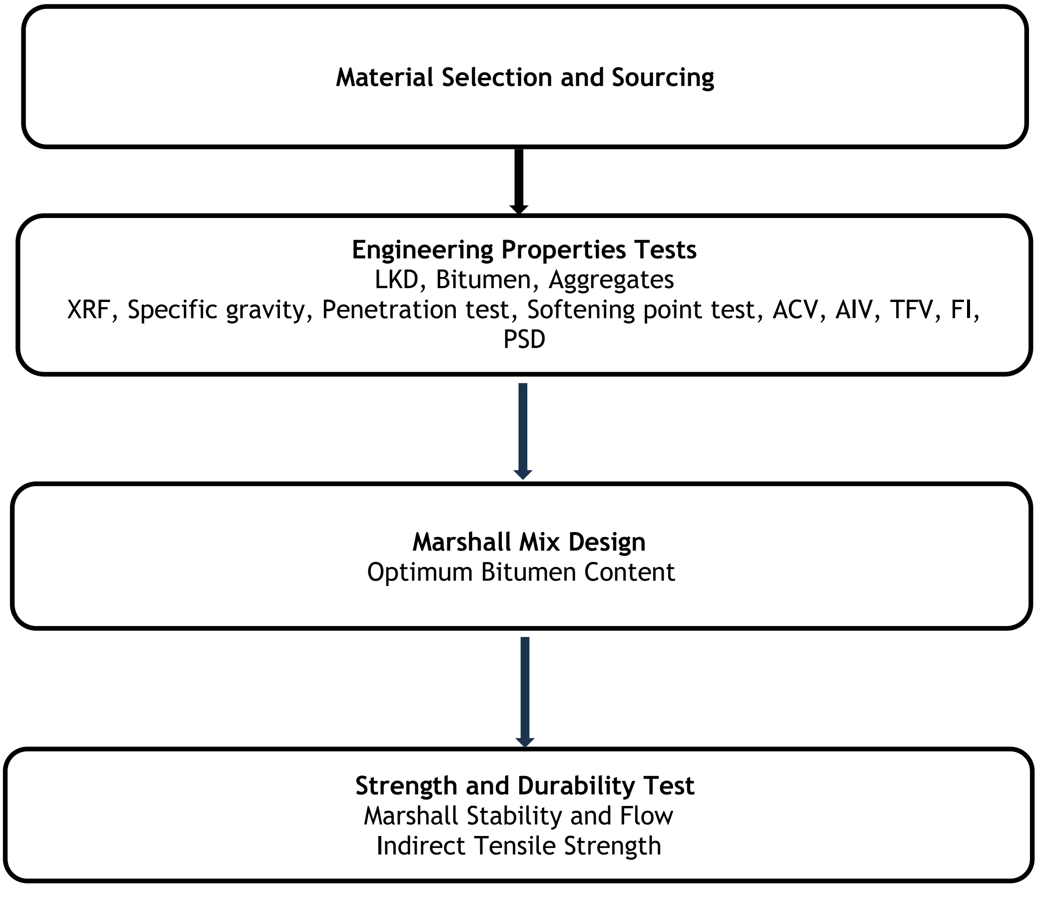

Figure 3. 1:Flow chart of methodology steps

3.1 Material Selection and Sourcing

a) Bitumen

The grade of bitumen used in the study was 60/70, which is commonly utilized worldwide. This material was sourced from Stirling Road Construction Company, located in Mbalala along Kampala Jinja Road.

b) Aggregates

The aggregates used were provided by Stirling Laboratory and were of AC-14 grade, indicating different sizes of aggregates used in the mix. These sizes include 14-20 mm, 10-14 mm, 6-10 mm, and 0-6 mm in gradation, with varying percentages in the mix design. The nominal size of aggregates is 14 mm.

c) Filler

Lime Kiln dust was sourced from Hima Cement Limited, located in the heart of Namanve Park near Namilyango, Uganda. The material was sieved to ensure that it passed through the #200 sieve fraction.

Figure 3. 2:Materials collection

3.2 Primary data collection methods

3.2.1 Aggregate Crushing Value (ACV)

The Aggregate Crushing Value (ACV) served as a means to assess the relative resistance of an aggregate to crushing under a gradually applied load, providing insight into the strength of coarse aggregates. Weak aggregates could potentially compromise the integrity of the pavement structure.

Test Standard - BS 812: Part 110: 1990

3.2.2 Aggregate Impact Value (AIV)

The Aggregate Impact Value (AIV) was used to obtain a relative measure of the resistance of different aggregate to sudden distortions. Its significance was to determine the mechanical properties of the individual aggregates, which, in turn, impacted the mix design.

Test Standard - BS812: Part 112: 1990.

3.2.3 Ten Percent Fine Value (TFV)

The Ten Percent Fines Value (TFV) test was used to assess the resistance of an aggregate to crushing under a gradually applied load. The TFV was intended to determine the load necessary to crush a prepared aggregate sample to yield 10% of material passing a specified sieve after crushing.

Test Standard - BS 812: Part 111: 1990.

3.2.4 Flakiness Index

Aggregates were categorized using the Flakiness Index, with certain standards established for the materials' flakiness index. Flaky particles were considered undesirable since they could be weak by nature and break easily under strong loads, especially when used as base course and in coarse aggregates. When an aggregate's thickness was less than 60% of the average sieve size, it was categorized as flaky.

Test Standard - BS 812-P105:1-1989

3.2.5 Particle Size Distribution

Particle size distribution test served as the classification test for soils, enabling the determination of relative proportions of various particle sizes. This method allowed for the identification of soil components such as sand, clay, gravel, and others. The sample was first prepared by wet sifting to remove clay and silt-sized particles, and then the residual coarse material was sieved dry.

Test Standard BS 812-P103-1

3.2.6 Specific Gravity

Specific gravity was used to ascertain the water absorption of aggregates and filler materials. This value served as an indicator of the strength of the materials, allowing for comparison with other materials. A high specific gravity confirmed the suitability of the filler and aggregates as good materials.

Test Standard - BS 812 Part 2:1975.

3.2.7 X-Ray Fluorescence

This standard outlined guidelines for developing and describing analytical procedures employing a wavelength dispersive X-ray spectrometer for elemental analysis of solid metals and associated materials. The method aimed to determine the chemical composition of the Lime Kiln Dust mineral filler.

Test Standard - ASTM E1621-22

3.2.8 Softening Point Test

The Softening Point test served as a means to evaluate the consistency of bitumen, indicating the temperature at which the transition from solid to liquid phase occurred, especially for bitumen of grade 60/70. This data played a crucial role in assessing temperature susceptibility, a key factor in asphalt design.

Test Standard - ASTM D36

3.2.9 Penetration Test

The standard penetration test was conducted using an Analis Penetrometer P734 on base bitumen. This test aimed to ascertain the hardness and softness of the bitumen by measuring its resistance to flow. The desired penetration grade for this test was 60/70, which was successfully achieved.

Test Standard - ASTM D5-86

3.2.10 Marshall Mix Design

Bituminous paving mixes were formulated and evaluated employing the Marshall method of mix design. This method made it possible to measure the physical characteristics of asphalt specimens, especially those that had to do with the asphalt mixtures' plastic deformation qualities. Samples comprising aggregates, filler, and binder were combined to form specimens, which were then compacted to assess air voids, stability, and flow under various conditions as shown in Figure 3.3. The mix design process was utilized and the optimal bitumen content was determined for the mix since it was crucial for achieving resistance to rutting and shearing stress. The mix design facilitated the calculation of the appropriate amount of bitumen for maximum stability, flow, density, and voids.

Test Standard - ASTM D1559

3.2.11 Bulk Specific Gravity

Specific gravity served as the method for determining the bulk specific gravity of asphalt as well as its water absorption rate. This procedure was instrumental in identifying cores with either high or low voids, thereby aiding in the selection of specimens eligible for Marshall stability or Indirect
tensile strength testing.

Test Standard - ASTM D2726

Table 3. 1:Specimen selection conditions

Void content in the specimens which should range between (3 -7)
VMA should be >15
VFB should be between (65-78)

3.2.12 Maximum Specific Gravity(Gmm)

The determination of the theoretical maximum specific gravity (Gmm) of the mix was conducted focusing on uncompacted bituminous paving mixtures. This procedure played a vital role in ensuring the quality assurance of asphalt specimens.

Test Standard - ASTM D2041

3.2.13 Marshall Stability Test

The Marshall stability test served as the method for determining the maximum load necessary to induce failure when subjecting the specimen to a specific amount of heat. Additionally, it facilitated the measurement of load and flow rate of asphalt specimens and the procedure was key for evaluating the strength of the asphalt under traffic conditions.

Test Standard – ASTM D6927

Table 3. 2:Key parameters recorded

Mixing temperature (˚C),	Number of blows during compaction	Flow value (1/10 mm)
Compacting temperature (˚C),	Height of test specimen to the closest 0.1 mm	Temperature of cores at testing (˚C)
Maximum load value (N)		

3.2.14 ITS (Indirect Tensile Strength)

The test was used to ascertain the indirect tensile strength and E-modulus of bituminous mixes. These results held significance in assessing the materials' relative strength and quality as well as how they are used in the analysis, evaluation, and design of pavements. The maximum load attained during the test was meticulously recorded and utilized to compute the indirect tensile strength. Furthermore, alternate hot and cold conditions as seen Figure 3.3, were imposed to assess pavement strength and durability.

Test Standard - ASTM D3967.

Flow chart for the Asphalt conditions

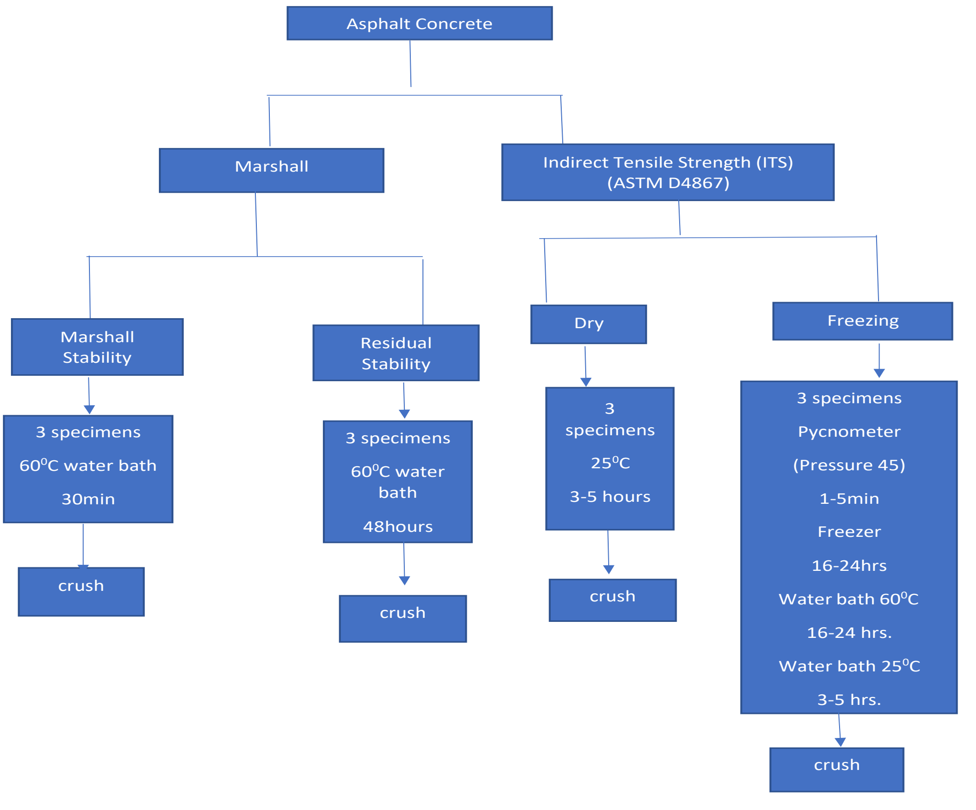

Figure 3. 3:Flow chart of Asphalt tests

3.3 Secondary data collection

The Secondary data of the chemical composition of Lime Kiln Dust was collected from published books and journals to help clarify results obtained in the laboratory for specified range.

CHAPTER FOUR : RESULTS AND DISCUSSION

This chapter shows the results from the tests carried out in this study. The data was analyzed, discussed and represented as per the results from tests to investigate use of Lime Kiln Dust as a Filler in Asphalt Concrete for Durable Flexible Pavements.

4.1 Aggregate Crushing Value Test Results (ACV)

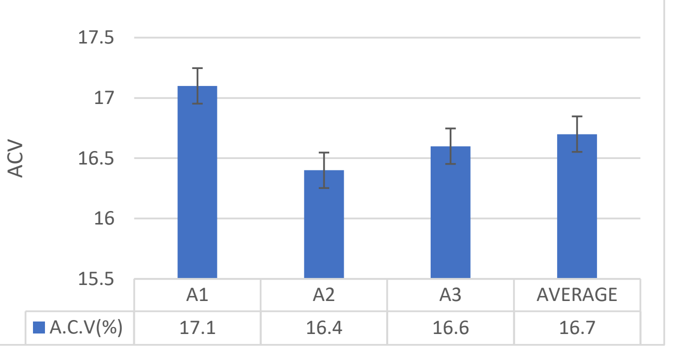

Figure 4. 1:Aggregate Crushing Value graph

The average ACV value was 16.7% as shown in Figure 4.1 which is less than 30% according to the specification BS PART 110:1990 .This implies that they lie within range and that the aggregates used had enough strength to resist crushing under a compressive and traffic load hence it was suitable to be used in the asphalt mix design.

4.2 Aggregate Impact Value Test Results (AIV)

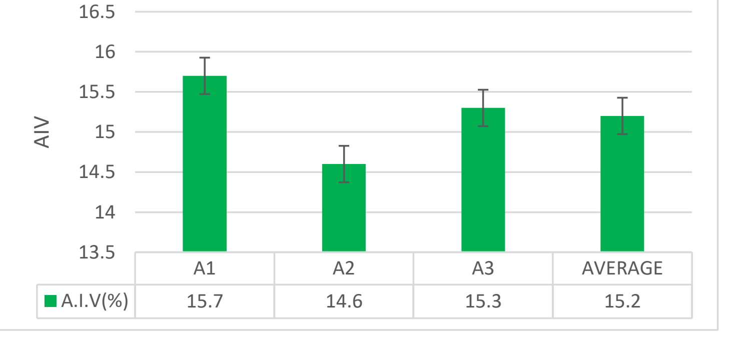

Figure 4. 2:A graph of AIV results

The average of the aggregate Impact Value was 15.2% as seen in Figure 4.2 which is less than 30% according to BS 812PART 110:1990 specification. This implies that they were within permissible limits and aggregates used had strong resistance to sudden shock or impact and hence suitable to be used in the study.

4.3 Ten Percent Fine Value Test Results

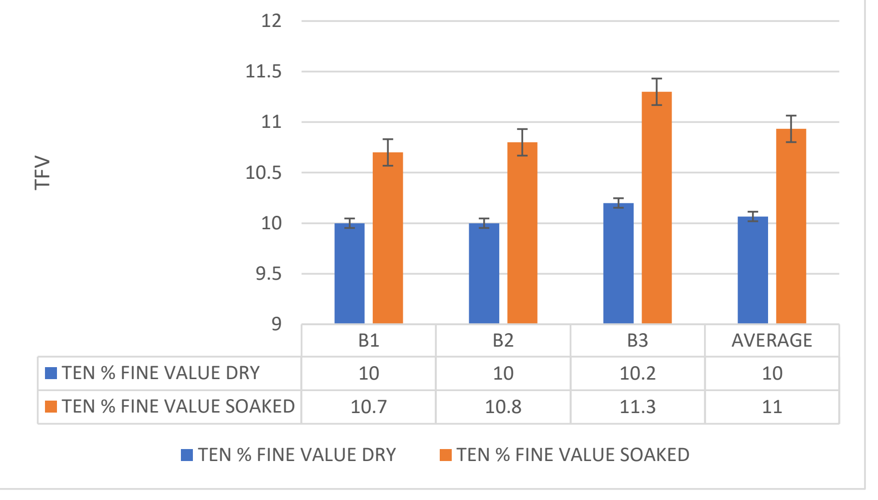

Figure 4. 3:combined Ten percent fine value graph

The TFV Dry obtained was 10KN and the TFV Soaked was 11KN as shown in Figure 4.3 with the maximum force applied to the aggregates of 262.3KN and 246.4KN. According to BS 812: Part 111:1990 specification, force of Ten Percent Fines Value wet/dry is greater than 75% and since the percentage obtained was greater with 94%. This implies that the aggregates were tough to resist crushing under traffic loads and suitable to be used in the mix design.

4.4 Specific Gravity and Water Absorption

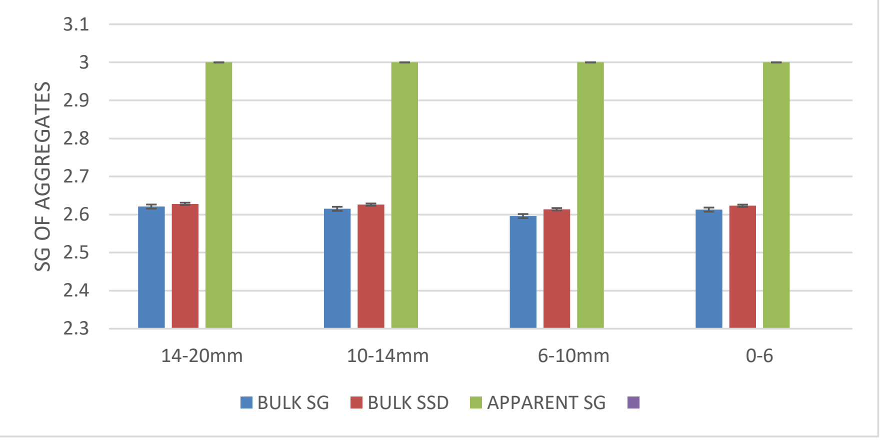

Figure 4. 4:specific gravity proportions of different aggregate sizes

The average value of the combined specific gravity was 2.608 in Figure 4.4 which was in range of 2.5 -3.0 according to ASTM C128 specification. This implies that the aggregates showed a low porosity, high strength and high durability of the aggregates which was suitable for the research.

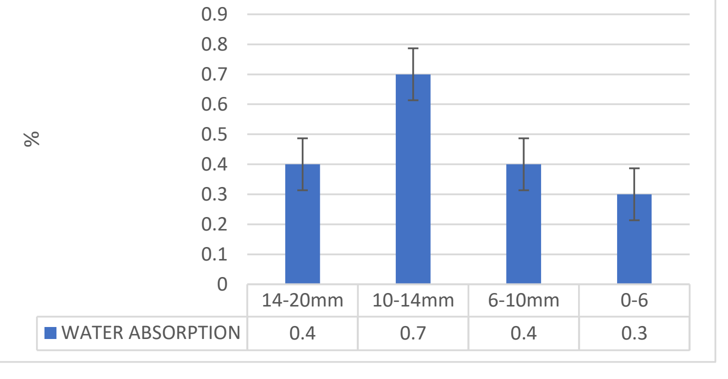

Figure 4. 5:water absorption graph

The average value of water absorption was 0.4% in Figure 4.5 which is with is less than 0.6% according to ASTM C128 specification. This implies that the aggregates had a low water absorption and high strength that made them suitable for use in the study.

4.5 Flakiness Index

The flakiness index value was 16.1% in Table 4.1 which must not exceed 25% according to BS 812: Section 105.1:1989. This implies that the aggregates were strong and not flaky that made them suitable for surfacing of pavements.

Table 4. 1:Flakiness Index results

BS sieve size (mm)	20mm	14mm	10mm	Total
weight retained gm	-	-	124.5	124.5
Riffled weight gm	-	-	124.5	-
Correction factor a/b	-	-	1	-
Wt. Passing sieve gm	-	-	20	-
Wt. Retained on sieve gm	-	42.5	104.5	-
Corrected Wt. passing (dxc)	-	-	20	20
%Retained	-	3.2	9.4	-

4.6 Penetration Test of Bitumen

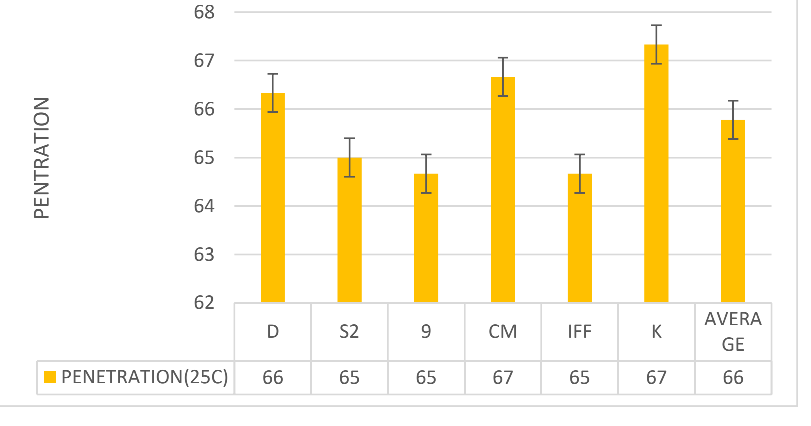

Figure 4. 6:penetration test result graph

The average value of the penetration test was 66mm in Figure 4.6 which is within range 0f 60-70 according to ASTM D5 specification. This implies the bitumen grade of 60/70 was suitable in terms of the hardness and consistency of the mix for the tropical regions as it provided more durability and stability.

4.7 Softening Point of Bitumen

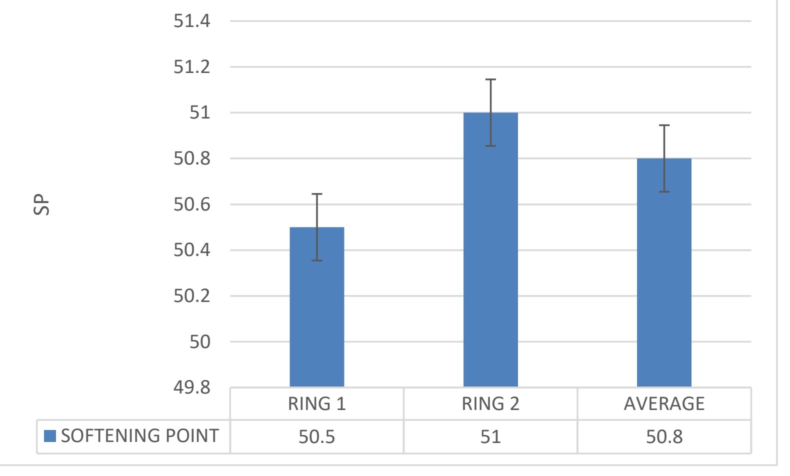

Figure 4. 7:softening point graph

The average value of softening point was 50.8 °C in Figure 4.7 which is within range of 49-56 ºC according to the ASTM D36 specification .The value obtained gave the temperature at which bitumen becomes soft enough to allow the steel ball to sink at specified distance. This implies that the bitumen used gave a high temperature susceptibility which was favourable for design.

4.8 Specific Gravity of Bitumen

The average value obtained was 1.028 in Figure 4.8 which is within range of 1.01-1.06 according to ASTM D70 specification . This implies that the density of bitumen used gave proper homogeneity and coating of the asphalt mix with the right proportions in the mix design.

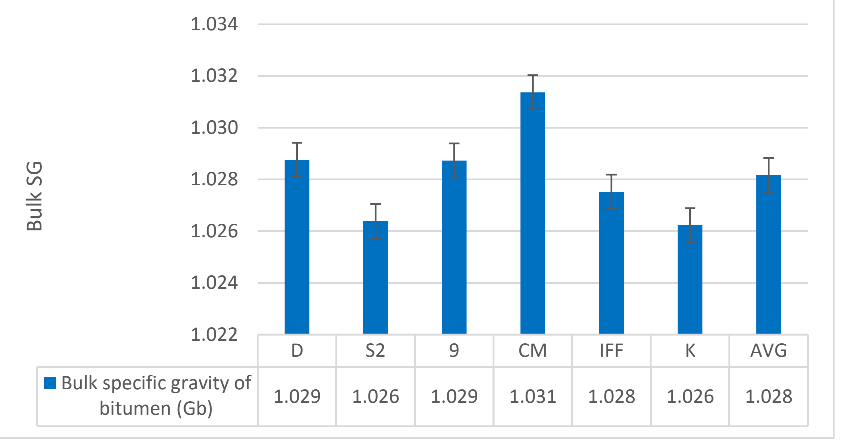

Figure 4. 8:Bulk Specific gravity of bitumen

4.9 Chemical Composition of Filler

Several tests were conducted to examine the chemical and physical properties of Lime Kiln Dust. Table 4.10 shows the chemical composition of lime kiln dust obtained from XRF-Spectrometer analysis. The test results revealed that the investigated major elements of lime kiln dust were Cao and SiO_2 and loss of ignition as a safety measure.

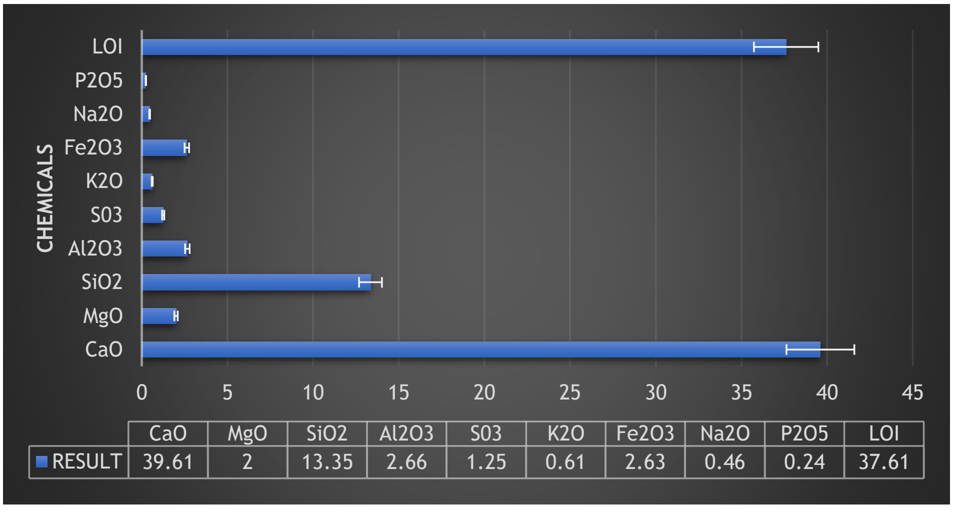

Figure 4. 9: Chemical composition of LKD

The chemical composition Lime Kiln Dust showed the right proportions of chemical elements with majorly Cao-39.61 and SiO2-13.35 as seen in Figure 4.9, which have been shown to improve the adhesion and bonding between aggregates and bitumen (Moser, 2015). A study by Golam showed that addition of SiO2 increases the rutting resistance of mixture by approximately 100%, increases the fatigue life of bitumen samples and improves the tensile strength of asphalt pavement (Gholam, 2020)

4.10 Specific Gravity for the Filler

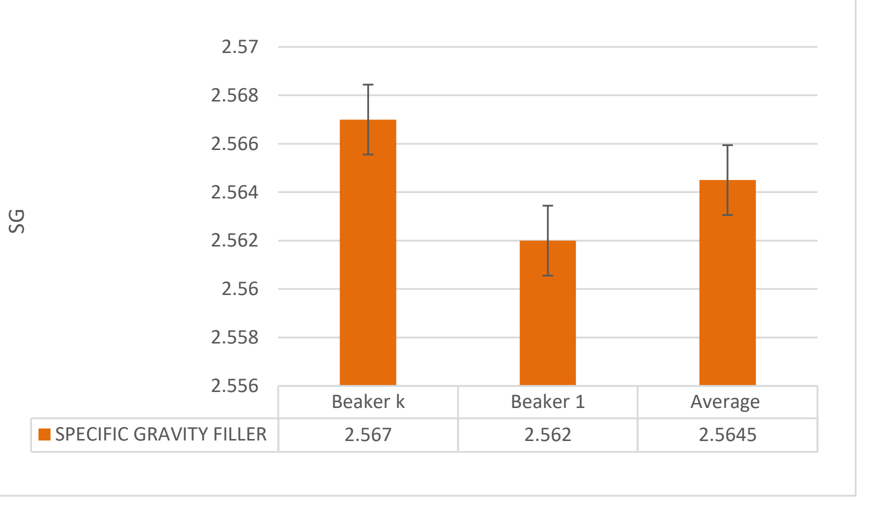

Figure 4. 10:lime kiln dust specific gravity graph

The average value of specific gravity was 2.564 as shown in Figure 4.10 which lies within the standard range of 2.4-3.0 according to AASHTO T100-95(1995) specification. This implies that the filler is fit to be used in the asphalt mix and this had a positive impact on the stability and volumetric properties of the mix and there was suitable to be used in the study.

4.11 Job Mix Formula Test Results

Figure 4.11 shows the particle size distribution of the individual grading of the Asphalt mix (Asphalt concrete 14) using the try and error method so as to obtain the different percentages of the aggregates and filler so that the mix design fits between the upper and lower limits of the gradation curve (target grading). The AC 14 mix composed of different sizes of aggregates to begin with the passing 20mm and retained on 14mm, 10/14, 6/10 and then filler of 4%. Figure 4.11 also represents the AC 14 individual gradation and shows that the grading lies between specified grading envelopes of both the upper and lower limits according to (MoWT ,2010) hence the distribution of the aggregates achieved a proper mechanical adhesion of aggregates which positively affects the durability of the mixture.

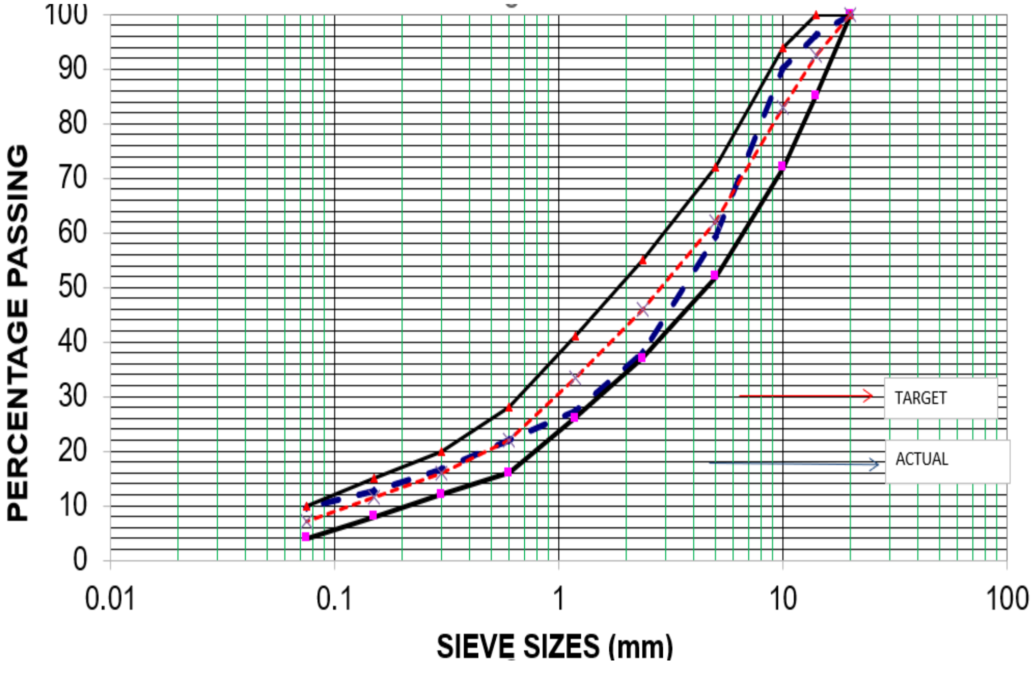

Figure 4. 11:combined grading curve

4.12 Marshall Mix design to Determine Optimum Bitumen Content

Table 4. 2:Performance of different bitumen percentages according to AC 14

BITUMEN%	3.5	4	4.5	5	5.5	6
DENSITY	2.33	2.336	2.365	2.386	2.372	2.368
STABILITY	7.1	13	15.5	15.4	13.8	12.1
FLOW	2.63	2.45	2.6	2.8	3.2	3.5
VOIDS	6.8	5.7	4.7	4.3	2.3	1.2

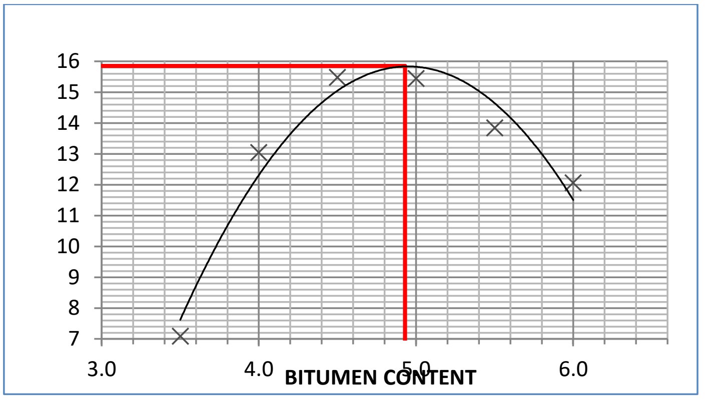

Figure 4. 12:Graph of air voids against bitumen content

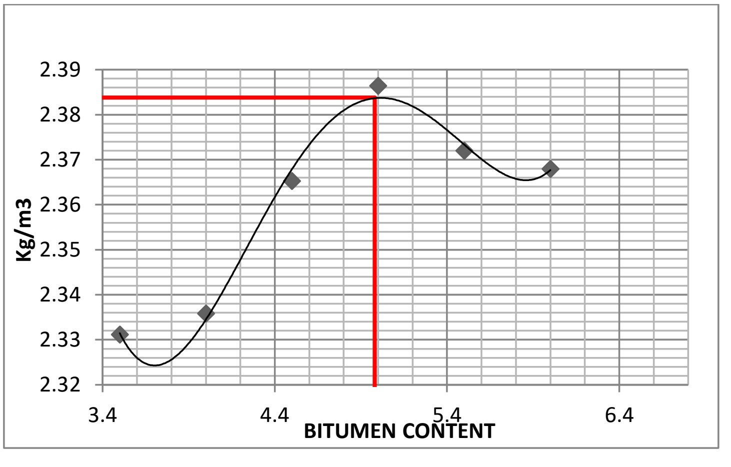

Figure 4. 13:Graph Density against bitumen content

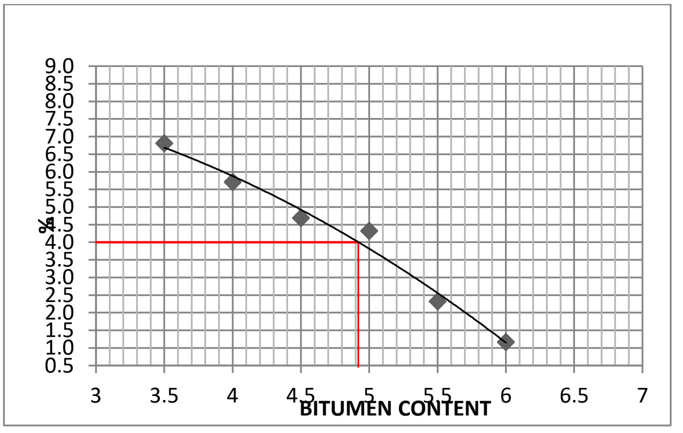

Figure 4. 14:Graph of voids against bitumen content

The optimum bitumen content was obtained using the Marshall Mix Design. Different mixes were made with varying bitumen content of ±0.5 to obtain three Marshall cores and two samples for Gmm for each mix. The varying mixtures were tested to obtain density, stability, voids, flow as seen in Table 4.2 and graphs were plotted as seen with Figure 4.12, 4.13, 4.14 to obtain the Optimum Bitumen Content. The Optimum for stability 4.9% and density 5% was obtained at maximum, at 4% voids the bitumen content of 4.9% obtained and for the flow at optimum so that our bitumen was not too brittle or too liquid to cause bleeding of the asphalt mix according to (MoWT,2010).

Table 4. 3:Determining the Optimum Bitumen Content

OPTIMUM BITUMEN	
Stability	4.90%
Density	5.00%
Voids	4.90%
Average	4.90%

The average of the optimum bitumen content for the asphalt mixture was obtained as 4.9% from the stability, density and voids calculations as seen in Table 4.3 . This is the percentage that was considered for bitumen in the Research Design.

4.13 Asphalt Design Mix Proportions

Table 4. 4:AC 14 conventional asphalt design mix

Asphalt Material Composition	Aggregate Blending Proportions (By mass)	Percentage Composition Asphalt Concrete (%)	Mass in the mix (g)
BITUMEN	_	4.9	882
14/20mm	5	4.8	856
10/14mm	7	6.7	1198
6/10mm	15	14.3	2568
0/6mm	*69*	65.6	11811
FILLER	4	3.8	685
TOTAL	100	100	18000

The Table 4.4 shows the mix proportions of the asphalt mixture used in the mixture with 4% of lime kiln dust filler. After the 4.9% Optimum Bitumen Content was obtained, the remaining percentage of 100 was divided to other aggregate sizes and filler and the mass in mix was obtained from(%Asphalt concrete x Total mass of mix) .The total mass of mix was 18kg for the asphalt mix design.

4.14 Performance Tests for Asphalt

Table 4. 5:Summary of Marshall Mix Results

BITUMEN CONTENT	4.9		
Marshall Mix Test Results	Neat asphalt mix with Stone Dust	4% Lime Kiln Dust asphalt mix	Specification (MoWT, 2010)
Marshall Flow (mm)	2.8mm	3.5mm	2-4mm
Marshall Stability (75blows)	14.8KN	17.1KN	9-18 KN
Marshall Air Voids (75blows)	4.9%	4.9%	3-5%
Voids in Mineral Aggregates	15.1%	15.1%	>15%
Voids Filled with Binder	67.7%	67.3%	65-75%
Indirect Tensile Strength @ 25C	1011kPa	1086kPa	>800kPa
Indirect Tensile Strength Wet Strength	90%	81%	>80% of dry

Marshall Stability

The Marshall stability value (Fig 4.15) increased by 2.3kN, rising from 14.8kN with neat asphalt stone dust to 17.1kN with lime Kiln dust filler. This enhancement signifies an overall improvement in the structural integrity of the pavement, which contributes to its long-term durability. Higher stability indicates improved resistance of the asphalt concrete to rutting, thereby verifying the performance and durability of the asphalt mixture. This improvement is attributed to enhanced adhesion between the aggregates and the bitumen, resulting in a more robust pavement that can better withstand the stresses of traffic loading.

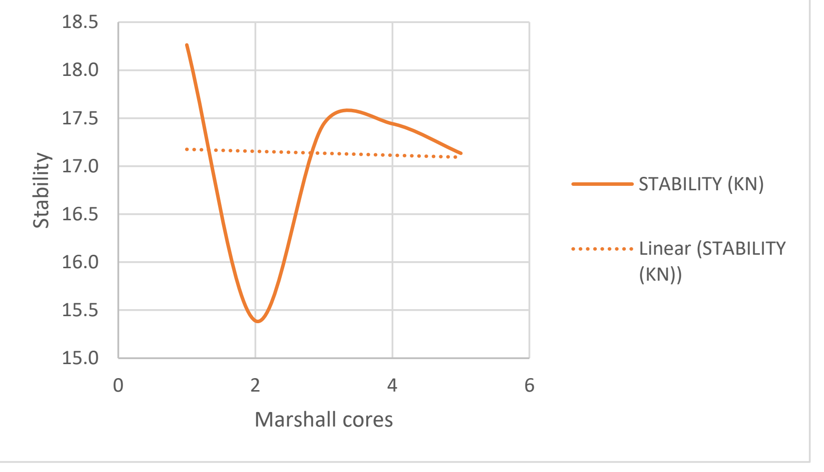

Figure 4. 15:AC14&LKD - Stability

Marshall Flow

The flow value (Fig 4.16) increased by 0.7mm when using lime kiln dust filler compared to stone dust filler (from 2.8mm to 3.5mm). The flow value is a measure of plasticity and deformation in Hot Mix Asphalt under repetitive loading Higher flow values signify enhanced flexibility and resistance to cracking, particularly at high temperatures. This improvement ensures proper compaction, enhancing the durability of asphalt pavement by reducing water infiltration.

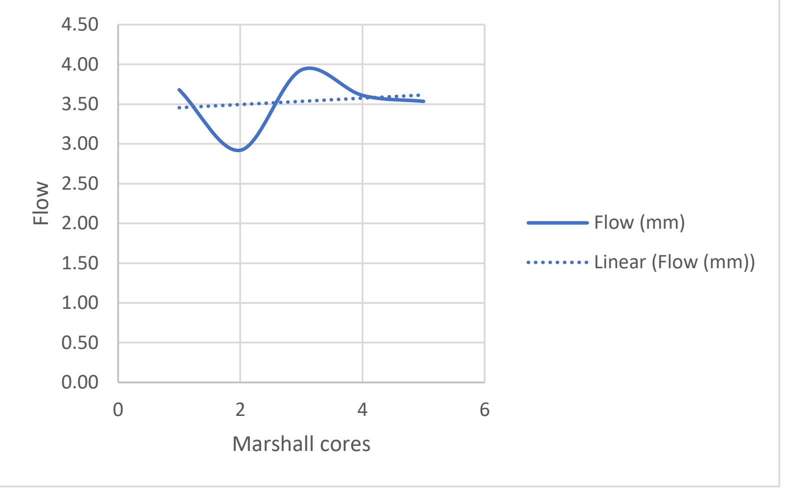

Figure 4. 16:AC 14& LKD- flow

Air Voids

The average value of air voids (Fig 4.17) in the pavement was measured at 4.9%, falling within the specified range of 3-5%. This indicates that the voids are appropriately controlled, which enhances the integrity of the pavement structure and extends its service life. Properly managed air voids are crucial for the durability of flexible pavements.

Excessive air voids can lead to permeability problems and cause damage from freeze-thaw cycles, oxidation, and moisture-related issues. On the other hand, insufficient air voids can result in inadequate coverage of asphalt binder and reduced flexibility, increasing the risk of cracking and rutting deformation. Therefore, maintaining air voids within the specified range is essential for ensuring pavement performance and longevity.

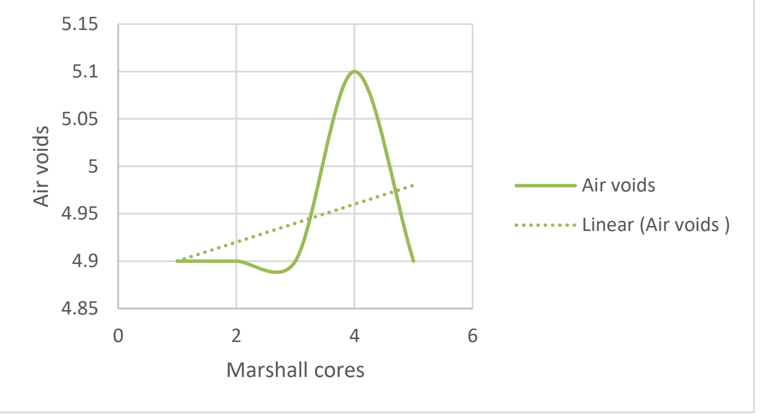

Figure 4. 17:AC14&LKD- Air voids

Voids in Mineral Aggregates (VMA)

The VMA value (Fig 4.18) measured at 15.1% falls within the specified range, indicating it exceeds the minimum requirement of 15%. This suggests that there are adequate voids present for the proper coating of aggregates by asphalt binder, enhancing resistance to moisture damage and promoting greater durability. A higher VMA facilitates better interlocking of particles within the asphalt mixture, thereby improving its resistance to deformation and rutting. This ultimately leads to a more stable and durable pavement surface capable of withstanding traffic loads and environmental stresses over time.

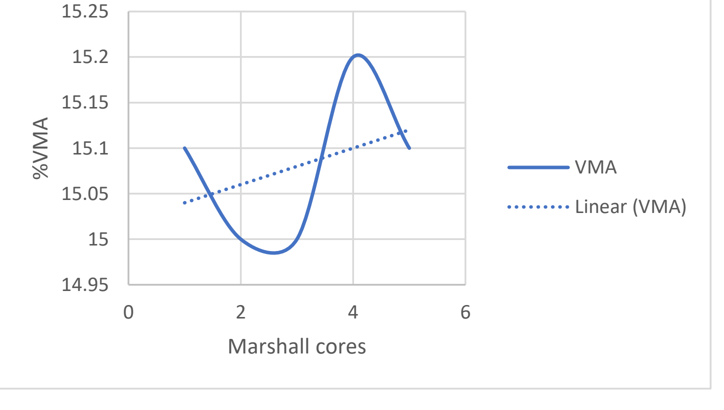

Figure 4. 18: AC14 & LKD- VMA

Voids Filled with Bitumen (VFB)

The value of VFB (Fig 4.19) measured at 67.3% falls within the specified range of 65-75%. This indicates that the mixture was adequately filled with voids, ensuring sufficient asphalt binder content and facilitating proper compaction.

A higher VFB promotes better cohesion and adhesion between aggregate particles, thereby enhancing the overall strength and durability of the pavement structure. This ensures that the pavement can withstand traffic loads and environmental stresses more effectively over its lifespan.

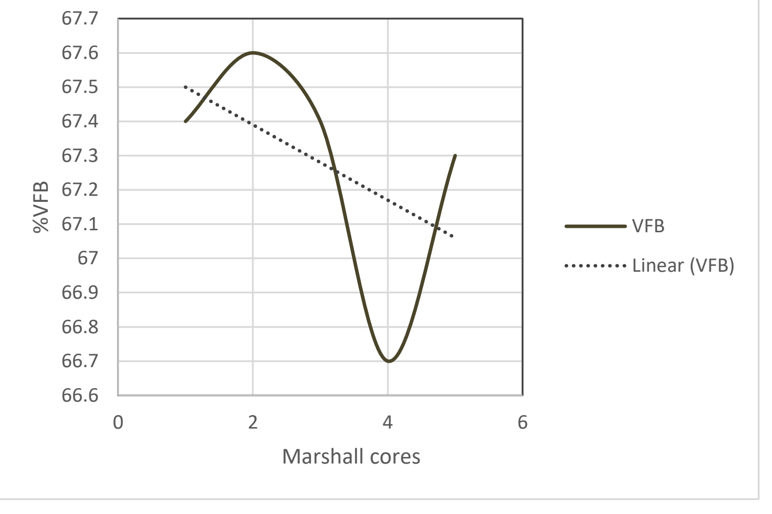

Figure 4. 19:AC14 & LKD- VFB

4.15 Indirect Tensile Strength (ITS)

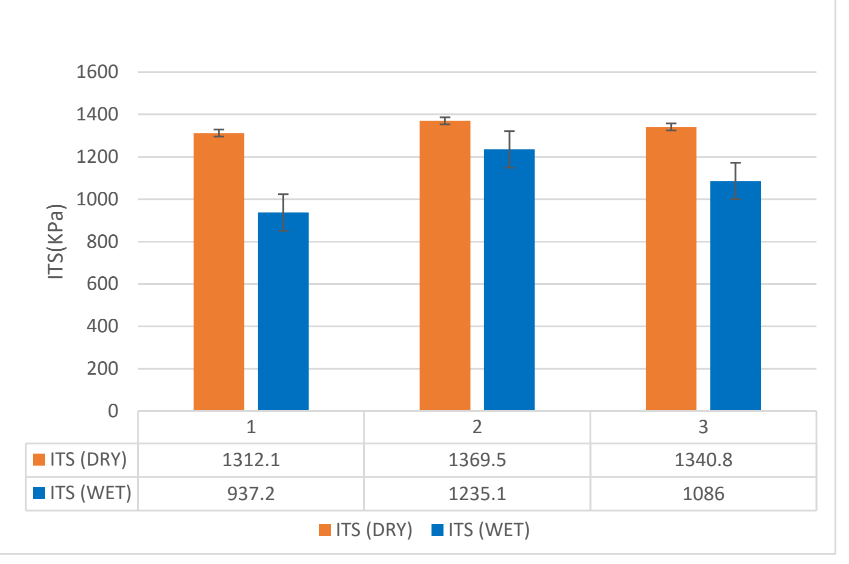

Figure 4. 20:ITS results both dry and wet

The Indirect Tensile Strength obtained are summarized in the Figure 4.20 and detailed in the annex. The Indirect Tensile Strength (ITS) results, summarized in Figure 4.20 and detailed in the annex, show promising performance indicators.

The average ITS (dry) value of 1086 kPa exceeds that of the neat asphalt filler (1011 kPa) and falls within the specification of (>800kPa) according (MoWT,2010). This suggests that the Asphalt Concrete mixture exhibits superior stiffness and strength resistance under traffic loading.

Furthermore, the average ITS (wet) value of 81% surpasses the 80% threshold of dry strength. This indicates high resilience to moisture damage, as improved tensile strength helps deter crack formation and delays the onset of pavement distress such as cracking and fatigue failure. Consequently, these findings contribute to enhancing the overall Durability of the Pavement Structure.

CHAPTER FIVE : CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study focused on the use of lime kiln dust as a filler in asphalt concrete for durable flexible pavements. The main objective of this study was to investigate the use of lime kiln dust to improve the stiffness and durability of flexible pavements. It was achieved through the following methods; Aggregate Crushing Value (ACV) test, Flakiness Index, Aggregate Impact Value (AIV) test, Ten Percent Fines Value (TFV) test, specific gravity, water absorption test, x-ray fluorescence, softening point test, penetration test which were to determine the engineering properties of lime Kiln dust, bitumen and aggregates. The second method was the Marshall Mix Design and which was used to determine the optimum bitumen content to be used in the mix and volumetric properties of the asphalt with lime kiln dust were determined in comparison to neat asphalt mixture with Stone dust.

The Indirect Tensile Strength was carried out to determine the stiffness and durability properties of asphalt mixtures with lime kiln dust filler in comparison to neat asphalt mixture of stone dust filler. From the study, it was concluded that;

1) Engineering properties of lime kiln dust, aggregates and bitumen; The X- ray fluorescence that provided the chemical composition of the filler with majorly Cao-39.61% and SiO2-13.35% which showed to improve the adhesion between bitumen and aggregates. The specific gravity of LKD-2.564 was also greater than most fillers like slaked lime of 2.342. The TFV-(Dry 262.3KN and Soaked 246.4KN), AIV-15.2%, Water absorption-0.4, FI-16.1%, SG-2.698, ACV-16.7%. Grading was all in the specified range and showed that aggregates were strong enough to be used in the study with the actual grading also being within the target grading envelope for a

firm mix. The bitumen properties of penetration 66mm , softening point-50.8°C and specific gravity-1.03 were all within the specification range to be used in the asphalt mix design.

2) The optimum bitumen content obtained was 4.9% with incorporation of 4% lime kiln dust filler and the Marshall cores were tested for parameters of stability, flow, air voids and density. There was a reduction in the air voids from 5.7% to 4.9% hence improving the adhesion and providing a higher stiffness of the mix addressing factors like durability.

3) There was improvement in the Marshall stability from 14.8KN of the neat asphalt mixture to 17.1KN of the asphalt mix with lime kiln dust as a filler. This value of 17.1KN indicates that the asphalt mix will be stable and resistant to deformation or rutting under varying heavy traffic loads hence improving durability of asphalt pavement.

5.2 Recommendations

5.2.1 Recommendations Based on Conclusions

Based on the findings from this study,

1) The mix proportions of the asphalt mixture involve an incorporation of 4% of lime kiln dust filler so as to fit well into the grading envelope for proper mix design.

2) The different aggregate sizes were 14/20, 10/14, 6/10, 0/6 and filler material for Asphalt Concrete 14 mix design for wearing course.

3) Consider a batch total mass of the mix of 18000g, 882g of Bitumen, 856g of 14/20, 1198g of 10/14, 2568g of 6/10, 11811g of 0/6, 685g of LKD filler.

5.2.2 Recommendations for Future Studies

1) Studies should be carried out on the effect of lime kiln dust as a filler in different types of asphalt concrete to assess the performances of the asphalt pavements.

2) The effect of the temperature on the storage of filler material should be investigated as it influences the fatigue response.

3) The cost of the whole process should be analyzed with cost benefit analysis. This is to determine the economic feasibility with incorporation of LKD than common fillers.

4) The effect of additives or modifications as partial replacement to further enhance the performance characteristics of asphalt mixtures containing lime kiln dust, such as improving rut resistance, fatigue life, and moisture susceptibility.

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APPENDIX

Figure 1:Aggregate collection

Figure 2: Sieve Analysis

Figure 3:Different sieze aggregate proportions

Figure 4:Riffling Process

Figure 5:Weighing of aggregates

Figure 6:Final mix by mass of mix design

Figure 7:Mixing of AC 14 with filler

Figure 8:Compaction of Marshall cores

Figure 9: Placing of asphalt in moulds

Figure 10:compacted Marshall cores

Figure 11:Lime Kiln Dust Oven dried sample

Figure 12: Marshall and ITS Testing

ANNEXS

ANNEX A – Engineering Properties of Lime Kiln Dust, Bitumen, Aggregates

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling
PROJECT:	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

SPECIFIC GRAVITY FILLER (AASHTO T100-95 (1995))

LOCATION: Mukono Lab	OPERATOR:
SAMPLE No	SAMPLE DATE: 1/15/2024
TYPE: KILN LIME DUST	TESTING DATE: 1/17/2024

	Beaker K		Beaker 1
[A) Wt. OVEN dry sample (gm	453.44		449.19
[B) Wt. of Pycnometer containing water alone (gm)	1805.95		1768.72
[C] Wt of Pyconometer containing Sample and water (	2082.72		2042.56
SPECIFIC GRAVITY OF FILLER $\frac{A}{A+(B-C)}$	2.567		2.562
AVERAGE	2.564		

FOR TESTING LAB

Lab Technician

STIRLING CIVIL ENGINEERING LTD
JAN 2024
P. O. BOX 795, KAMPALA (U)

Materials Engineer

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling
PROJECT:	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

DETERMINATION OF AGGRGATE'S 10% FINES VALUE DRY AND SOAKED

(BS 812PART 111:112:1990)

LOCATION:	Lab	OPERATOR	
		DATE SAMPLED	15 January 2024
MATERIAL DESCRIPTION:	AGGREGATES FOR ASPHALT	DATE TESTED	16 January 2024

10% FINE VALUE DRY

TEST NO	1	2	3
CRUSHING FORCE (KN)	263	263	263
WT. OF AGGREG (gm)after crushing (M1)	2832.9	2868.7	2,896.3
WT. OF AGGREG. RETAINED ON SIEVE 2.36 mm (M3)	2550.1	2582.7	2601.2
WT.AGGREG.(gm) PASSING SIEVE 2.36 mm (M2)	282.8	286.0	295.1
TEN % FINE VALUE (M=M2/M1*100)	10.0	10.0	10.2
AVERAGE RESULTS % (M)		10.0	
AVERAGE CRUSHING FORCE (F)		263.2	

$F = \frac{14F}{M+4}$ 262.3 DRY 262.3 KN

10% FINE VALUE SOAKED

TEST NO	1	2	3
CRUSHING FORCE (KN)	263	263	263
WT. OF AGGREG (gm)after crushing (M1)	2863.0	2864.0	2851.8
WT. OF AGGREG. RETAINED ON SIEVE 2.36 mm (M3)	2555.3	2555.3	2528.5
WT.AGGREG.(gm) PASSING SIEVE 2.36 mm (M2)	307.7	308.7	323.3
TEN % FINE VALUE (M=M2/M1*100)	10.7	10.8	11.3
AVERAGE RESULTS % (M)		11.0	
AVERAGE CRUSHING FORCE (F)		263.2	

$F = \frac{14F}{M+4}$ 246.4 SOACKED WET/DRY(%)= 94

SPEC >110 SPEC >75%

f= Maximum force (KN)

of material passing the 2.36mm sieve at the maximum force

SPEC REQUIREMENT:7.5%-12.5% (BS 812-111) (if <or> discard

TESTING LAB

STIRLING CIVIL ENGINEERING LTD 23 JAN 2024 P.O. BOX 796, KAMPALA (U)

Materials Engineer

INSTITUTION	CLIENT	TESTING LAB
UGANDA CHRISTIAN UNIVE	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling
PROJECT:	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

A.C.V. LABORATORY TEST RESULT FORM

(BS 812PART 110:1990)

LOCATION:	MUKONO SITE	Oparator	15/Jan/24
MATERIAL DESCRIPTION:	AGGREGATES FOR ASPHALT	Date	16/Jan/24

A.C.V

(A) WT BEFORE CRUSHING (gm)	2860.5	2826.2	2799.6
(B) WT AFTER CRUSHING (gm)	2859.5	2825.8	2799.1
(C) WT RETAINED AFTER CRUSHING (gm)	2371.8	2363.5	2335.7
(D) WT PASSING SIEVE 2.36 mm	488.7	462.7	463.9
A.C.V(%) (D/B)*100	17.1	16.4	16.6
AVERAGE RESULTS %		16.7	

NB more than B by 10gms repeat the test

A.I.V

(A) WT BEFORE TEST (gm)	356.2	358.1	367.5
(B) WT AFTER TEST (gm)	355.5	357.9	367.5
(C) WT RETAINED AFTER TEST (gm)	300.5	305.9	311.1
(D) WT PASSING SIEVE 2.36 mm	55.7	52.2	56.4
A.I.V(%) (D/B)*100	15.7	14.6	15.3
AVERAGE RESULTS %		15.2	

NB If c+d is more than B by 1gms repeat the test

SPECIFIED LIMITS IN ACCORDANCE WITH TYPE OF MATERIAL

FOR TESTING LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
23 JAN 2024
P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

RESISTANCE TO DEGRADATION BY ABRASION AND IMPACT TO LOS ANGELES MACHINE (AASHTO T96 - 99)

JOB:	MUKONO SITE	OPERATOR	
LOCATION :	MUKONO CRUSHER	TOTAL BY DRY WT. OF THE SAMPLE:1	4,956.0
SUPPLIER:	STIRLING	TOTAL BY DRY WT. OF THE SAMPLE:2	4,999.0
MATERIAL:	AGGREGATES FOR ASPHALT	DATE SAMPLED:	15/Jan/2024
SPECIFICATION...		DATE TESTED:	16/Jan/2024

Test 1 Grading of Test Samples

SIEVE SIZE		Mass of indicated Sizes,g			Grading
Passing	Retained on	A 12 balls	B 11balls	C 8 balls	D 6balls
mm 20	10				
37.5 (1 1/2in)	25.0 (1 in)	1250 ± 25	......	......	......
25.0 (1 in)	19.0 (3/4 in)	1250 ± 25	......	......	......
19.0 (3/4 in)	12.5 (1/2 in)	1250 ± 10	2500 ± 10	......	......
12.5 (1/2 in)	9.5 (3/8 in)	1250 ± 10	2500 ± 10	......	......
9.5 (3/8 in)	6.3 (3/4 in)	.....	.....	2500 ± 10	......
6.3 (3/4 in)	4.75 (No. 4)	.....	.....	2501 ± 10	......
4.75 (No. 4)	2.36 (No. 8)	.....	.....	......	5000 ± 10
TOTAL:........................		5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10

Speed of Rotation: 33Rev/min. Max. 500 Rev.

Max.Duration 15 min

			Wt after crushing:	4,932.8
GRADING USED FOR TEST:	SAMPLE: 1	SAMPLE: 2	Wt after crushing :	4,948.2
Wt of Mat. Retained on 1.7mm sieve :	4,131.0	4,156.0		
Wt of fine material_	825.0	843.0	Average: %	16.8
Percentage of wear_ %	16.6	16.9	Spec Req	40%

FOR TESTING LAB

LAB TECHNICIAN

MATERIALS ENGINEER

STIRLING CIVIL ENGINEERING LTD
23 JAN 2024
P. O. BOX 796, KAMPALA (U)

INSTITUTION	CLIENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS
TEST	SPECIFIC GRAVITY
TEST METHOD	ASTM:C128-97

Sample Ref:	AC 14 MM	Technician :	
SOURCE:	Mukono Stirling quarry	Sampling date:	1/15/2024
Aggregate size :	COMBINED	Testing date:	1/17/2024
Description of aggregates:	HOT BINS		

Aggregate size :	20-14	14-10	10-6.0	6.0-0	FILLER
GS bulk :	2.621	2.615	2.596	2.613	2.564
PROPORTIONS:	5	7	18	66	4
COMBINED SG :	2.608				
WATER ABSOPTION	0.3	0.4	0.7	0.4	
COMBINED WATER ABSOPTION	0.4				

REMARKS

FOR CONTRACTOR

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
P. O. BOX 796, KAMPALA (U)
2024

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling
PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES

(AASHTO ; T85—91)

ASTM DESIGNATION ; C127—88

LOCATION: Mukono Quarry	OPERATOR:
SAMPLE No	SAMPLE DATE: 1/15/2024
TYPE: 14-20 mm	TESTING DATE: 1/17/2024

TEST NO.		A	B	C
[A] wt. of oven dry sample in air	(gm)	2251.1		2182.9
[B] wt. of saturated surface dry sample in air	(gm)	2257.2		2188.7
[C] wt of saturated sample in water	(gm)	1398.4		1355.7
Bulk Specific Gravity on oven dry basis	A / (B-C)	2.621		2.621
Bulk Specific Gravity on saturated surface dry basis	B / B-C	2.628		2.627
Apparent Specific Gravity	A / A-C	2.640		2.639
Water Absorption(%)=	100(B-A) / A	0.3		0.3

AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.621
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.628
APPARENT SPECIFIC GRAVITY	2.639
WATER ABSORPTION	0.3

FOR TESTING LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
23 JAN 2024
P.O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling
PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES

(AASHTO ; T85—91)

ASTM DESIGNATION ; C127—88

LOCATION: Mukono Quarry	OPERATOR:
SAMPLE No	SAMPLE DATE: 1/15/2024
TYPE: 14-10 mm	TESTING DATE: 1/17/2024

TEST NO		A	B	C
[A] wt. of oven dry sample in air	(gm)	1911.6		1779.2
[B] wt. of saturated surface dry sample in air	(gm)	1918.9		1786.5
[C] wt of saturated sample in water	(gm)	1187.7		1106.4
Bulk Specific Gravity on oven dry basis	A / (B-C)	2.614		2.616
Bulk Specific Gravity on saturated surface dry basis	B / B-C	2.624		2.627
Apparent Specific Gravity	A / A-C	2.641		2.644
Water Absorption(%)=	100(B-A) / A	0.4		0.4

AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.615
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.626
APPARENT SPECIFIC GRAVITY	2.643
WATER ABSORPTION	0.4

FOR TESTING LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
3 JAN 2024
P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling
PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES

(AASHTO ; T85—91)

ASTM DESIGNATION ; C127—88

LOCATION:	Mukono Quarry	OPERATOR:	
SAMPLE No		SAMPLE DATE:	1/15/2024
TYPE:	10 - 6 mm	TESTING DATE:	1/17/2024

TEST NO		A	B	C
[A] wt. of oven dry sample in air	(gm)	1917.4		1973.5
[B] wt. of saturated surface dry sample in air	(gm)	1931.1		1986.8
[C] wt of saturated sample in water	(gm)	1192.9		1226.1
Bulk Specific Gravity on oven dry basis	A / (B-C)	2.597		2.594
Bulk Specific Gravity on saturated surface dry basis	B / B-C	2.616		2.612
Apparent Specific Gravity	A / A-C	2.647		2.640
Water Absorption(%)=	100(B-A) / A	0.7		0.7

AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.596
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.614
APPARENT SPECIFIC GRAVITY	2.644
WATER ABSORPTION	0.7

FOR TESTING LAB

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UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling
PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

SPECIFIC GRAVITY & WATER ABSORPTION FINE AGGREGATES

(AASHTO ; T84—00)

ASTM DESIGNATION ; C128—97

LOCATION:	OPERATOR:
SAMPLE No	SAMPLE DATE: 1/15/2024
TYPE: QUARRY DUST (O/6 mm)	TESTING DATE: 1/17/2024

TEST NO		1		K
[A] wt. of oven dry sample in air	(gm)	502.6		515.6
[B] wt. of pycnometer filled with water	(gm)	1805.2		1772.6
[C] wt. of pycnometer with specimen and water	(gm)	2117.2		2093.2
[S] wt of saturated surface dry sample	(gm)	504.3		518
Bulk Specific Gravity on oven dry basis	(B-C) / (B+S-C)	2.614		2.612
Bulk Specific Gravity on saturated surface dry basis	S / (B+S-C)	2.622		2.624
Apparent Specific Gravity	A / 100(B-A)	2.637		2.644
Water Absorption(%)=	A / A	0.3		0.5

BULK SPECIFIC GRAVITY	2.613
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.623
APPARENT SPECIFIC GRAVITY	2.641
WATER ABSORPTION	0.4

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23 JAN 2024
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INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling
PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

FLAKINESS INDEX OF AGGREGATES (BS 812 PART 105.2 1990)

Location:	STIRLING LAB	Operator:	
Material:	COMBINED AGGREGATES FOR AC 14 ASPHALT	Date:	1/22/2024
		weight of sample (gms)	1326.7

BS sieve Size	Weight Retained (gm) (from grading sheet)	% Retained
20mm	0	0.0
14mm	42.5	3.2
10mm	124.5	9.4

s less than 5% that size is not tested for flakiness

BS sieve size(mm)			28.0	20.0	14.0	10.0		Total
Weight retained gm (A)						124.5		124.5
iffled weight (if needed) gm (B)						124.5		
Coorrection factor a/b (C)						1.0		
Wt. Passing sieve gm (D)						20.0		
Wt. Retained on sieve gm (E)						104.5		
Corrected Wt. Passing (dxc) (F)						20.0		20.0

Flakiness Index = $\frac{TOTALF}{TOTALA}$ * 100 16.1

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2024

ANNEX B – Optimum Bitumen Content

INSTITUTION	STUDENTS	CONTRACTOR
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

JOB ASPHALT MIX DESIGN

LOCATION MUKONO LAB

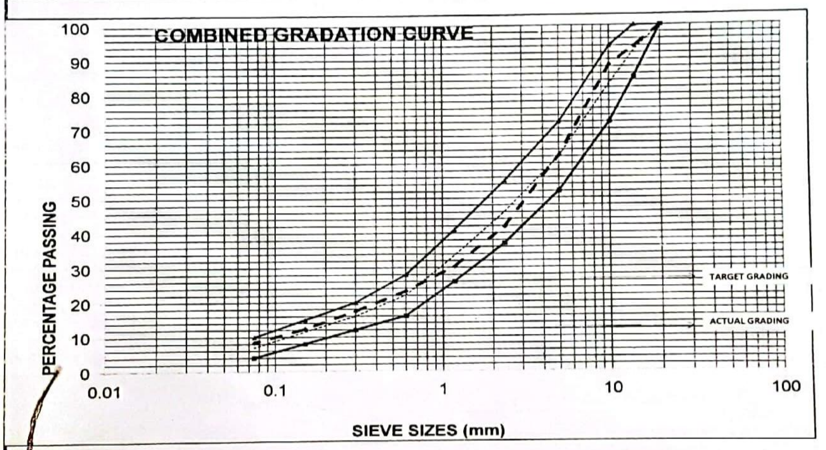
JOB MIX GRADING COMPOSITION

SUPPLIER HOTBIN

DATE 1/17/2024

MATERIAL AC 14 INDIVIDUAL GRADATION

	14/20MM		10/14MM		6/10MM		0/6MM		Lime Kiln dust		actual	TARGET GRADING	SPEC
		5.0		7.0		15.0		69.0		4.0	100.0		
20	98.6	4.9	99.4	7.0	100.0	15.0	100.0	69.0	100.0	4.0	100	100	100
14	18.7	0.9	70.3	4.9	99.4	14.9	100.0	69.0	100.0	4.0	94	93	85—100
10	1.6	0.1	18.7	1.3	93.9	14.1	100.0	69.0	99.7	4.0	88	83	72—94
5	0.4	0.0	1.3	0.1	6.6	1.0	83.0	57.2	99.1	4.0	62	62	52—72
2.36	0.4	0.0	0.9	0.1	4.9	0.7	53.7	37.1	98.2	3.9	42	46	37—55
1.18	0.4	0.0	0.8	0.1	4.1	0.6	37.4	25.8	97.1	3.9	30	34	26—41
0.6	0.4	0.0	0.7	0.0	3.4	0.5	27.3	18.8	96.0	3.8	23	22	16—28
0.3	0.4	0.0	0.6	0.0	2.8	0.4	19.1	13.2	94.5	3.8	17	16	12—20
0.15	0.4	0.0	0.5	0.0	2.3	0.3	12.0	8.2	92.7	3.7	12	12	8—15
0.075	0.4	0.0	0.4	0.0	2.0	0.3	6.5	4.5	89.7	3.6	8	7	4—10



FOR CONTRACTOR

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Materials Engineer

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JAN 2024
P.O. BOX 793, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

PROJECT:	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

LOCATION
SUPPLIER
TEST METHOD: EN 12591-2000
18-Jan-24
BITUMEN TYPE 60/70

OPERATOR Lab team

BITUMEN TESTS

TEST NO	D		S2		9	CM	IFF	K	AVERAGE	TEST METHODS	REMARKS
PENETRATION 100gr 5 sec 25 C	65 66 68		65 66 64		64 62 68	70 65 65	66 65 63	65 68 69	66	ASTM D5	60-70
SOFTENING POINT (°C)		50.5		51.0					50.8	ASTM D36	(49-56)°C
BITUMEN AFFINITY									>95		>95
SPECIFIC GRAVITY	1.029		1.026		1.029	1.031	1.028	1.026	1.03	ASTM D70	1.01-1.06

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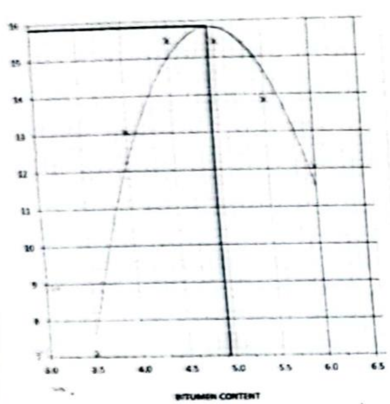
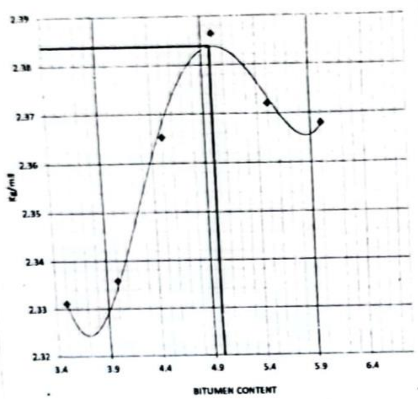
AC 14 JOB MIX DESIGN

STABILITY AT MAXIMUM



DENSITY AT MAXIMUM



DATE: 18-01-2024

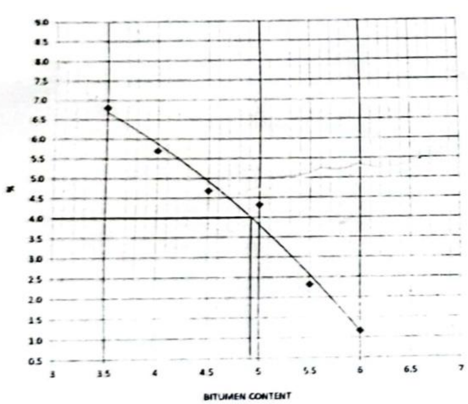
Optimum Bitumen

Stability	4.9	%
Density	5.0	%
Voids	4.9	%
Average	4.9	

MIX PROPORTION

FILLER	4	%
Q / Dust	69	%
10mm	15	%
14mm	7	%
20mm	5	%
TOTAL	100	

VOIDS



Summary for Optimum BitumenContent Determination Data

BITUMEN %	3.5	4	4.5	5	5.5	6
DENSITY	2.33	2.336	2.365	2.386	2.372	2.368
STABILITY	7.1	13.0	15.5	15.4	13.8	12.1
FLOW	2.63	2.45	[illegible]	2.8	3.2	3.5
VOIDS	6.8	5.7	4.7	[illegible]	2.3	1.2

Signed:

Contractor:

STIRLING CIVIL ENGINEERING LTD
P. O. BOX 796, KAMPALA (U)
FEB 2024

ANNEX C – Strength Performance Properties of Asphalt Mix

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

PROJECT :	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

NEAT ASPHALT WITH ORIGINAL FILLER

SUMMARY OF A/C 14 TEST RESULTS

BITUMEN CONTENT		4.9
MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW	2.8	2—4
MARSHALL STABILITY 75BLOWS	14.8	9-18
MARSHALL AIR VOIDS 75BLOWS	4.9	3—5
VOIDS IN MINERAL AGGREGATES	15.1	>15%
VOIDS FILLED WITH BINDER	67.7	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,011	>800kpa
INDIRECT TENSILE WET STRENGTH	90	>80% of dry
BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
RATIO STABILITY/FLOW	5.0	>2.5

TESTING LAB

Lab technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
12 FEB 2024
P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

PROJECT: INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

Field Ref. No:	Lab. no.	MIX	NEAT ASPHALT WITH ORIGINAL FILLER	Sampling date:	21-Jan-24
Sample grade: AC 14	Compaction: 75 blows			Testing date:	22-Jan-24
Sample Description:			AC 14		

Test Type	Done by	Test Type	Done by
B.R.D	lab team	B.C/Grad.	lab team
T.M.R.D.	lab team	Stab. & Flow	lab team

ASTM D2726 - Standard Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures.

Marshall specim.	Mass in air	Mass in Water	Saturated surface Dry in air	Bulk S.G (G_{mb})	Unit Wt. (Kg/m³)	% Air Voids	% VMA	% VFB
1	1195.0	686.00	1196.50	2.341	2.330	4.9	15.2	67.5
2	1194.5	686.00	1196.00	2.342	2.331	4.9	15.1	67.8
3	1189.0	686.00	1194.50	2.338	2.327	5.0	15.2	67.1
4	1188.0	685.00	1191.50	2.346	2.334	4.7	15.0	68.4
Average Sample 1				2.342	2.330	4.9	15.1	67.7
-						-		
-				-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2				2.342	2.330	4.9	15.1	67.7

ASTM D6927 Standard Method for Marshall Stability and Flow

Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Stability (KN) Adjusted	Flow (mm)	Ratio (Stab./Flow)
65.4	65.3	65.4	65.4	0.95	14.0	13.26	3.07	4.318
66.4	66.0	65.4	65.9	0.95	15.0	14.23	2.60	5.473
64.5	65.2	65.2	65.0	0.96	15.4	14.77	2.91	5.077
66.2	65.1	66.4	65.9	0.95	15.0	14.23	2.80	5.082
Average Sample 1			65.5	1.0	14.8	14.1	2.8	5.0
-	-	-	-	-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2								

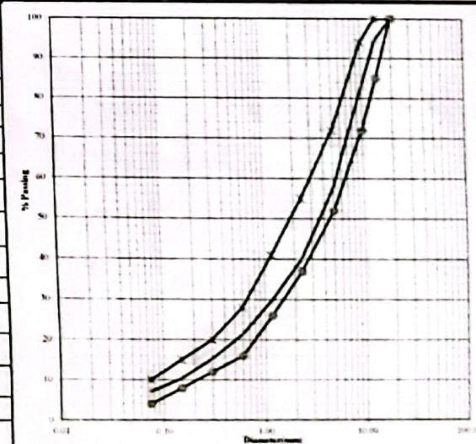
ASTM D 2172 - Standard Test Method for Quantitative Extraction of Bitumen from Asphalt Mixtures

Mass (g)	Sample 1	Sample 2
Bowl	232.3	167.8
Bowl + Asphalt	1937.5	1869.0
Asphalt	1705.2	1701.2
Filter paper before extraction	29.3	31.8
Filter paper + Filler After extraction	30.8	33.1
Recovered Filler	1.5	1.3
Oven dry extracted Mtl (dry)	1619.6	1614.1
Oven dry extr. mtl + filler	1621.1	1615.4
Bitumen	84.1	85.8
% of Bitumen	4.9	5.0
Av. % of Bitumen	5.0	

ASTM D2041 - Standard Test Method for Theoretical Maximum Specific gravity and Density of Bituminous Mixtures

SAMPLE 1 (Pycnometer with Water)			SAMPLE 2 (Pycnometer with Water)		
Temperature of water (°c)	25°C		Temperature of water (°c)	25°C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1288		Asphalt	1126.5	-
Pycn. + Water	7363		Pycn. + Water	7363	-
Pycnometer + Asph + Water	8125.8		Pycnometer + Asph. + Water	8029.3	-
Volume of asphalt	525.2	-	Volume of asphalt	460.2	-
G_{mm}	2.452	-	G_{mm}	2.448	-
Av. G_{mm}	2.452		Av. G_{mm}	2.448	
Av. Gmm (Kg/m3) Sample 1& 2			2.450		

Sieve (mm)	Smp1 Mass retained	Smp2 Mass retained	Av. Mass retained	% Av. Retained	% Av. passing	JMF Lower	JMF Upper
20	0.0	0.0	0.0	0.0	100	100	100
14	97.9	80.4	89.2	5.5	94	85	100
10	185.0	196.7	190.9	11.8	83	72	94
5	388.0	420.0	404.0	25.0	58	52	72
2.36	287.9	282.1	285.0	17.6	40	37	55
1.18	170.0	160.2	165.1	10.2	30	26	41
0.600	146.4	127.2	136.8	8.5	21	16	28
0.300	106.8	89.8	98.3	6.1	15	12	20
0.150	76.0	83.2	79.6	4.9	10	8	15
0.075	55.0	52.4	53.7	3.3	7	4	10
Total filler	102.1	115.8	109.0				
Bot. Pan	3.0	5.00	4.0				
Extr. filler	1.5	1.30	1.4				
Sum of extr. Agg	1619.6	1614.1	1616.9				



Comment:

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2 FEB 2024
P.O. BOX 796, KAMPALA (U)
FOR TESTING
Materials Engineer

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

PROJECT: INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

INDIRECT TENSILE STRENGTH

BITUMINOUS MIXTURE SAMPLED ON 1/21/2024 | 102 | GMM 2.450 | Bit.content,% 4.9 | NO OF BLOWS 47

SAMPLE NO.	THICKNESS				Compacted material parameters										
	HEIGHT 1 (mm)	HEIGHT 2 (mm)	HEIGHT 3 (mm)	Av. Thickness (mm)	Weight of Core in Air (g) A	Weight of Core in Water (g) B	Weight of Core in SSD condition (g) C	Volume of Core (cc) D=(C-B)	Bulk Density (g/cm³) E=(A/D)	GMM (maximum theoretical density) (g/cm³) F	VOLUME OF AIR	SATURATED SPECIMEN	VOLUME OF WATER	DEGREE OF SATURATION	VIM, AIR VOIDS (%) =100*(F-E)/F spec min 3.0% G
MIX	NEAT ASPHALT WITH ORIGINAL FILLER														
	WET														
1	66.1	66.0	65.7	65.9	1191.5	679.0	1197.5	518.5	2.275	2.450	37.061	1220.5	29.000	78.249	7.1
4	64.3	65.4	65.0	64.9	1188.5	681.5	1198.5	517.0	2.276	2.450	36.773	1218.5	30.000	81.581	7.1
3	65.7	65.8	66.1	65.9	1192.0	678.5	1195.9	517.4	2.281	2.450	35.759	1215.5	23.500	65.718	6.9
	DRY														
2	65.2	65.6	66.2	65.7	1189.0	678.0	1195.0	517.0	2.277	2.450	36.571				7.1
5	65.2	65.4	66.1	65.6	1179.5	672.0	1184.0	512.0	2.281	2.450	35.410				6.9
6	65.3	65.3	66.1	65.6	1187.5	678.0	1195.0	517.0	2.274	2.450	37.177				7.2

INDIRECT TENSILE STRENGTH

DRY						WET							WET/DRY
SPECIMEN No	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD P	SINGLE TENSILE STRENGTH, S_t	AVERAGE TENSILE STRENGTH, S_t	SPECIMEN No	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD,P	SINGLE TENSILE STRENGTH, S_t	AVERAGE TENSILE STRENGTH,S_t		
	div	kn/div	kn	spec min 800 kPa			div	kn/div	kn	kPa	kPa	S_t =2P/ΠtD where P= maximum load(N) t=specimen thickness (mm)	spec 80%
2	57	0.217	12.4	1,169.3	1,125.5	1	50	0.217	10.8	1,025.7	1,011		90
5	56	0.217	12.1	1,155.2		4	48	0.217	10.4	1,000.4			
6	51	0.217	11.1	1,052.1		3	49	0.217	10.6	1,006.2			

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LIME KILN DUST AS FILLER

SUMMARY OF A/C 14 TEST RESULTS

BITUMEN CONTENT		4.9
MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW	3.5	2—4
MARSHALL STABILITY 75BLOWS	17.1	9-18
MARSHALL AIR VOIDS 75BLOWS	4.9	3—5
VOIDS IN MINERAL AGGREGATES	15.1	>15%
VOIDS FILLED WITH BINDER	67.3	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,086	>800kpa
INDIRECT TENSILE WET STRENGTH	81	>80% of dry
BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
RATIO STABILITY/FLOW	5.1	>2.5

TESTING LAB

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02 FEB 2024
P. O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
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PROJECT

INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

Field Ref. No.:	Lab. no.	MIX	LIME KILN DUST AS FILLER	Sampling date:	22-Jan-24		
SUMMARY OF A/C AC 14	Compaction: 75 blows			Testing date:	23-Jan-24		
Sample Description:			AC 14				

Test Type	Done by	Test Type	Done by
B.R.D	lab team	B.C/Grad.	lab team
T.M.R.D.	lab team	Stab. & Flow	lab team

ASTM D2726 - Standard Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures.

Marshall specim.	Mass in air	Mass in Water	Saturated surface Dry in air	Bulk S.G (G_{mb})	Unit Wt. (Kg/m³)	% Air Voids	% VMA	% VFB
1	1195.5	687.40	1197.30	2.345	2.333	4.9	15.1	67.4
2	1204.9	692.50	1206.10	2.346	2.335	4.9	15.0	67.6
3	1195.4	686.40	1196.20	2.345	2.334	4.9	15.0	67.4
4	1204.0	692.80	1207.10	2.341	2.330	5.1	15.2	66.7
Average Sample 1				2.344	2.333	4.9	15.1	67.3
	.					.		
-				-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2				2.344	2.333	4.9	15.1	67.3

ASTM D6927Standard Method for Marshall Stability and Flow

Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Stability (KN) Adjusted	Flow (mm)	Ratio (Stab./Flow)
62.2	62.7	63.1	62.7	1.02	18.3	18.63	3.68	5.062
61.1	61.4	61.7	61.4	1.06	15.4	16.31	2.92	5.587
62.0	62.7	62.5	62.4	1.03	17.4	17.97	3.93	4.571
61.3	61.7	61.8	61.6	1.05	17.4	18.31	3.61	5.073
Average Sample 1			62.0	1.0	17.1	17.8	3.5	5.1
				.				
-	-	-	-	-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2								

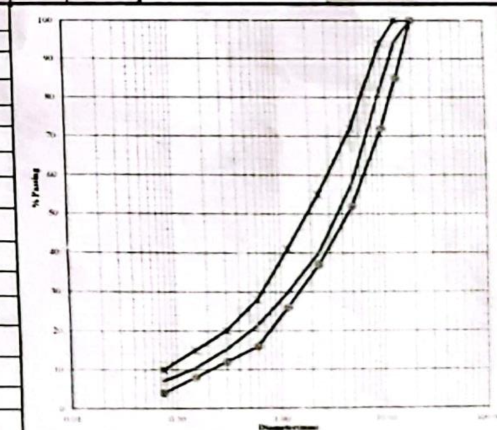
ASTM D 2172- Standard Test Method for Quantitative Extraction of Bitumen from Asphalt Mixtures

Mass (g)	Sample 1	Sample 2
Bowl	232.3	167.8
Bowl + Asphalt	1937.9	1869.0
Asphalt	1705.6	1701.2
Filter paper before extraction	29.3	31.8
Filter paper + Filler After extraction	30.8	33.1
Recovered Filler	1.5	1.3
Oven dry extracted Mtl (dry)	1619.6	1614.1
Oven dry extr. mtl + filler	1621.1	1615.4
Bitumen	84.5	85.8
% of Bitumen	5.0	5.0
Av. % of Bitumen	5.0	

ASTM D2041- Standard Test Method for Theoretical Maximum Specific gravity and Density of Bituminous Mixtures

SAMPLE 1			SAMPLE 2		
(Pycnometer with Water)			(Pycnometer with Water)		
Temperature of water (°c)	25°C		Temperature of water (°c)	25°C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1213.1		Asphalt	1256.1	-
Pycn + Water	8553.5		Pycn. + Water	8553.5	-
Pycnometer + Asph. + Water	9272.9		Pycnometer + Asph. + Water	9297	-
Volume of asphalt	493.7	-	Volume of asphalt	512.6	-
G_{mm}	2.457		G_{mm}	2.450	-
Av. G_{mm}			Av. G_{mm}	2.450	
Av. Gmm (Kg/m³) Sample 1& 2			2.454		

Sieve (mm)	Smp1 Mass retained	Smp2 Mass retained	Av. Mass retained	% Av. Retained	% Av. passing	JMF Lower	JMF Upper
20	0.0	0.0	0.0	0.0	100	100	100
14	97.9	80.4	89.2	5.5	94	85	100
10	185.0	196.7	190.9	11.8	83	72	94
5	388.0	420.0	404.0	25.0	58	52	72
2.36	287.9	282.1	285.0	17.6	40	37	55
1.18	170.0	160.2	165.1	10.2	30	26	41
0.600	146.4	127.2	136.8	8.5	21	16	28
0.300	106.8	89.8	98.3	6.1	15	12	20
0.150	76.0	83.2	79.6	4.9	10	8	15
0.075	55.0	52.4	53.7	3.3	7	4	10
Total filler	102.1	115.8	109.0				
Bot. Pan	3.0	5.00	4.0				
Extr. filler	1.5	1.30	1.4				
Sum of extr. Agg	1619.6	1614.1	1616.9				



Comments:

For: [illegible]

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
12 FEB 2024
P.O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

INDIRECT TENSILE STRENGTH

BITUMINOUS MIXTURE SAMPLED ON 1/22/2024 | 102 | GMM 2.454 | Bit.content,% 4.9 | NO OF BLOWS 47

SAMPLE NO.	THICKNESS				Compacted material parameters										
	HEIGHT 1 (mm)	HEIGHT 2 (mm)	HEIGHT 3 (mm)	Av. Thickness (mm)	Weight of Core in Air (g) A	Weight of Core in Water (g) B	Weight of Core in SSD condition (g) C	Volume of Core (cc) D=(C-B)	Bulk Density (g/cm^3) E=(A/D)	GMM (maximum theoretical density) (g/cm^3) F	VOLUME OF AIR	SATURATED SPECIMEN	VOLUME OF WATER	DEGREE OF SATURATION	VIM, AIR VOIDS (%) =100*(F-E)/F spec min 3.8% G
MIX	LIME KILN DUST AS FILLER														
SUMMARY OF A/C 14 TEST RESULTS															
1	69.7	66.4	68.8	68.3	1187.6	677.0	1191.3	514.3	2.286	2.454	35.157	1226.2	38.600	109.794	6.8
2	64.9	64.1	63.8	64.3	1185.1	676.8	1189.0	512.2	2.291	2.454	34.065	1203.9	18.800	55.188	6.7
DRY															
1	65.1	64.1	65.1	64.8	1210.6	694.2	1213.2	519.0	2.309	2.454	30.577				5.9
2	63.6	63.4	63.7	63.6	1192.2	680.4	1195.8	515.4	2.290	2.454	34.401				6.7

INDIRECT TENSILE STRENGTH

DRY						WET							WET/DRY
SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD,P	SINGLE TENSILE STRENGTH,S_t	AVERAGE TENSILE STRENGTH,S_t	SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD,P	SINGLE TENSILE STRENGTH,S_t	AVERAGE TENSILE STRENGTH,S_t		
	div	kn/div	kn	spec min 800 kPa			div	kn/div	kn	kPa	kPa	S_t =2P/∏tD where P= maximum load(N) t=specimen thickness(mm) D=specim	spec 80%
1	70	0.2052	14.4	1,312.1	1,340.8	1	50	0.2052	10.3	937.2	1,086		81
2	68	0.2052	14.0	1,369.5		2	62	0.2052	12.7	1,235.1			

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
FOR TESTING LAB
2 FEB 2024
P.O. BOX 795, KAMPALA (U)