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

STEVEN KISITU

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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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ABSTRACT

Primarily utilized in Uganda, flexible pavements are made of bitumen, aggregates, and mineral filler. Investigating the use of lime kiln dust as a mineral filler in asphalt concrete for long-lasting flexible pavements in proportions by mass of the active filler of 4% was the primary goal of this study.

The Marshall test, determining the engineering parameters of bitumen, aggregates, and mineral filler, as well as measuring the asphalt mixtures' indirect tensile strength (ITS), were the primary techniques employed. For each mix, a number of factors need to be ascertained, including Marshall stability, flow, unit weight, air voids (Va), voids filled with asphalt (VFA), and voids in the mineral aggregate (VMA). Air voids decreased from 5.7% to 4.9%, Marshall stability increased from 14.8 to 17.1%, and indirect tensile strength wet strength increased from 81% to 90% as a result of using lime kiln dust. Findings suggested that adding 4% of lime kiln dust filler increased the stability and stiffness of asphalt mixtures, enhancing their resistance to rutting; however, experiments utilising different percentages of lime kiln dust should be experimented.

Accordingly, this study demonstrates that 4% lime kiln dust can be added to asphalt concrete as a mineral filler to decrease air voids, increase mix stability, and eventually strengthen the asphalt mixture's rigidity and durability.

DECLARATION

I so attest that this is my own original work, has not been submitted for credit to any other organisation, and has not been plagiarised.

Name: ....…………………………………

Signature: ………………………………………..

Date ………………………………………..

APPROVAL

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

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

NAME: **MS.JOSEPINE AGUTI**
Department of Engineering and Environment

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Asphalt Concrete
LKD	Lime Kiln Dust
GHG	Greenhouse gas
PSD	Particle Size Distribution
FI	Flakiness Index
OPC	Ordinary Portland Cement
RD	Rock dust
HMA	Hot mix asphalt
AASHTO	American Association of the State Highway and Transportation Officials
TFV	Ten Percent Fine Value
VFA	Voids in Mineral Aggregate
VFA	Voids Filled with Asphalt
XRF	X-Ray Fluorescence
Gmm	Theoretical Maximum Specific Gravity
PCFA	Portland Cement Filler Asphalts
LOI	Loss of Ignition

DEFINITIONS

Rutting: A type of deformation when pavement becomes depressed or worn down in the wheel tracks (Chance, 2018).

Pavement: A firm surface or hard surface that is intended for foot or vehicle activity (Mahajan, 2019).

Concrete: A composite material made by combining a binding agent e.g. cement along with aggregate (sand, gravel, stone) and water in specific proportions (Rahman, 2019)

Lime Kiln Dust(LKD): is a by-product in the manufacturing of lime and is composed of calcium oxide, and calcium carbonate and calcium hydroxide (Moser, 2015).

Bitumen: This is a viscous, black complex mixture of hydrocarbons, and highly sticky material that is obtained from the refining of crude oil (Kumar, 2021).

Air voids: A specific amount of air voids is required in all densely graded roadway mixes in order to allow for flexibility under traffic loading. Air voids are defined as the volume of air pockets or percentage of void spaces in the compacted AC mixture.

CHAPTER ONE: INTRODUCTION

1.1 Background

The development of road infrastructure and the building of road pavements demonstrate how Uganda's road network has greatly improved as a result of greater financing and the 1990s road sector reforms (Kagina, 2021). There are two main forms of road pavement: flexible pavement made of asphalt concrete and rigid pavement made of concrete (Mahajan, 2019).

Uganda mostly uses asphalt concrete roads because of their ability to flex and move somewhat under the influence of high traffic and changing environmental conditions. However, with time, a variety of distresses or failures can occur in flexible pavements made of asphalt concrete, leading to problems such rutting, thermal fatigue, shoving, and cracking (Tasnim, 2021).

Numerous reasons, such as inadequate compaction, weak subgrade soil, poorly designed mixtures, and heavy axle loads in high traffic volumes, can lead to pavement failures. Rutting is the result of the pavement surface gradually deforming and developing a groove or depression that gathers water, accelerates the pavement's deterioration, and also causes the bitumen and aggregates to separate from one another (Su, 2020).

Mineral fillers, which are finely split mineral components that strengthen the mixture's stiffness and resistance to deformation or rutting in flexible pavements, are used to improve the properties of asphalt concrete mixtures. A segment of the Masaka Road in Mbambire that suffers from rutting pavement distress serves as a case study for this issue. But as a byproduct of making lime, lime kiln dust (LKD) can fill the void and increase asphalt concrete's resistance to rutting defects in the road. (Ghasemi, 2015).

1.2 Problem Statement

Rutting, which is shown by the wheel path being incised in the road, is one of the main bituminous deteriorations with asphalt concrete pavements in Uganda. Rutting occurs when persistent deformation or consolidation develops on surface over time. Numerous things, including shoddy mix designs, insufficient compaction, flimsy subgrade soil, and heavy axle loads in heavy traffic, are to blame for this.

Furthermore, to providing superior viscoelasticity properties, tests conducted by Jitsanigam revealed that a 50% LKD in hot mix asphalt mixture may potentially reduce embodied energy consumption and greenhouse gas emissions from lime kiln dust by 2.4% and 18.5%, respectively, when compared to other fillers in the asphalt's "cradle to gate" life cycle assessment. (Jitsanigam, 2018). Another study by Nitin Tiwari revealed the experimental results regarding Marshall stability and air voids. The mixture containing LKD gave better adhesion with fewer voids of roughly 70%, decreased mixture porosity, and hardened bitumen (Type-169) with marginally better mechanical strength and durability than OPC of 15% stiffness over a 15-year design period. (Nitin Tiwari, 2023).In order to assess reactions under extreme circumstances, James' study conditioned specimens with LKD and rock dust using several freeze-thaw cycles and prolonged soak times. The findings indicate that the LKD utilised in this study outperformed the rock dust mineral filler by 25.4% voids in mineral aggregates. (James, 2006).

Therefore, to increase the mix's stiffness and promote the longevity of asphalt concrete pavements, this study looks into the use of lime kiln dust as a mineral filler in asphalt concrete.

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 fordurable 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 LKD
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 are the strength performance properties of Asphalt Concrete with and withoutLime Kiln Dust?

1.5 Justification of the study

The by-product known as lime kiln dust (LKD) is formed of calcium carbonate, calcium oxide, and calcium hydroxide. It has been demonstrated to enhance aggregate adhesion. Additionally, the presence of LKD can lead to the formation of calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H), which can function as a bonding agent or gel between the aggregates and bitumen. As a mineral filler, lime kiln dust can assist lower the asphalt binder's temperature susceptibility by 18.5% and 2.4% compared to other typical fillers.

In addition, lime kiln dust satisfies the requirements for a mineral filler and has a greater specific surface area than other usual fillers, enabling it to interact with the aggregate particles and asphalt binder more successfully. (Moser, 2015).

1.6 Significance of the Study

The primary purpose of lime kiln dust, which is easily obtainable from cement manufacturing industries, is to offer a practical and effective remedy for the high expenses of road maintenance brought on by early flexible pavement deterioration (Christopher, 2019) because it strengthens the material's adhesion and stiffness to fend off rutting and cracking.

1.7 Scope

1.7.1 Content Scope

This study is 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 is a section in Mbamire along Masaka road.

1.7.3 Time Scope

The project took a duration of eight months.

CHAPTER TWO: LITERATURE REVIEW

2. Pavements

A hard, level surface meant for walking or driving is called a pavement (Mahajan, 2019).The building of highways with asphalt pavement receives a large amount of money in Uganda. Rutting, fatigue, and thermal cracking are common failures that can be ascribed to a variety of factors, including increased traffic volumes, inadequate mix designs, inadequate drainage, and poor binder adhesion and bonding, to name a few. There has been a focus on enhancing the performance of rigid and flexible pavements, two types of road pavements, in order to handle the growing traffic load in diverse climates and withstand such failures.

2.1 Rigid pavements

Concrete firm surfaces known as "rigid pavements" have a high flexural strength, which makes them perfect for shifting wheel load to a broader area. Rigid pavement is composed of fewer material layers than flexible pavement. It is either rigidly laid on top of a well-compacted subgrade or a single layer of stabilized or granular material.

There is only one layer—known as the base or sub-base course—between the concrete and the subgrade. Rigid roads likewise work like an elastic plate resting on a viscous liquid, shifting the load of traffic on them by slab action. (Mahajan, 2019)

2.2 Flexible pavements

The term "flexible pavements" refers to a kind of asphalt concrete road surface that is intended to be both flexible and resilient under various traffic loads and weather circumstances. The base course is selected and placed based on its stiffness and strength. It is typically composed of multiple layers of materials, such as asphalt concrete (Association, 2021).

2.2.1 Design and performance requirements of flexible pavements

Flexible pavements use grain-to-grain transmission via the granular structure's points of contact to transfer wheel load strains to the lower layers. In order to guarantee that the transmitted stresses resulting from wheel load are appropriately minimised and do not surpass the subgrade's bearing capacity, they must to be able to offer a surface with adequate resistance to skidding, superior reflecting properties, smooth riding, and minimal noise pollution. (Mathew, 2009).

Wheel weight pressing against the pavement will be distributed over a greater area and cause less stress as depth increases. Flexible pavements usually have several layers to take use of this aspect of stress dispersion.

As a result, flexible pavement is designed using the layered system concept. This implies that several layers of flexible pavement may be constructed, with the best-quality layer at the top able to bear the most compressive stress and wear and tear. As a result, the lower layers may employ lower-quality materials and experience less stress.

Pavements that are flexible are built using bituminous materials. These can be surface treatments like bituminous surface treatments, which are usually seen on low volume roads, or asphalt concrete surface courses, which are usually used on high volume roads like national highways.

Flexible pavement layers reflect the surface layer's deformation from the bottom layers. Any subgrade undulation, for instance, will reflect onto the surface layer. The overall performance of the material determines the design of flexible pavement; the stresses created must be kept well below the maximum levels allowed by each layer of pavement (P Tom, 2009).

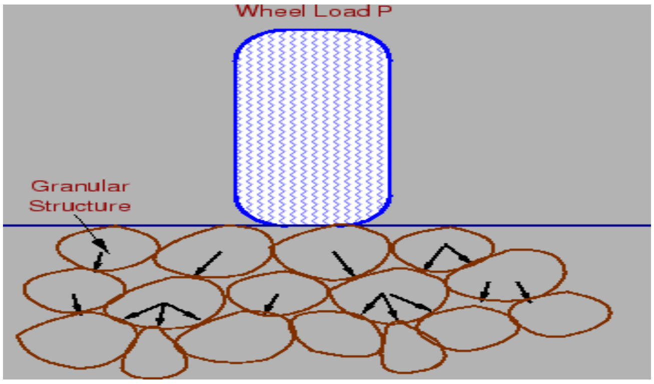

Figure 2.1: Load transfer in granular structure

Factors to consider in the design and performance of flexible pavement.

Table 2.1: Design and Performance requirements of flexible pavement (AASHTO 1993 AND FHWA 2001)

Traffic loads	Consideration of the type, volume, and weight of traffic that the pavement will bear. Use of appropriate design traffic loads, often expressed in terms of axle loads and repetitions.
Subgrade soil characteristics	Evaluation of the subgrade soil's bearing capacity and resilience. Soil classification and determination of soil properties, such as California Bearing Ratio (CBR).
Climate and Environmental conditions	Adaptation of the pavement design to the local climate, including factors like temperature variations, rainfall, and freeze-thaw cycles. Incorporation of drainage systems to mitigate the impact of water on pavement performance

Materials Selection	Selection of suitable materials for different layers of the pavement structure, including the surface course, base course, and subbase. Consideration of material properties, such as stiffness, fatigue resistance, and durability.
Pavement Structure:	Determination of the appropriate pavement structure based on the design traffic, subgrade strength, and material properties. Common flexible pavement structures include asphalt concrete overlays on granular base or stabilized subgrade.
Load-Bearing Capacity	Ensuring that the pavement can support the applied traffic loads without excessive deformation or rutting
Durability and Fatigue Resistance	Designing the pavement to withstand repeated loading cycles without developing fatigue cracks or permanent deformation.
Resistance to Environmental Distress	Ability to resist distresses such as cracking, rutting, and surface deterioration caused by environmental factors like moisture, temperature variations, 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 Aggregate (%)	sphaltMix	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 800 Tested at 25 °C
Indirect wet tensile strength (KPa) AASHTO T 283			80 % of dry strength

2.2.2 Layers of flexible pavements

Subgrade: All pavement layers are supported by the compacted subgrade, which transfers all stress to it. Therefore, good compaction to the appropriate density lowers stress in the subgrade.

Subbase: A layer of high-quality, well-graded material aggregates that sits beneath the base course and serves to enhance drainage, decrease the intrusion of fines from the subgrade, and provide structural support.

Base: A layer of materials that lies immediately beneath the binder course's surface, it aids in subsurface draining and distributes additional load.

Wearing course: The surface course, or layer, is the primary layer of flexible pavement. It bears direct traffic while maintaining sufficient friction to ensure road safety, giving the pavement its smooth, resilient, and abrasion-resistant qualities. Typically, bitumen-bound aggregate, or asphalt concrete, is used to make it. Mahajan (2020)

Parts of the wearing Course

Seal Coat: a thin coating of surface treatment that offers water and skid resistance. In order to apply a "tack coat," which is a very thin layer of asphalt, asphalt emulsion is typically diluted with water. It must be thin, cover the entire surface evenly, and set quickly to guarantee that the two layers of binder course combine correctly.

Prime Coat: A low viscosity cutback bitumen mixture is used to prime an absorbent surface, like granular bases, before the binder layer is applied. It makes it easier for two layers to join. Fills in the spaces, prime coat penetrates the layer under tack coat, and creates a waterproof surface (Mathew, 2009).

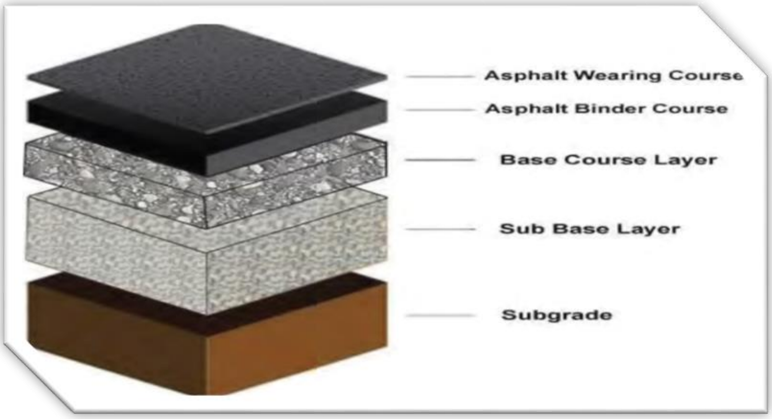

Figure 2.2: Road layers

2.2.4 Failures in flexible pavements

Although asphalt flexible pavements are generally resilient and can tolerate a range of traffic loads and weather conditions, they can fail for a number of reasons. For instance, as they age and oxidise, the pavement's protective layer becomes weaker. The following are a few typical categories of flexible pavement layer failures:

a) Cracking

Traffic stresses, ageing pavement, and thermal expansion and contraction can all cause cracks in the base courses, binder, and surface. Water intrusion and faster pavement deterioration can result from cracking.

b) Raveling

When there is insufficient adherence of the asphalt binder to the aggregate, the aggregate particles might get displaced from the pavement's surface, a condition known as raveling. It may be brought on by inadequate asphalt composition, subpar asphalt binder, or inadequate compaction during construction.

c) Bleeding

One kind of surface distress is called bleeding, which happens when too much asphalt binder comes to the pavement's surface as a result of high temperatures. This may lead to a slick surface, raising questions about motorist safety.

d) Rutting

The accumulation of traffic loads over time causes a certain kind of depression to form in the pavement's wheel path. Rutting may be brought on by insufficient thickness, improper mix design, or insufficient compaction in the surface, binder, or base courses (Liley, 2018).

Deep and shallow rutting are the two categories into which rutting can be divided. Within the AC layer, shallow rutting usually occurs at a depth of less than 1.5 cm. A stronger, stiffer subbase is required because it provides the foundation for roads, which is essential to road networks. This is one of the requirements to develop a high-quality road with less chance of rutting. Quality control monitoring of the pavement is also necessary. (Chance, 2018). To ensure that the road is sufficiently compacted, a roller typically needs to pass over an HMA stretch three or four times in the short amount of time it takes for the asphalt to cool down. This can be challenging to accomplish. A significant factor in guaranteeing the quality of the asphalt surface is the weight and quantity of passes made by the roller over a given segment of asphalt. As the temperature of the HMA decreases, the aggregate loses its capacity to compress (Smith, 2018).

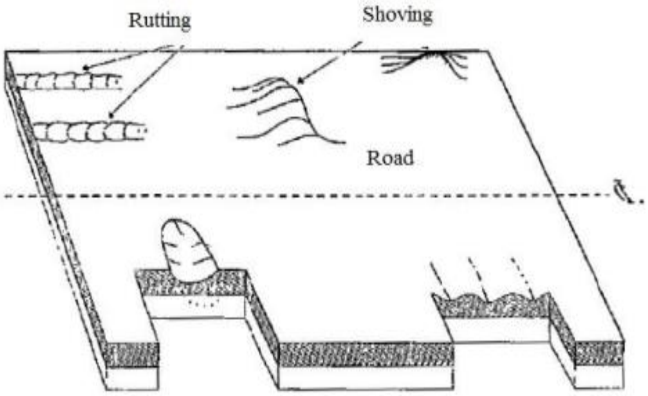

Figure 2.3: Rutting image

2.2.5 Materials used in the construction of the flexible pavement

1. **Bitumen**

The dark, sticky, and viscous substance known as bitumen is produced during the refining of crude oil. It is an intricate blend of hydrocarbons. (Kumar, 2021). To name a few, bitumen grades include 60/70 and 80/100.

Typically, bitumen is classified into two sorts of grades:

- Grades for viscosity

The viscosity of a bituminous material defines its fluid property. A basic, scientific viscosity test using poise as the measurement unit is conducted at 60 °C, which is around the maximum temperature of summer pavement. This test forms the basis for viscosity grading.

- Levels of penetration

The penetration test is performed to characterise and evaluate the bitumen's hardness. The basic idea behind penetration grading is that, in certain conditions of load, temperature, and loading time, the thinner the asphalt, the deeper the piercing of the material specimen.

Table 2.3: Bitumen ASTM standards

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

2. **Aggregates**

Granular materials used in construction, such as sand, gravel, crushed stone, and recycled concrete, are known as aggregates. Limestone and granite are two examples of aggregate kinds used in asphalt concrete. Aggregate sizes utilised in an asphalt mixture include

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

Table 2.5: Aggregates BS AND ASTM standards

TEST	UNIT	SPECIFICATION
AIV	%	<25
ACV	%	<45
TFV (DRY)	KN	

TEST	UNIT	SPECIFICATION
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

3. **Filler**

The performance of asphalt mixtures is greatly influenced by mineral filler, which can be produced artificially or found naturally in aggregates (Chen, 2020). Particle sizes less than 0.075 mm are considered to constitute its definition. These particles can come from aggregate fines or be added in the form of cement or lime.

Reduced specific density or finer particles are advantageous for the filler-asphalt system. Particle shape, plasticity, texture, size, gradation, and particle-size distribution are examples of filler characteristics. Specific surface area (SSA) is the total surface area for a unit mass of material. One of the key elements influencing the interfacial interaction between mineral filler and asphalt binder is specific surface area.

Use of a fillers

- Filling the voids in the aggregate skeleton to create a denser mixture.
- Improving the cohesion of asphalt binder and the stability of the mixture.
- Improving the grading of aggregates therefore the asphalt mixture pavement should be resistant to water and frost, pavement deformations, fatigue cracks and low temperature cracks.

Examples of Fillers include;

Slaked lime, Hydrated lime, Cement Kiln Dust, Fly Ash, lime, Portland Cement, Lime Kiln Dust to mention a few

1. **Hydrated lime.**

Despite being largely insoluble in water, At room temperature, hydrated lime dissolves in clean water to produce an alkaline solution with a pH of about 12.4.. Limewater is an aqueous solution of hydrated lime. It is a medium strong base that reacts with acids to attack some metals, like aluminum, while passivating the surfaces of other metals, like iron and steel, to prevent corrosion. Similar to all metal hydroxides, hydrated lime also takes on a polymeric structure. Commercial production involves processing lime with water. (Company, 2024)

One of the numerous possible bitumen additives used to enhance the characteristics and functionality of asphalt mixtures is hydrated lime. The literature has a good deal of information on hydrated lime's water sensitivity control and its widely recognized anti-stripping properties, which prevent moisture damage.

But new research shows that lime in asphalt mixtures has additional consequences as well. In particular, hydrated lime contains antioxidant properties and functions as an active filler.

Pavements benefit greatly from these attributes in several ways;

Asphalt mixtures have long benefited from the addition of hydrated lime. Its effects are not entirely understood, though. Hydrated lime may show to be an ingredient with a distinctive effect on the damage mechanics and rheology of asphalt mastics due to its distinct characteristics.

To regulate oxidative hardness and ageing in asphalt pavements, additional effective treatments or additives still need to be developed and achieve this, a thorough investigation is required to improve knowledge of the ageing processes, as well as the elements influencing bitumen ageing in the presence of various fillers, particularly hydrated lime. Thus, it is quite interesting to learn how various fillers and hydrated lime affect the ageing of asphalt mixtures. (M.ALfaqawi, 10 Jan 2022)

2. **Ordinary Portland Cement**

The use of Ordinary Portland Cement (OPC) as a filler substitute to increase the stiffness of asphalt concrete mixes including low-quality aggregates and bitumen B60/70 is the subject of this research.

The pavement is more stable and resistant to high temperatures thanks to this new composition. Four different percentages of OPC (0%, 2%, 4%, and 6%) are employed as filler alternatives in three distinct mixes to determine the impact of OPC on the performance of asphalt mixtures in hot climates. The Asphalt Pavement Rutting Analyzer and the Superpave Gyratory Compactor are used to evaluate the three mixes' performance.

The results show that mixes with larger filler percentages of OPC are considerably more rut-resistant. Because of the greater resultant modulus of stiffness, these experimental results demonstrate that Portland Cement Filler Asphalts (PCFA) constitute a more stable option to traditional asphalt while also lowering thickness requirements.

This is especially crucial in arid rural regions like Libya, where there are few quarries and the cost of transporting materials is high. (Assaf, 2020)

3. **Recycled waste lime**

The objective of this research is to ascertain the engineering properties of asphalt concrete that employs recycled waste lime, a by-product of soda ash production, in combination with mineral fillers ($Na2CO3$). In order to examine the viability of employing recycled waste lime, the materials examined in this study were prepared utilizing a 25%, 50%, 75%, and 100% mixing ratio based on the standard mineral filler ratio.

The basic engineering characteristics of the asphalt concretes—recycled waste lime, hydrated lime, and conventional asphalt concrete—such as Marshall stability, indirect tensile strength, resilient modulus, permanent deformation characteristics, moisture susceptibility, and fatigue resistance—were assessed.

The findings show that using recycled waste lime as a mineral filler enhances asphalt concrete's stiffness, fatigue endurance, and permanent deformation characteristics across a broad temperature range. It was also shown that compared to regular asphalt concrete, combinations including recovered waste lime demonstrated a greater resilience against stripping.

Numerous test findings led to the conclusion that waste lime can be utilized as a mineral filler and, in particular, can significantly increase asphalt concrete's resistance to permanent deformation at high temperatures. (Hwang Sung D, 2008)

4. **Bagasse ash**

According to the results of the current experiments, the traditional OPC filler in SMA Mix is replaced by sugarcane bagasse ash (SBA). When 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, given its particle size, shape, specific surface area, and chemical makeup, it appears to be a superior substitute for traditional OPC filler since building roads requires a significant quantity of raw materials, using inexpensive, waste-derived materials like SBA could strengthen the idea of "waste to use." (P.K.Akarsh, 2022)

5. **Lime kiln dust**

Lime Kiln dust is Lime kiln dust (LKD) is a byproduct of the lime manufacturing process, which is generated during the production of quicklimein 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 so improved pavement performance.

Bala and Albrka (2019) investigated the effect 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.

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. (West, 2006)

Several studies have investigated the effect of LKD 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.

Marshall mix design

The MARSHALL METHOD OF MIX DESIGN, devised by Bruce Marshall in the late 1930s for the Mississippi highway department, is a widely adopted technique globally for assessing bituminous paving mixes (White, 1985). It involves blending binder and aggregate in precise ratios to determine the Optimum Binder Content (OBC) and evaluate the strength and flow properties of the asphalt mixture. Mix design entails establishing the relative proportions of these materials, influencing the physical characteristics and performance of the pavement. Key Marshall Characteristics like Marshall stability (ASTM D6927), flow value, and air voids are examined. Flexibility, gauged through the 'flow value,' is assessed by measuring the change in diameter of the sample in the direction of load application from the start of loading to maximum load. A dial gauge records the specimen's deformation (plastic flow) during loading, and the flow value represents the associated plastic flow at material failure.

Gradation of aggregates

One of the most crucial elements in the design of asphalt mixtures is aggregate gradation. One of the main factors affecting gradation is the sieve analysis, mixing, and the set boundaries of the mixture. The most crucial characteristics, such as stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and moisture susceptibility, are determined by gradation. (Roberts, 1996). Therefore, gradation is a primary concern in mix design.

Volumetric mix properties

Volumetrics play a crucial role in asphalt mixtures as they significantly impact pavement performance. Mix design aims to ascertain the volume of bitumen binder and aggregates required to achieve the desired mixture properties (Roberts, 1996). Weight measurements are typically taken due to their convenience and then converted to volume using specific gravities. Key volumetric properties of bituminous mixtures include the theoretical maximum specific gravity (Gmm), bulk specific gravity of the mix (Gmb), percentage of air voids (Va), and percentage volume of bitumen (Vb).

- Theoretical Maximum Specific Gravity

The test was conducted following the standard procedure outlined in ASTM D204. The theoretical maximum specific gravity and voids in the mix were determined using equations 2.1 and 2.2, respectively.

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

VIM $=100\frac{G_{mm}-G_{mb}}{G_{mm}}$ …………………………………………………………….....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

  This is achieved by measuring both the total weight and volume of the mix. Bulk specific gravity (Gmb) represents the specific gravity while accounting for air voids.

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

  Volume is determined by measuring the dimensions of the sample or volume ofwater it displaces.

- Air voids

  The tiny air pockets or voids that form between the coated aggregate particles in the fully compacted mix are significant and directly linked to the performance standards of the mixture. The equation used to calculate the percentage of air voids is essential for assessing mix performance.

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

- Bulk density

  Bulk density was assessed following the guidelines outlined in ASTM D2726-96 (ASTM, 1989). The weight of the compacted specimen was measured in three conditions: in air, in water, and at saturated surface dry condition, after removal from the mold. Bulk density was subsequently computed utilizing equation 2.5.

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

  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 represents the volume of air present between the coated aggregate particles, while VFB denotes the volume occupied by effective bitumen. Both VMA and VFB are expressed as a percentage of the total mix weight and were determined using equations 2.6 and 2.7, respectively.

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

  VFB = $100\frac{VMA-VIM}{VMA}$ .... 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

2.2.8 Traffic loading design

According to AASHTO standards, there exists a correlation between the number of load cycles, pavement structural capacity, and performance assessed by serviceability. For instance, the Kampala-Masaka road study, which experiences high traffic volumes, estimated at 54 MESA currently compared to a projected 44.1 MESA as per Moses (2022), exemplifies this correlation.

To determine the annual traffic loading for design purposes, the total daily traffic loading (ESA/day) values are multiplied by 365, yielding the annual traffic loading for each direction. This figure is typically expressed as millions of equivalent standard axles per year (MESA/year) for each direction.

According to guidelines from the Ministry of Works and Transport (MoWT, 2010), for pavement design purposes, the larger of the two directional values should be utilized.

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 and trailer or heavy truck and semi trailer (more than 5 axles)	33.9 MESA
Total cumulative ESA	54.0 MESA

$$Equivalence\ factor, EF = \left(\frac{Axle\ load\ (in\ tonnes)}{8.16}\right)^{4.5}$$ ....Equation2 .8

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.

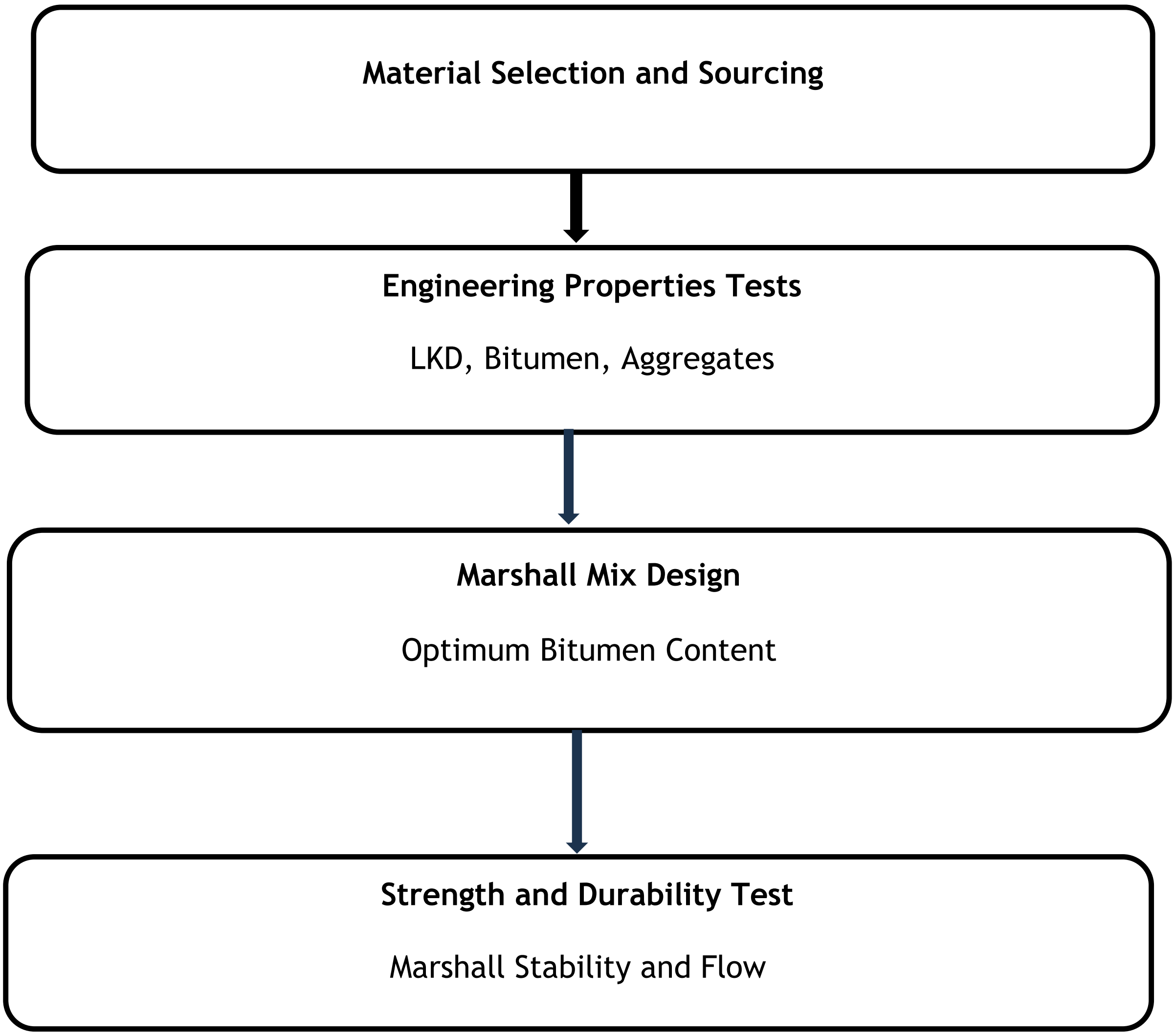

Figure 3.1: Flow chart of methodology steps

3.2 Material selection and sourcing

a) Bitumen

The grade of bitumen used in the study was 60/70 which is commonly used around the world and 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 of AC- 14 which means different sizes of aggregates used in the mix which are 14-20,10-14, 6-10, 0-6 (mm) in gradation with varying percentages in the mix design. Nominal size of aggregates is 14mm

c) Filler

Lime Kiln dust was sourced from Hima cement Limited located in the deep of Namanve Park close to Namilyango, Uganda. The material was sieved to ensure that it's the fraction that passed the #200 sieves.

Figure 3.2: material sourcing

3.3 Primary data collection methods

3.3.1 Aggregate Crushing Value (ACV)

The Aggregate Crushing Value (ACV) was employed to assess the extent to which an aggregate can withstand crushing under a gradually applied load, thereby gauging the strength of coarse aggregates. Weak aggregates could potentially compromise the integrity of the pavement structure. REFRENCE- BS 812: Part 110: 1990

3.3.2 Aggregate Impact Value (AIV)

The Aggregate Impact Value (AIV) was utilized to gauge the relative resistance of diverse aggregates against sudden distortions. Its significance lies in determining the mechanical attributes of the individual aggregates, which in turn influence the mix design process. REFERENCE- BS812: Part 112: 1990

3.3.3 Ten Percent Fine Value (TFV)

The ten per cent fines value test was conducted to assess an aggregate's ability to withstand crushing under a gradually applied load. The TFV (10% Fines Value) aimed to determine the load necessary to crush a prepared aggregate sample to yield 10% of material passing a specified sieve after crushing. REFRENCE- (BS 812: P111: 1990)

3.3.4 Flakiness Index

The Flakiness Index served as a method for categorizing aggregates, with particular attention to meeting specific requirements concerning the presence of flaky particles. In the context of base course and wearing coarse aggregates, the existence of flaky particles was deemed undesirable due to their potential to introduce inherent weaknesses, which could lead to failure under heavy loads. Aggregates were classified as flaky if their thickness was less than 60% of the mean sieve size. REFERENCE- (BS 812-P105:1-1989)

3.3.5 Particle Size Distribution

Particle size distribution analysis served as the primary method for classifying soils, as it provided insights into the relative proportions of various particle sizes, enabling determination of whether the soil contained predominantly sand, clay, gravel, or other components. The procedure involved preparing the sample through wet sieving to eliminate silt and clay-sized particles, followed by dry sieving of the remaining coarse material. Its objective was to evaluate the relative proportions of different particle sizes, as well as aggregates and fillers to some extent. REFERENCE- (BS 812-P103-1)

3.3.6 Specific Gravity

Specific gravity was used to determine the water absorption of aggregates and the filler which gave a value of the strength of the material that was compared with other materials and since specific gravity was high, it confirmed the filler and aggregates as good materials.(BS 812 Part 2:1975)

3.3.7 X-Ray Fluorescence Spectrometry

This standard provided guidelines for developing and describing analytical procedures using a wavelength dispersive X-ray spectrometer for elemental analysis of solid metals, ores, and related materials. The method gave the chemical composition of the mineral filler (LKD) Reference- ASTM E1621-22

3.3.8 Softening point test (ASTM D36)

The softening point test was utilized to assess the consistency of bitumen, representing the temperature at which a transition from solid to liquid occurs for bitumen grade 60/70. This determination aided in understanding temperature susceptibility, a critical factor in asphalt design.

3.3.9 Penetration test (ASTM D5-86)

The standard penetration test was conducted using an Analis Penetrometer P734 on base bitumen, aiming to assess the hardness and softness of the bitumen and its resistance to flow. The desired penetration grade of 60/70 was achieved.

3.3.10 Marshall Mix Design

Bituminous paving mixes were designed and assessed using the Marshall method of mix design. The Marshall test was used to measure physical properties of asphalt specimens that relate to plastic deformation properties of asphalt mixes. Samples of the aggregates, filler, binder were mixed together to for specimens and compacted to determine the air voids, stability and flow at different conditions.

In order to achieve a mix that is resistant to distortion, displacement, rutting, and shearing stress, we were able to determine the ideal bitumen content to use in the mix by using the mix design, which allowed for the determination of bitumen amount for the mix for the cases where we had maximum stability, maximum flow, maximum density, and voids.

3.3.11 Specific gravity

Specific gravity was used to determine the bulk specific gravity of the asphalt and its water absorption rate. ASTM D2726. This was done to identify which cores had high or low voids so as to determine which one of them qualified to Marshall stability or Indirect tensile strength.

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)

3.3.12 Maximum specific gravity(Gmm)

The theoretical maximum specific gravity (Gmm) of the mix was determined usingASTMD2041 of uncompacted bituminous paving mixtures as it was an intergral part for quality assurance of asphalt specimens.

3.3.13 Marshall stability test

Marshall stability test was used to determine the maximum load required to produce failure when the specimen was subjected to a given amount of heat and to measure the load and flow rate of asphalt specimens. The load was applied with the Marshall breaking head at a constant rate of 50.8 mm/min and this was needed to determine strength in traffic conditions.

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 nearest 0.1 mm	temperature of test specimen at testing (°C)
maximum load value (N)		

3.3.14 ITS (Indirect Tensile Strength)

The test was employed to ascertain the indirect tensile strength and E-modulus of bituminous mixes, with the obtained results serving multiple purposes such as evaluating material quality/strength and aiding in pavement design, evaluation, and analysis. The maximum load recorded during the test was utilized to compute the indirect tensile strength under alternate hot and cold conditions, providing insights into pavement strength behavior.(ASTM D3967)

Flow chart for the Asphalt conditions

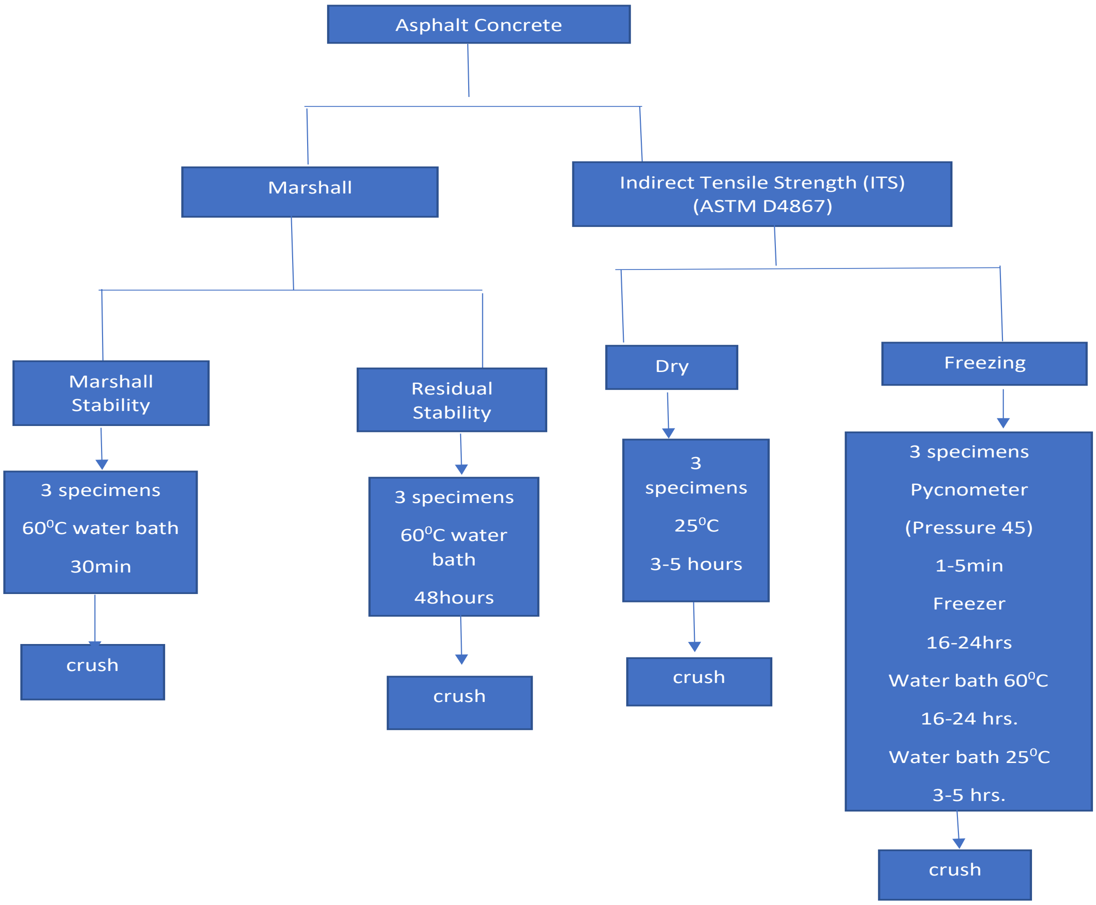

Figure 3.3: Flow chart of Asphalt tests

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter shows the results from the tests carried out in this study. The data is analyzed, discussed and represented as per the results from tests to investigate use of lime kiln dust as a filler in asphalt concrete.

4.1 Aggregate Crushing Value

Table 4.1: Aggregate Crushing Value

ACV	1	2	3
(A) WT BEFORE CRUSHING	2860.5	2826.2	2799.6
(B) WT AFTER CRUSHING	2859.5	2825.8	2799.1
(C) WT RETAINED AFTER CRUSHING	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		

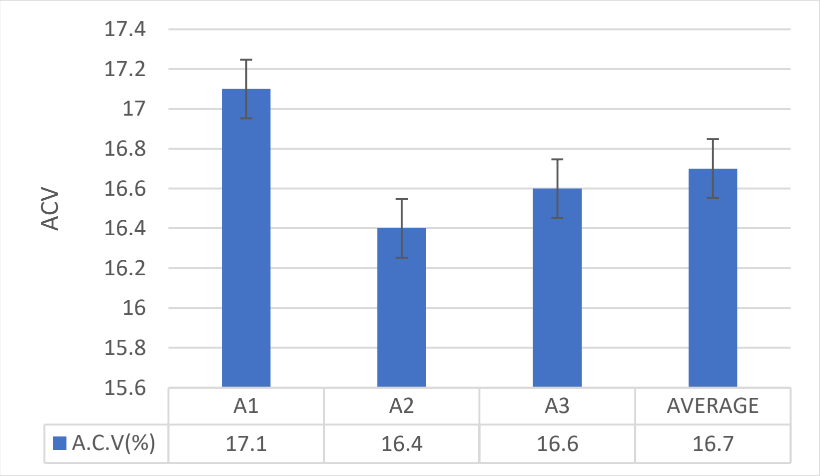

Figure 4.1: Aggregate Crushing Value graph

The average ACV value was 16.7% as shown in table 4.1 which is less than 30% according to the specification BS PART 110:1990 hence it was suitable to be used in the asphalt mix design.

This implies that they lie within range and that the aggregates used had enough strength to resist crushing under a compressive and traffic load.

4.2 Aggregate Impact Value Test Results (AIV)

Table 4.2: Aggregate Impact Value

A.I. V	TEST 1	TEST 2	TEST 3
(A) WT BEFORE TEST	356.2	358.1	367.5
(B) WT AFTER TEST	355.5	357.9	367.5
(C) WT RETAINED AFTER TEST	300.5	305.9	311.1
(D) WT PASSING SIEVE 2.36mm	55.7	52.2	56.4
A.I.V(%) (D/B) *100	15.7	14.6	15.3
AVERAGE RESULTS %	15.2		

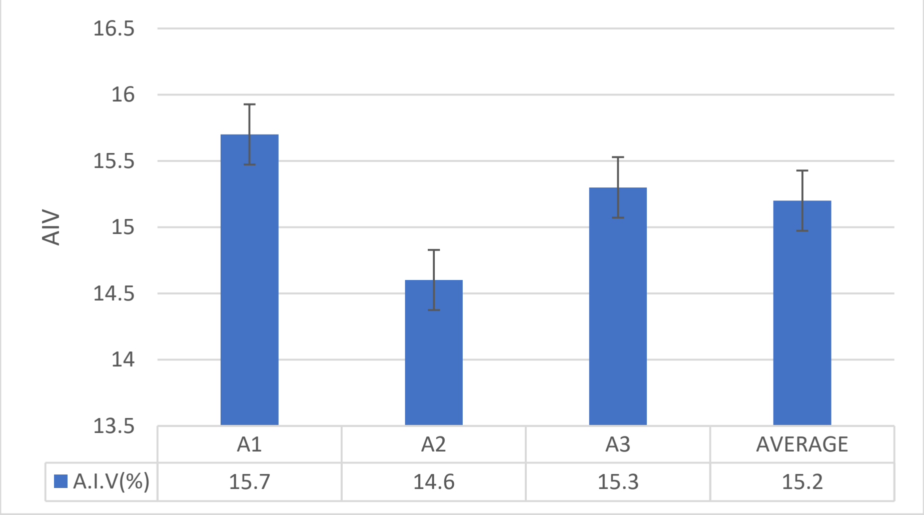

Figure 4.2: A graph of Aggregate Impact value results

The average of the aggregate Impact Value was 15.2% as seen in table 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

Table 4.3: 10% Fine Value Dry

TEST NO	B1	B2	B3
CRUSHING FORCE (KN)	263	263	263
WT. OF AGGREG (gm) after crushing (M1)	2832.9	2868.7	2896.3
WT. OF AGGREG. RETAINED ON SIEVE 2.36mm(M3)	2550.1	2582.7	2601.2
WT. AGGREG. (gm) PASSING SIEVE 2.36 mm (M2)	282.8	286	295.1
TEN % FINE VALUE (M=M2/M1*100)	10	10	10.2
AVERAGE RESULTS % (M)	10		
AVERAGE CRUSHING FORCE (F)	263.2		

Table 4.4:10% Fine Value Soaked

TEST NO	B1	B2	B3
CRUSHING FORCE (KN)	263	263	263
WT. OF AGGREG (gm) after crushing (M1)	2863	2864	2851.8
WT. OF AGGREG. RETAINED ON SIEVE 2.36mm(M3)	2555.3	2555.3	2528.5

TEST NO	B1	B2	B3
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		
AVERAGE CRUSHING FORCE (F)	263.2		

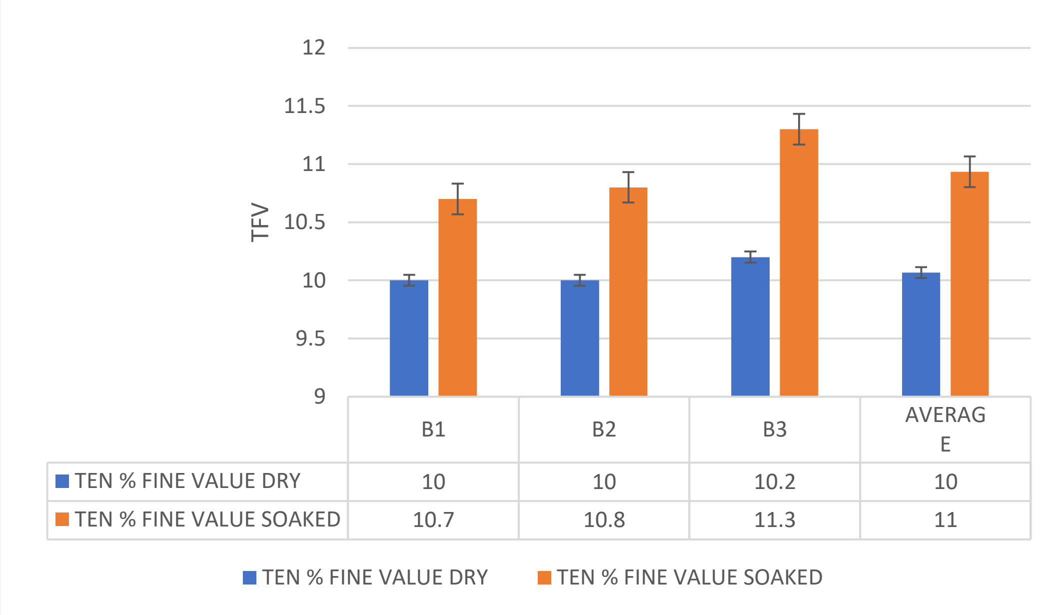

Figure 4.3: combined Ten percent fine value graph

The TFV Dry obtained was 10KN and the TFV Soaked was 11KN as shown in tables 4.3 and 4.4 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 strong enough to resist crushing under traffic loads and suitable to be used in the mix design.

4.4 Specific gravity and water absorption

Table 4.5: combined specific gravity and water absorption

BLEND SIZE	BULK SG	BULK SSD	APPARENT SG	WATER ABSORPTION
14-20mm	2.621	2.628	3	0.3
10-14mm	2.615	2.626	3	0.4
6-10mm	2.596	2.614	3	0.7
0-6	2.613	2.623	3	0.4

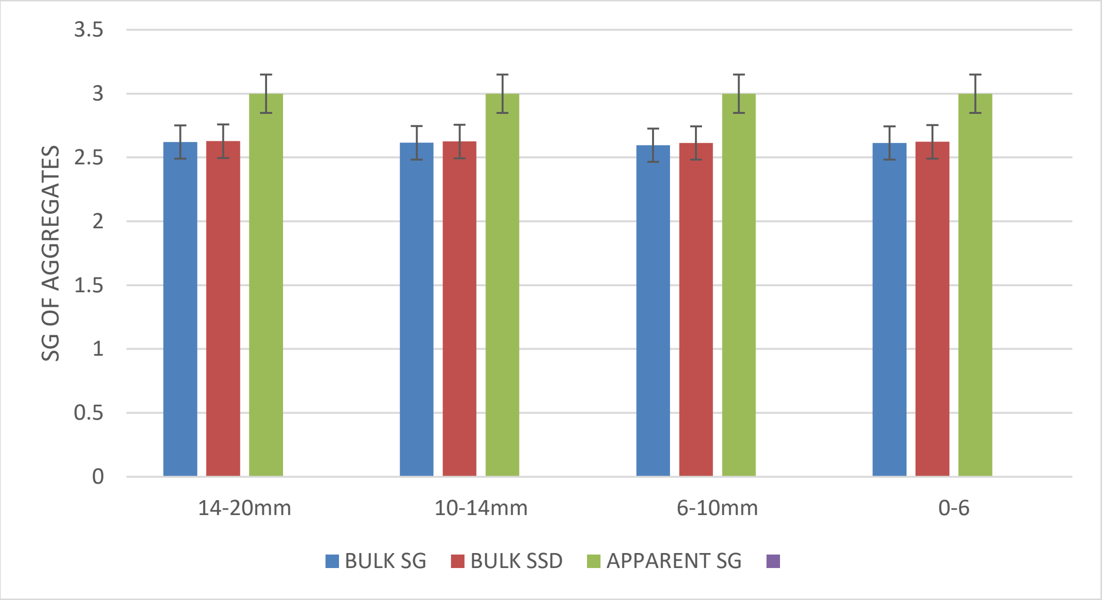

Figure 4.4: specific gravity proportions of different aggregate sizes

The average value of the combined specific gravity was 2.608 and water absorption was 0.4%.The average specific gravity of aggregates was 2.608 which is in range of 2.5 -3.0 according to ASTM C128 specification and this indicated low porosity, high strength and high durability of the aggregates.

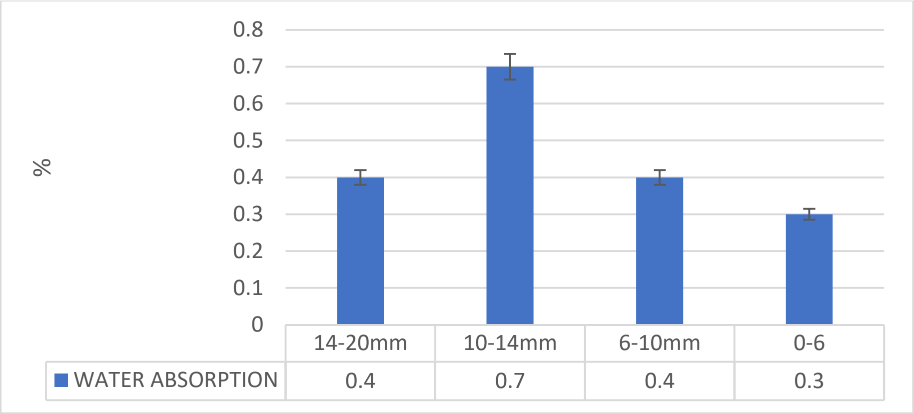

Figure 4.5: water absorption

The average value of water absorption was 0.4% should ideally be less than 0.6% based on the ASTM C128 , hence the above aggregates, having an average water absorption which is low, 0.4% made them suitable for the study.

4.5 Flakiness index

According to BS 812: Section 105.1:1989, aggregates used in road construction should have a flakiness index of less than 15% and normally does no go beyond 25%.

Table 4.6: Flakiness Index

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

BS sieve size (mm)	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	104.5	
Corrected Wt. passing (dxc)	20	20

4.6 Penetration Test of Bitumen

Table 4.7: Penetration test

CUP LABEL	D	S2	9	CM	IFF	K	AVERAGE
	65	65	64	70	66	65	
	66	66	62	65	65	68	
	68	64	68	65	63	69	
PENETRATION (25C)	66	65	65	67	65	67	66

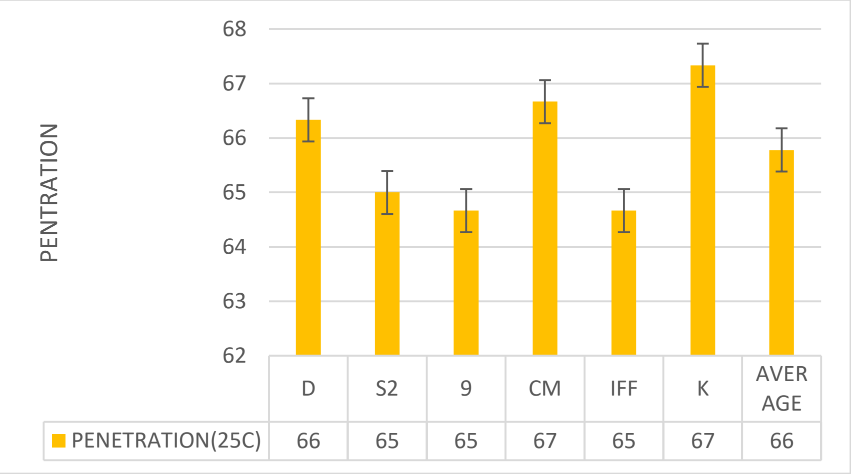

Figure 4.6: penetration test result graph

The average value of the penetration test from table 4.7 was 66. The specification used to carry out the test according to ASTM D5 gives a permissible range of 60-70 and therefore the bitumen grade of 60/70 was suitable in terms of the hardness and consistency of the mix for the tropical regions as it provides more durability and stability.

4.7 Softening Point of Bitumen

Table 4.8: Softening point Test

RING 1			RING 2			AVERAGE
TIME (MINUTES)	TEMP °C	TEMP RISE °C	TIME (MINUTES)	TEMP °C	TEMP RISE °C	
0	9.0	9.0	0	9.0	9	
1	13.0	4.0	1	13.0	4	
2	17.0	4.0	2	17.0	4	
3	22.0	5.0	3	22.0	5	
4	27.0	5.0	4	27.0	5	
5	32.0	5.0	5	32.0	5	
6	37.0	5.0	6	37.0	5	
7	42.0	5.0	7	42.0	5	
8	47.0	5.0	8	48.0	6	
9	50.5		9	51.0		
SOFTENING POINT (°C)	50.5			51.0		50.8

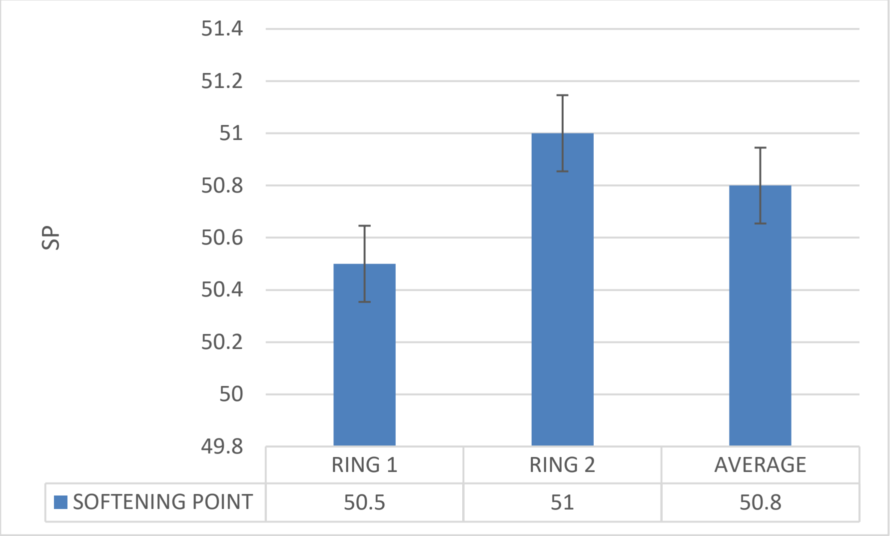

Figure 4.7: softening point graph

The value of softening point was 50.8 from table 4.8 and the specification was according to ASTM D36 that gives a range of (49-56) °C. The value obtained gave the temperature at which bitumen becomes soft enough to allow the steel ball to sink at specified distance which means that the bitumen used will have a high temperature susceptibility which was favourable for Asphalt.

4.8 Specific gravity of bitumen

Table 4.9:Specific gravity of bitumen

Cup No.		**D**	**S2**	**9**	**CM**	**IFF**	**K**	**AVG**
Weight of cup in air	A	112.6	113.73	114.65	114.04	108.80	112.28	
Weight of cup filled with water	B	191.6	193.30	195.28	196.18	182.76	191.68	
Weight of cup partially filled with bitumen in air	C	178.04	177.91	176.23	176.8	165.91	173.71	
Weight of cup filled with bitumen & water	D	193.38	194.95	197.00	198.1	184.29	193.25	
Volume of the cup	B-A	79.0	79.6	80.6	82.1	74.0	79.4	
Weight of bitumen	C-A	65.460	64.180	61.580	62.790	57.110	61.430	
Volume of the water above bitumen level.	D-C	15.340	17.040	20.770	21.260	18.380	19.540	
Volume of the bitumen	((B-A)-(D-C))	63.630	62.530	59.860	60.880	55.580	59.860	
Bulk specific gravity of bitumen (Gb)		1.029	1.026	1.029	1.031	1.028	1.026	1.028
Average Bulk specific gravity of bitumen (Gb)		1.028						

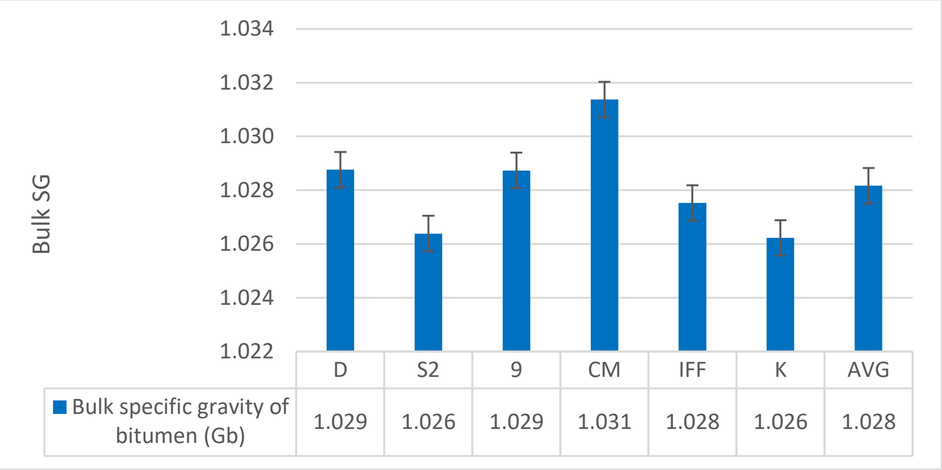

Figure 4.8: Bulk Specific gravity of bitumen

The value obtained from table 4.9 was 1.028 in line with the specification used according to ASTM D70 with range of 1.01-1.06 as the permissible density of bitumen to be used for proper homogeneity of the asphalt mix with the proper proportions of the 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 reveal that the investigated major elements of lime kiln dust were Cao and SiO_2

Table 4.10: Chemical composition of Lime Kiln Dust

CHEMICAL COMPOSITION	UNIT	RESULT
Cao	%	39.61
MgO	%	2
SiO2	%	13.35
Al2O3	%	2.66

CHEMICAL COMPOSITION	UNIT	RESULT
S03	%	1.25
K2O	%	0.61
Fe2O3	%	2.63
Na2O	%	0.46
P2O5	%	0.24
LOSS OF IGNITION	%	37.61

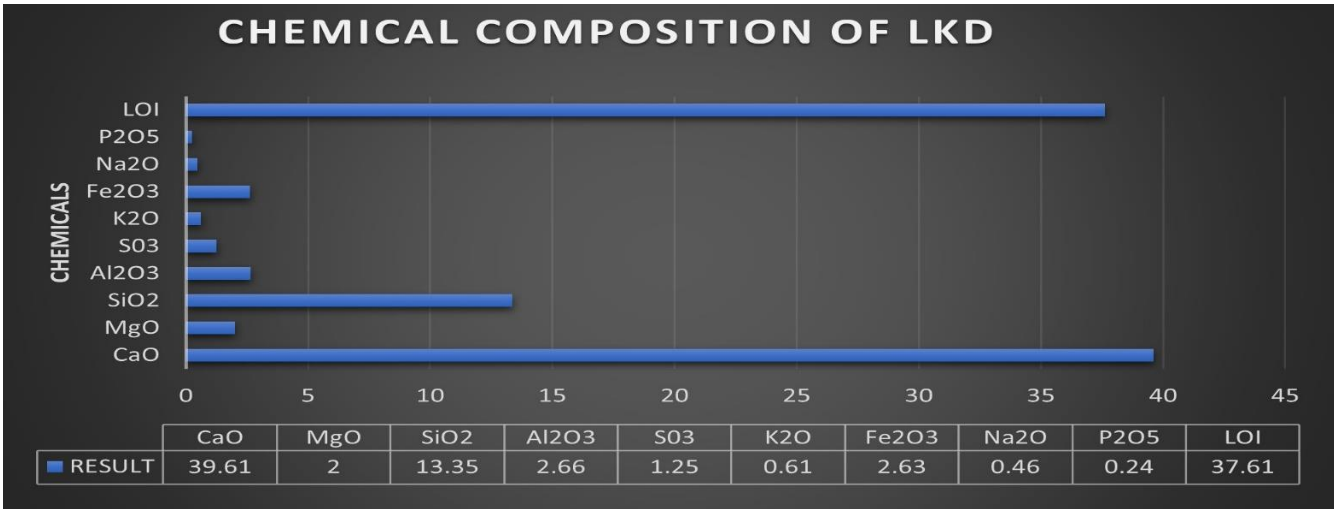

Figure 4.9: Chemical composition of LKD

Figure 4.9 show the chemical composition of the LKD that is CaO-39.62 and SiO2-13.35 which improve the adhesion and the bonding between the aggregates (Moser, 2015). The SiO2 also increases the rutting resistance, improves tensile strength of an asphalt pavement as well as fatigue life if bitumen (Gholam,2020).

4.10 Specific gravity for the filler

Table 4.11: Specific gravity of filler

SPECIFIC GRAVITY FILLER (AASHTO T100-95(1995)			
	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 Pycnometer containing sample and water	2082.72		2042.56
SPECIFIC GRAVITY FILLER	2.567		2.562
AVERAGE	2.564		

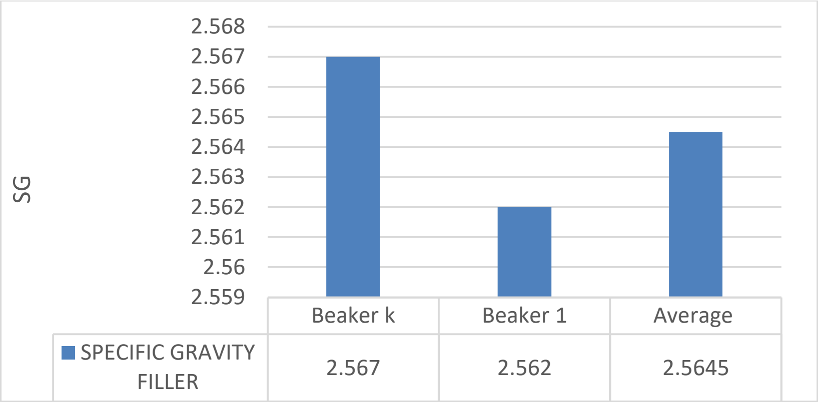

Figure 4.10: lime kiln dust specific gravity graph

The value (2.564) lies within the standard specification ranges of 2.4 to 3 and hence is fit to be used in the asphalt mix and this will have a positive impact on the stability and volumetric properties of the mix.

4.11 JOB MIX FORMULA TEST RESULTS

Job mixes for combined grading

Table 4.12: Job mixes for combined grading

	14/20 MM		**10/14MM**		**6/10MM**		**0/6MM**		**FILLER**		**Theoretical actual**	**TARGET GRADING**	**SPEC**
		5.0		**7.0**		**15.0**		**69.0**		**4.0**	**100.0**		
20	98.9	4.9	100.0	7.0	100.0	15.0	100.0	69.0	100.0	4.0	**100**	**100**	**100**
14	32.2	1.6	96.3	6.7	100.0	15.0	100.0	69.0	100.0	4.0	**96**	**93**	**85—100**
10	6.1	0.3	29.8	2.1	99.2	14.9	100.0	69.0	100.0	4.0	**90**	**83**	**72—94**
5	2.4	0.1	2.3	0.2	10.0	1.5	77.4	53.4	100.0	4.0	**59**	**62**	**52—72**
2.36	2.2	0.1	1.9	0.1	3.9	0.6	48.3	33.3	100.0	4.0	**38**	**46**	**37—55**
1.18	2.0	0.1	1.7	0.1	3.1	0.5	33.0	22.8	99.6	4.0	**27**	**34**	**26—41**
0.6	1.9	0.1	1.6	0.1	3.0	0.4	25.2	17.4	97.3	3.9	**22**	**22**	**16—28**
0.3	1.8	0.1	1.4	0.1	2.8	0.4	18.3	12.6	88.8	3.6	**17**	**16**	**12—20**
0.15	1.6	0.1	1.4	0.1	2.7	0.4	13.2	9.1	72.8	2.9	**13**	**12**	**8—15**
0.075	1.5	0.1	1.3	0.1	2.5	0.4	10.2	7.0	53.3	2.1	**10**	**7**	**4—10**

Table 4.12 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%.

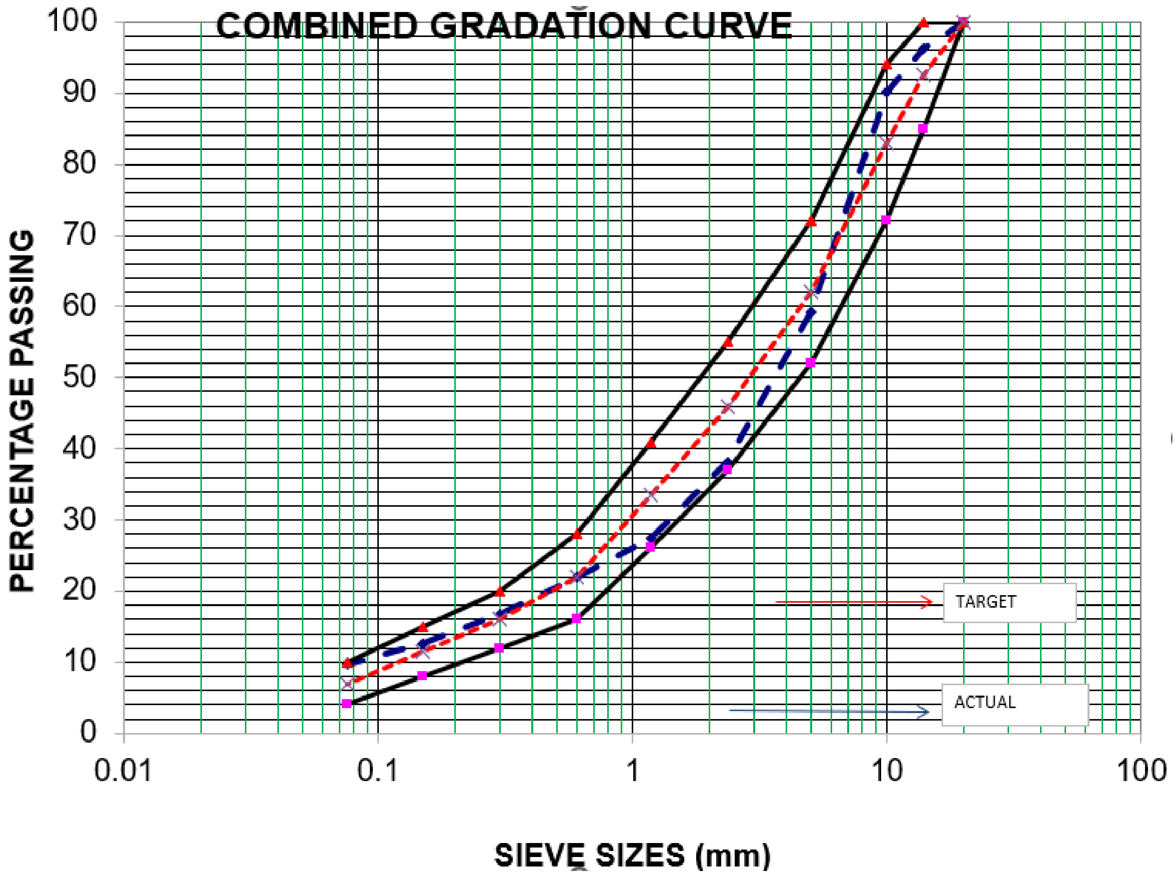

Figure 4.11: combined grading curve

Figure 4.11 represents the AC 14 individual gradation and shows that the grading lies between specified grading envelopes of both the upper and lower limits hence the distribution of the aggregates achieved a proper mechanical adhesion of aggregates which positively affects the durability of the mixture.

4.12 Marshall Mix design to determine Optimum Bitumen Content

Table 4.13: 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

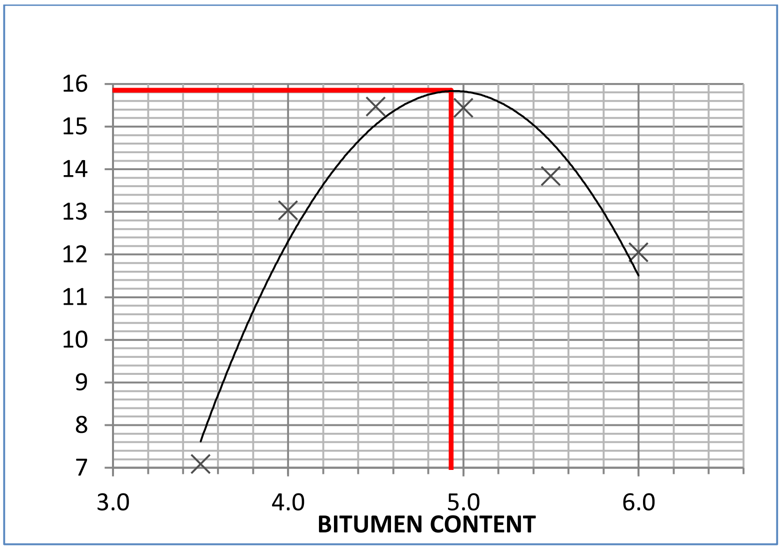

Figure 4.12: Graph of air voids against bitumen content

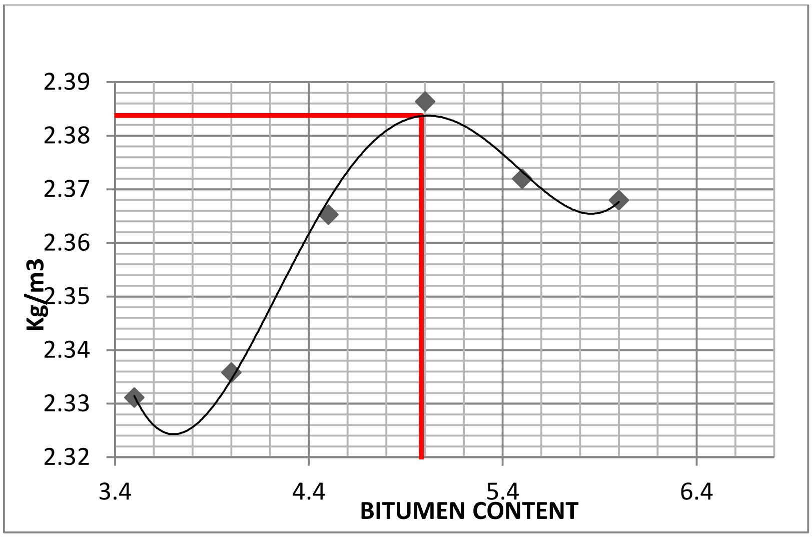

Figure 4.13: Graph Density against bitumen content

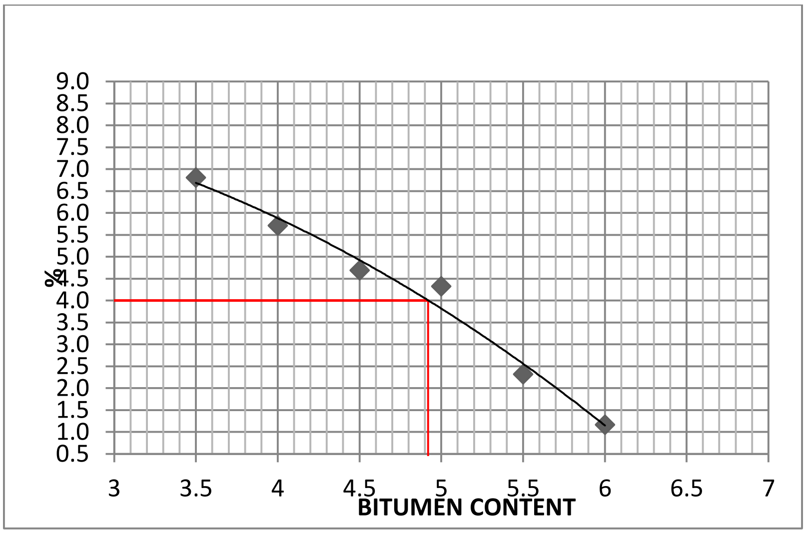

Figure 4.14: Graph of voids against bitumen content

The Marshall Mix Design was used to determine the optimum bitumen content. For each mix, two samples for Gmm and three Marshall Cores were obtained by changing the bitumen content by ±0.5. As shown in Table 4.13, the various mixes were tested to determine their density, stability, voids, and flow. Graphs were then plotted to determine the optimal bitumen content, as shown in Figures 4.11, 4.12, and 4.13. In order to ensure that our bitumen was neither too brittle nor too liquid to produce bleeding of the asphalt mix, we reached the optimal stability and density levels of 4.9% and 5% and at 4% voids the optimum bitumen was 4.9% and for the flow at optimum.

Table 4.14: Determining the Optimum Bitumen Content

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

Table 4.14 shows that the stability, density, and voids calculations yielded an average of 4.9% for the asphalt mixture's optimum bitumen content. This represents the percentage that the research design took into account for bitumen.

4.13 Asphalt Design Mix Proportions

Table 4.15: 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 mix proportions of the asphalt mixture with 4% lime kiln dust filler are displayed in table 4.15. Following the determination of the 4.9% Optimum Bitumen Content, the remaining 100 percent was split between filler and different aggregate sizes. The mass in the mix was calculated using the formula (%Asphalt concrete x Total mass of mix).For the asphalt mix design, the total mass of mix was 18 kg.

4.14 Performance Tests for Asphalt

Table 4.16: 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

With lime kiln dust filler, the Marshall stability value (Fig. 4.14) rose by 2.3 KN from 14.8 KN of neat asphalt stone dust to 17.1 KN. This suggests that improved pavement structural integrity is a factor in its long-term durability.

Increased stability validates the longevity and performance of the asphalt mixture and suggests that the asphalt concrete is more resistant to rutting. This results from increased bitumen and aggregate adhesion.

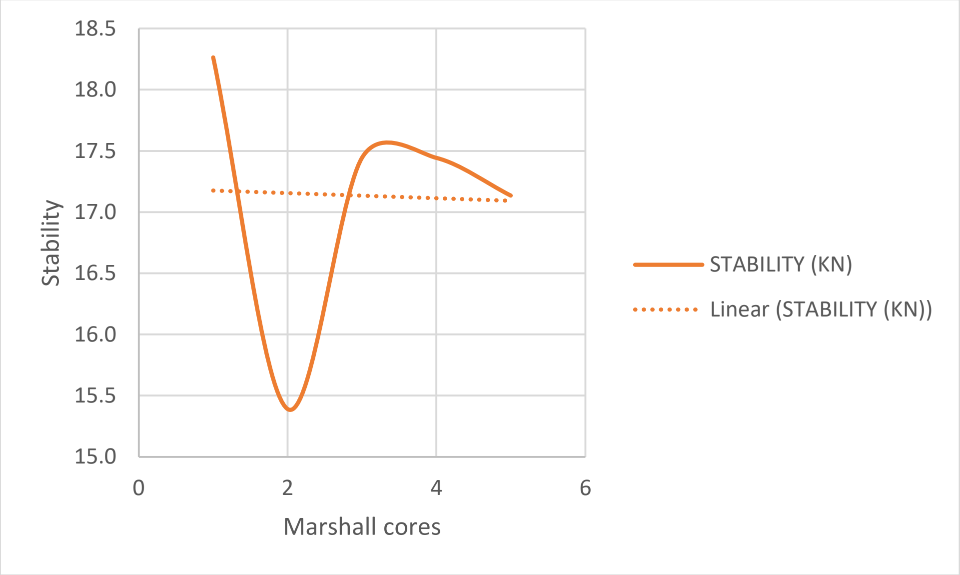

Figure 4.15: AC14 & LKD - Stability

Marshall Flow

With stone dust filler, the flow value (Fig. 4.15) rose by 0.7 mm to 3.5 mm with lime kiln dust filler. The flow value displays the Hot Mix Asphalt's plasticity or deformation under repeated loading (MoWT, 2010).

Greater flow values signify enhanced pliability and resilience against cracking, particularly in warm climates where appropriate compaction is crucial for preserving the longevity of asphalt pavement due to the absence of water infiltration.

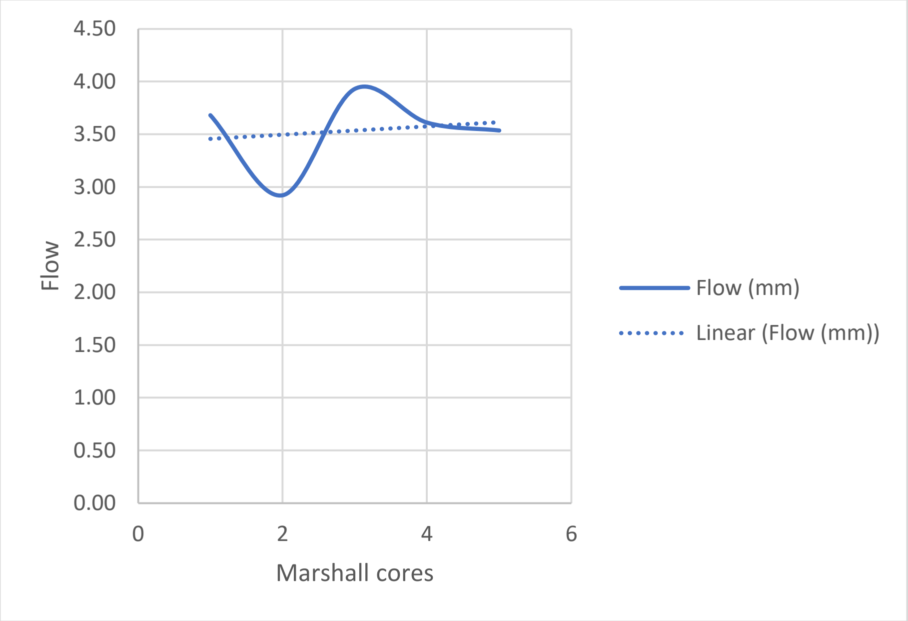

Figure 4.16: AC 14 & LKD- flow

Air voids

According to (MoWT, 2010), the average air void value (Fig. 4.16) was 4.9%, falling within the authorized range of 3-5%. Given that appropriately managed air gaps are necessary for the longevity of flexible pavements, this suggests that the voids are neither too high nor too low, improving the integrity of the pavement structure and extending its service life.

Elevated air gaps may result in problems with permeability and harm due to oxidation, moisture-induced distresses, and freeze-thaw cycles. On the other hand, insufficient air spaces may lead to insufficient coverage of asphalt binder and less flexibility, which may increase the material's vulnerability to rutting and cracking deformation.

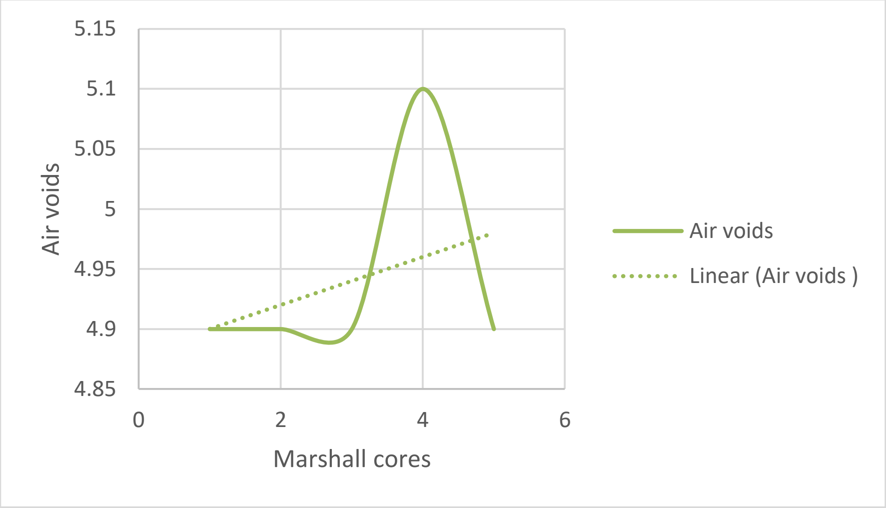

Figure 4.17: AC14&LKD- Air voids

Voids in Mineral Aggregates (VMA)

The VMA value (Fig. 4.17) was 15.1%, falling within the MoWT (2010) specified range of greater than 15%. The result suggests that there are adequate voids in the aggregates for a suitable coating of asphalt binder, which increases the aggregates' resistance to moisture damage and increases their longevity. Increased VMA helps the asphalt mixture's particles interlock, which strengthens its resistance to rutting and deformation. As a result, the pavement surface becomes more resilient and solid, making it better equipped to tolerate traffic volumes and environmental pressures over time.

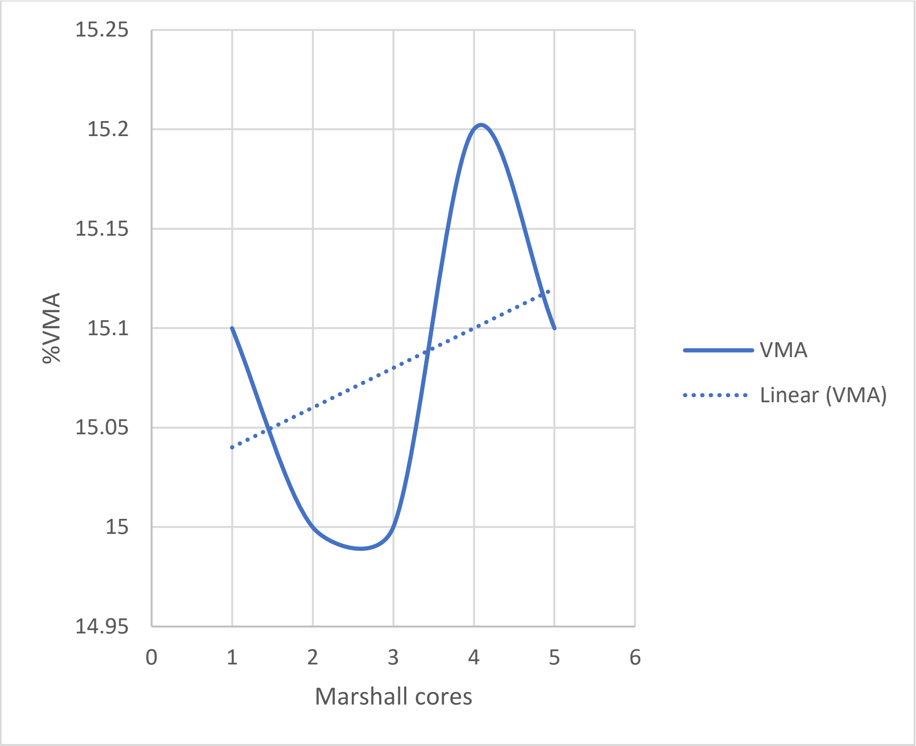

Figure 4.18: AC14 & LKD- VMA

Voids filled with Bitumen (VFB)

According to (MoWT,2010), the value of VFB (Fig. 4.18) was 67.3%, falling within the specified range of 65-75%. In order to guarantee sufficient compaction and an appropriate amount of asphalt binder in the mix, the value of VFB indicates that the mixture is appropriately filled with voids.

The cohesiveness and adherence of aggregate particles are improved by a higher VFB, which also increases the pavement structure's overall strength and durability.

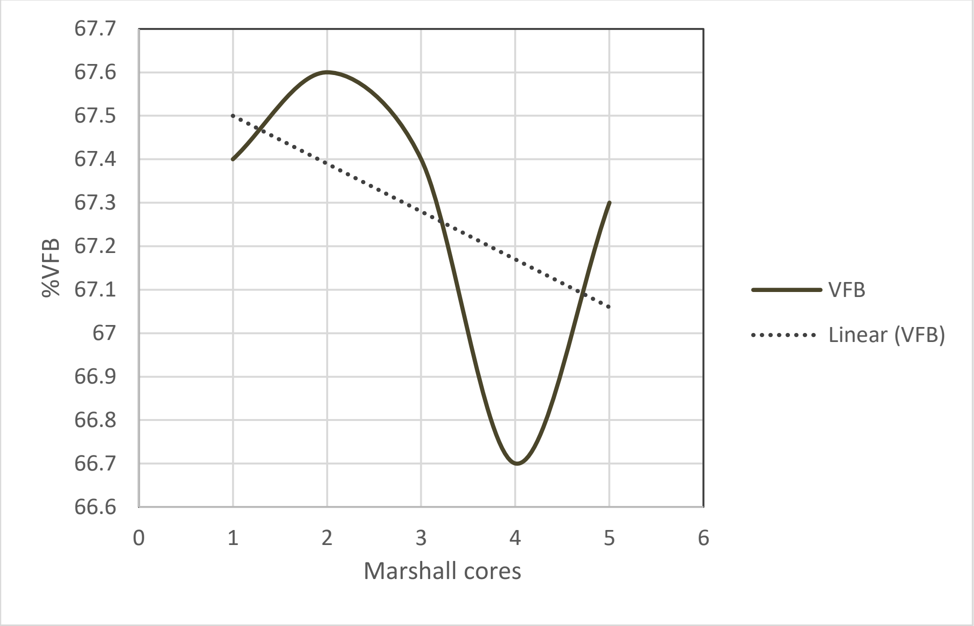

Figure 4.19: AC14 & LKD- VFB

4.15 Indirect Tensile Strength (ITS)

Table 4.17: Indirect Tensile Strength Results

Indirect Tensile Strength(ITS)	Lime kiln Dust filler	Neat Asphalt filler	Specification
Indirect Tensile Strength @ 25ºC	1086kPa	1011kPa	>800kPa
Indirect Tensile Strength Wet Strength	81%	90%	>80% of dry

Table 4.16 provides a summary of the obtained Indirect Tensile Strength, while the annex provides more details. According to (MoWT, 2010), the average value for the ITS (dry) of 1086 kPa was greater than the value for the neat asphalt filler of 1011 kPa and fell inside the (>800 kPa) criteria. This suggests that the stiffness and

strength resistance of the asphalt concrete mixture are superior under traffic loading.

As per the MoWT (2010), the average wet ITS value was 81%, surpassing the dry strength threshold of 80%.This suggests a strong resistance to moisture damage because increased tensile strength prolongs pavement distress such fatigue failure and crack formation, preventing them from occurring and increasing longevity.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The study focused on the use of lime kiln dust as a mineral filler in asphalt concrete to improve the stiffness and durability of asphalt concrete for flexible pavements.

The main objective of the project was to investigate the use of Lime Kiln Dust as a filler in asphalt concrete for durable flexible pavements which was attained by the aid of three other specific objectives. The three specific objectives comprised of the following test and the results that were obtained;

- The ACV-16.7%,AIV-15.2% ,TFV dry-10KN and for the wet 11,FI-16.1 and the PSD which were for obtaining the engineering properties of the aggregates; the penetration test for the consistency of the bitumen which was 66 , the softening point test for temperature susceptibility of the bitumen which was 50.8 and the specific gravity test to find out the coating ability of the bitumen on to the aggregates which was 1.028 and then the XRF and specific gravity for the filler material where the XRF was used to obtain the composition of the filler to ascertain whether it has the essential chemical that SiO_2 and CaO necessary for the adhesion. The purpose of these tests was to determine if the materials meet the standards to be used for the project which they did.
- The second objective was obtained by the Marshall Mix Design to determine the optimum bitumen content which was 4.9% an average gotten from the density, stability and voids graphs that were plotted against bitumen content.
- For the final objective, The Marshall stability improved 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 implies stability and resistance to rutting under different heavy traffic loads hence improving durability of asphalt pavement.

5.2 Recommendations

Based on study findings,

1. The 4% incorporation of lime kiln dust in asphalt concrete should be used to obtain a flexible pavement with enhanced durability.

For future studies

1. Investigations should be carried out on the performance of the asphalt concrete with the different percentages of lime kiln dust.
2. Investigations should also be done to determine how lime kiln dust reacts with the different types of asphalt concrete.

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APPENDIX

Sieve analysis

Final mix by mass of mix design

Softening point test

Compacted Marshall cores

Compaction of Marshall Cores

Aggregate collection

Oven dried lime kiln dust sample

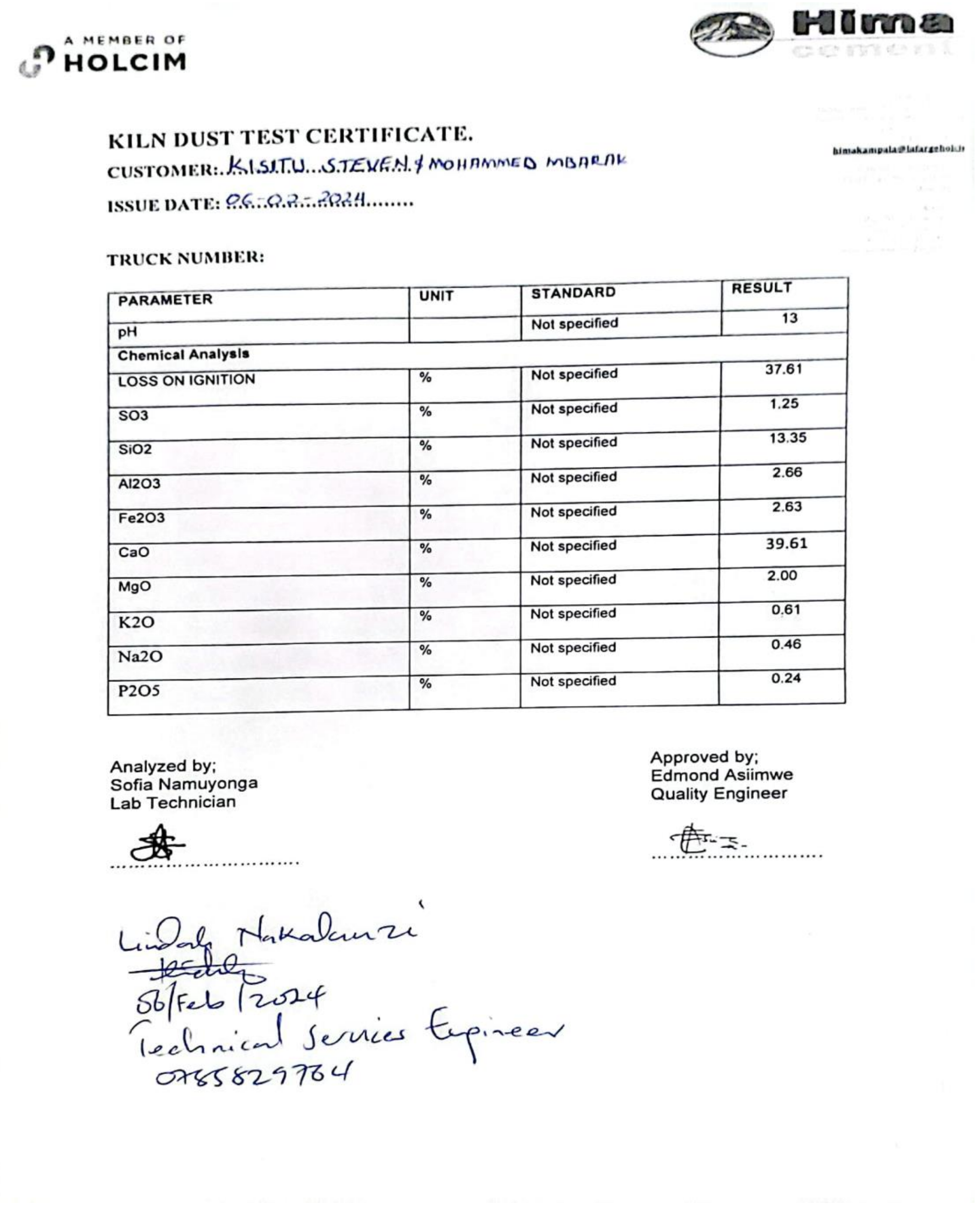
Marshall and ITS testing

Mixing AC 14 with filler

Weighing of aggregates

ANNEXES

Annex A: the results of engineering properties of Lime Kiln Dust, Bitumen and Aggregates.



A MEMBER OF HOLCIM

Hima cement

himakampala@lafargehol

KILN DUST TEST CERTIFICATE.

CUSTOMER: KISITU STEVEN & MOHAMMED MBARAK

ISSUE DATE: 06-02-2024

TRUCK NUMBER:

PARAMETER	UNIT	STANDARD	RESULT
pH		Not specified	13
Chemical Analysis			
LOSS ON IGNITION	%	Not specified	37.61
SO3	%	Not specified	1.25
SiO2	%	Not specified	13.35
Al2O3	%	Not specified	2.66
Fe2O3	%	Not specified	2.63
CaO	%	Not specified	39.61
MgO	%	Not specified	2.00
K2O	%	Not specified	0.61
Na2O	%	Not specified	0.46
P2O5	%	Not specified	0.24

Analyzed by;
Sofia Namuyonga
Lab Technician

Approved by;
Edmond Asiimwe
Quality Engineer

Linda Nakalanzi
06/Feb/2024
Technical Services Engineer
0785829764

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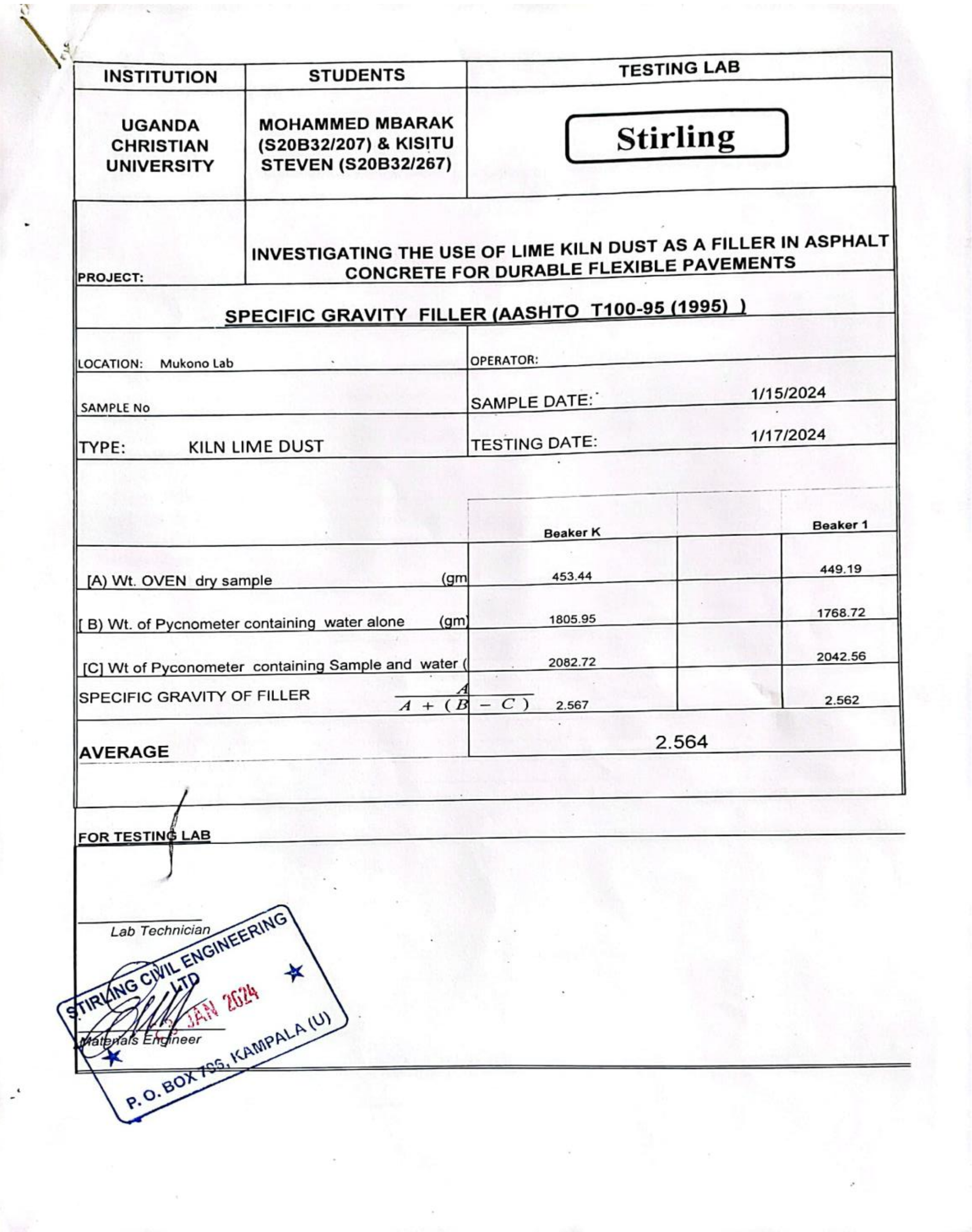


INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	**Stirling**
PROJECT:	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

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

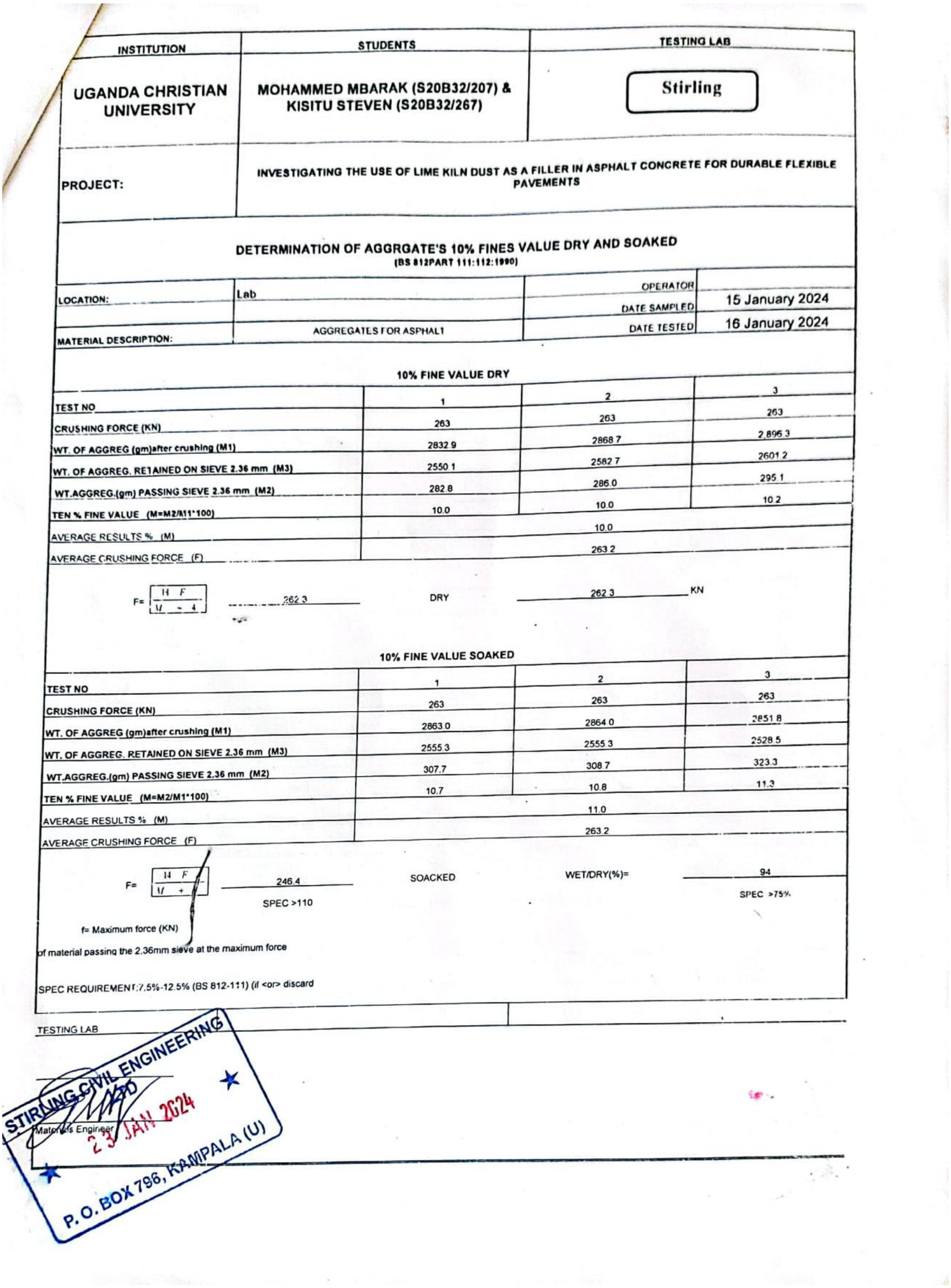
	Beaker K		Beaker 1
[A) Wt. OVEN dry sample (gm	453.44		449.19
[B) Wt. of Pycnometer containing water alone (gm)	1805.95		1768.72
[C] Wt of Pyconometer containing Sample and water (	2082.72		2042.56
SPECIFIC GRAVITY OF FILLER $\frac{A}{A+(B-C)}$	2.567		2.562
AVERAGE	2.564		

FOR TESTING LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
JAN 2024
P. O. BOX 795, 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**	

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

SPEC >110 SPEC >75%

f= Maximum force (KN)

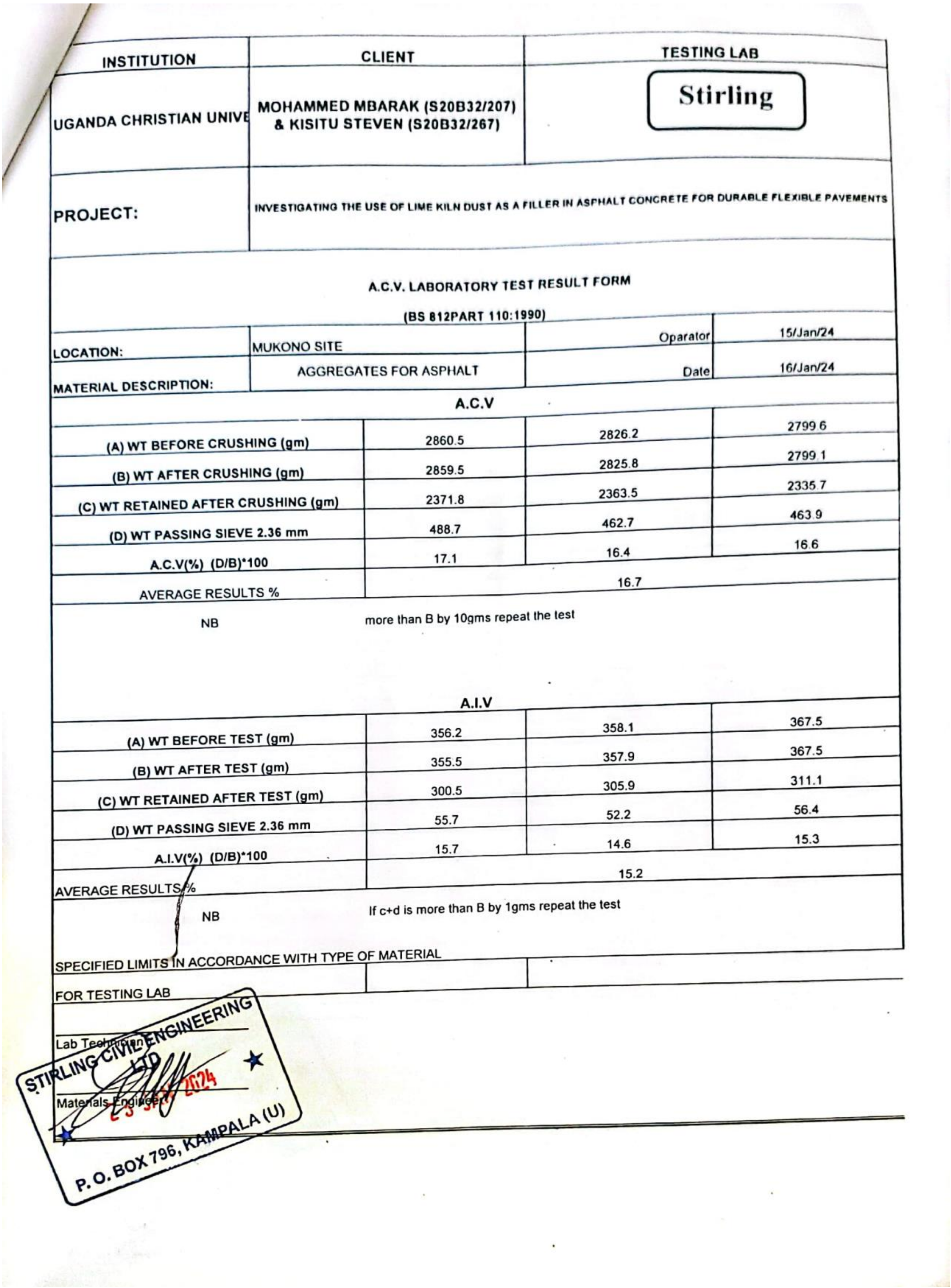
of material passing the 2.36mm sieve at the maximum force

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

TESTING LAB

Materials Engineer

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



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

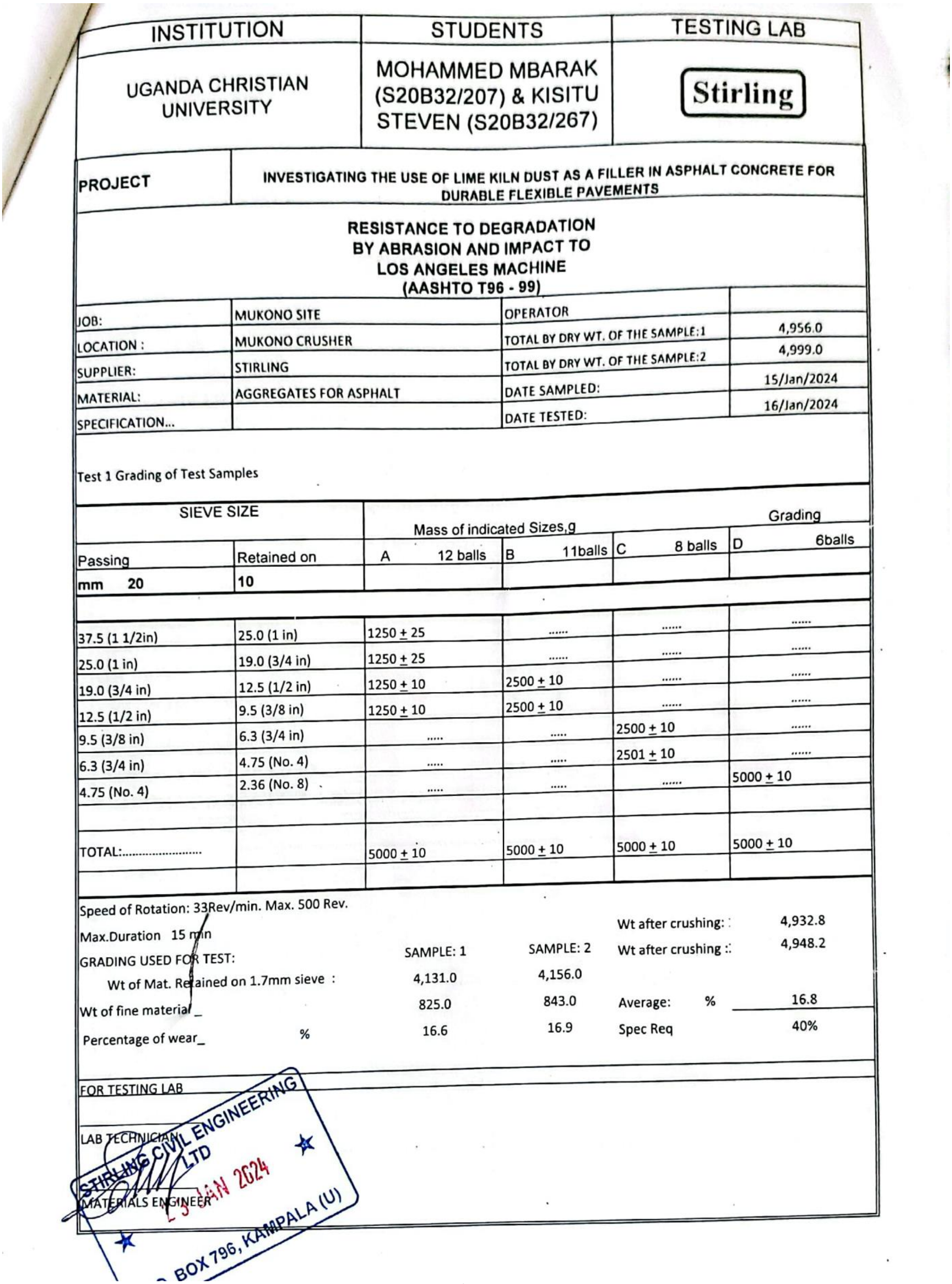
SPECIFIED LIMITS IN ACCORDANCE WITH TYPE OF MATERIAL

FOR TESTING LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
23 [illegible] 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

		SAMPLE: 1	SAMPLE: 2		
GRADING USED FOR TEST:				Wt after crushing:	4,932.8
				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

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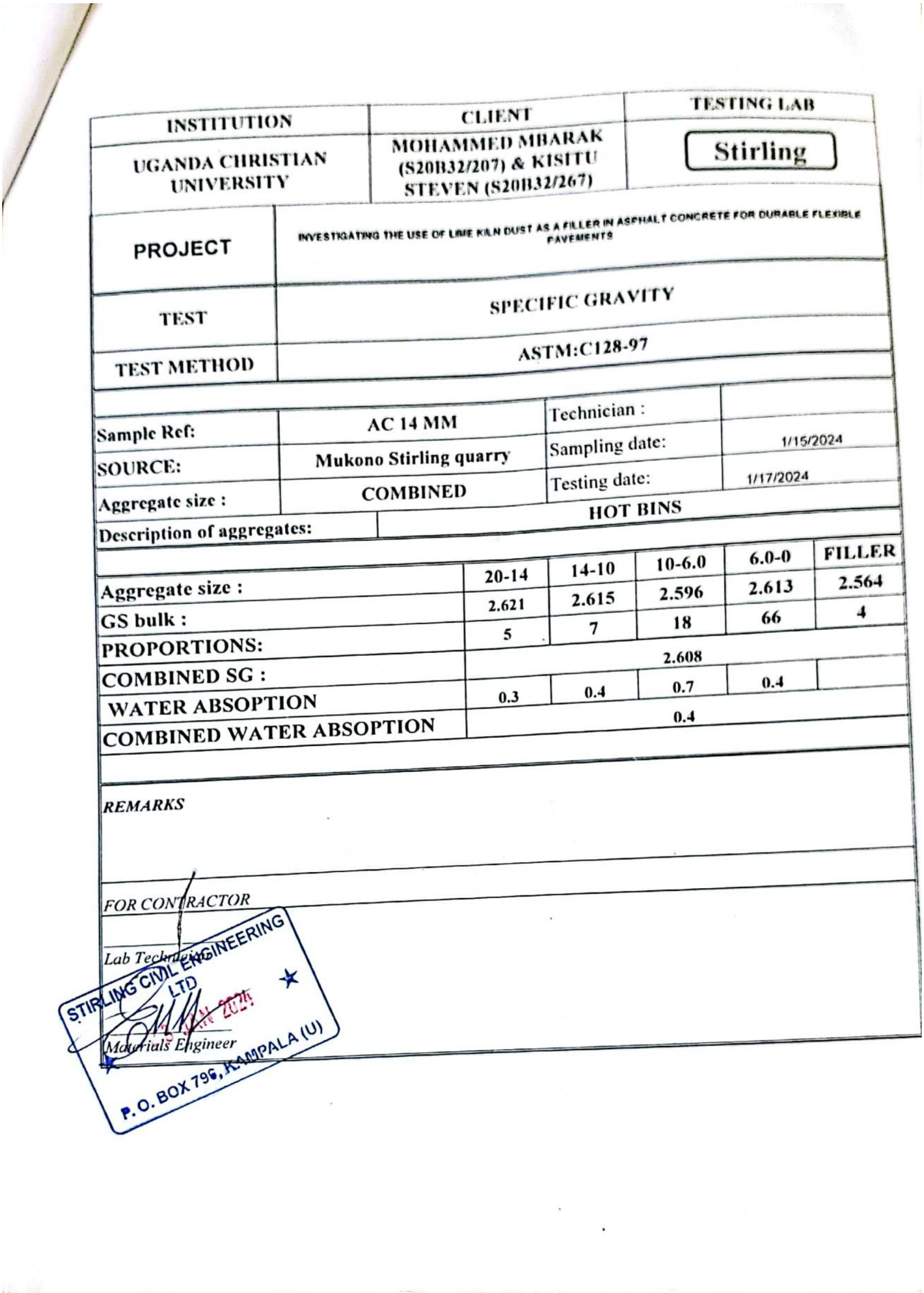
25 JAN 2024
BOX 796, KAMPALA (U)



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				

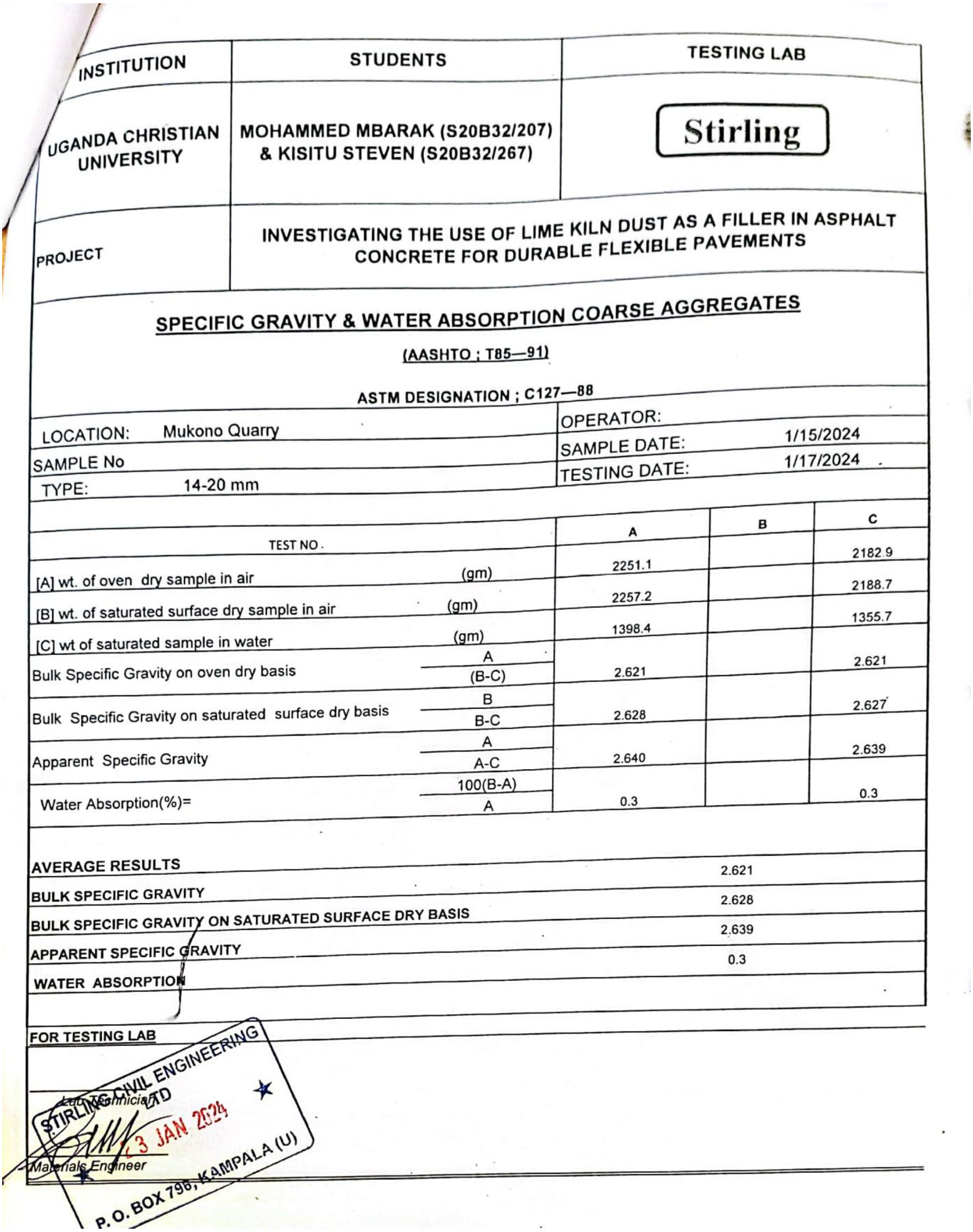
REMARKS

FOR CONTRACTOR

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
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:	14-20 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	$\frac{A}{(B-C)}$	2.621		2.621
Bulk Specific Gravity on saturated surface dry basis	$\frac{B}{B-C}$	2.628		2.627
Apparent Specific Gravity	$\frac{A}{A-C}$	2.640		2.639
Water Absorption(%)=	$\frac{100(B-A)}{A}$	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
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:	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	$\frac{A}{(B-C)}$	2.614		2.616
Bulk Specific Gravity on saturated surface dry basis	$\frac{B}{B-C}$	2.624		2.627
Apparent Specific Gravity	$\frac{A}{A-C}$	2.641		2.644
Water Absorption(%)=	$\frac{100(B-A)}{A}$	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

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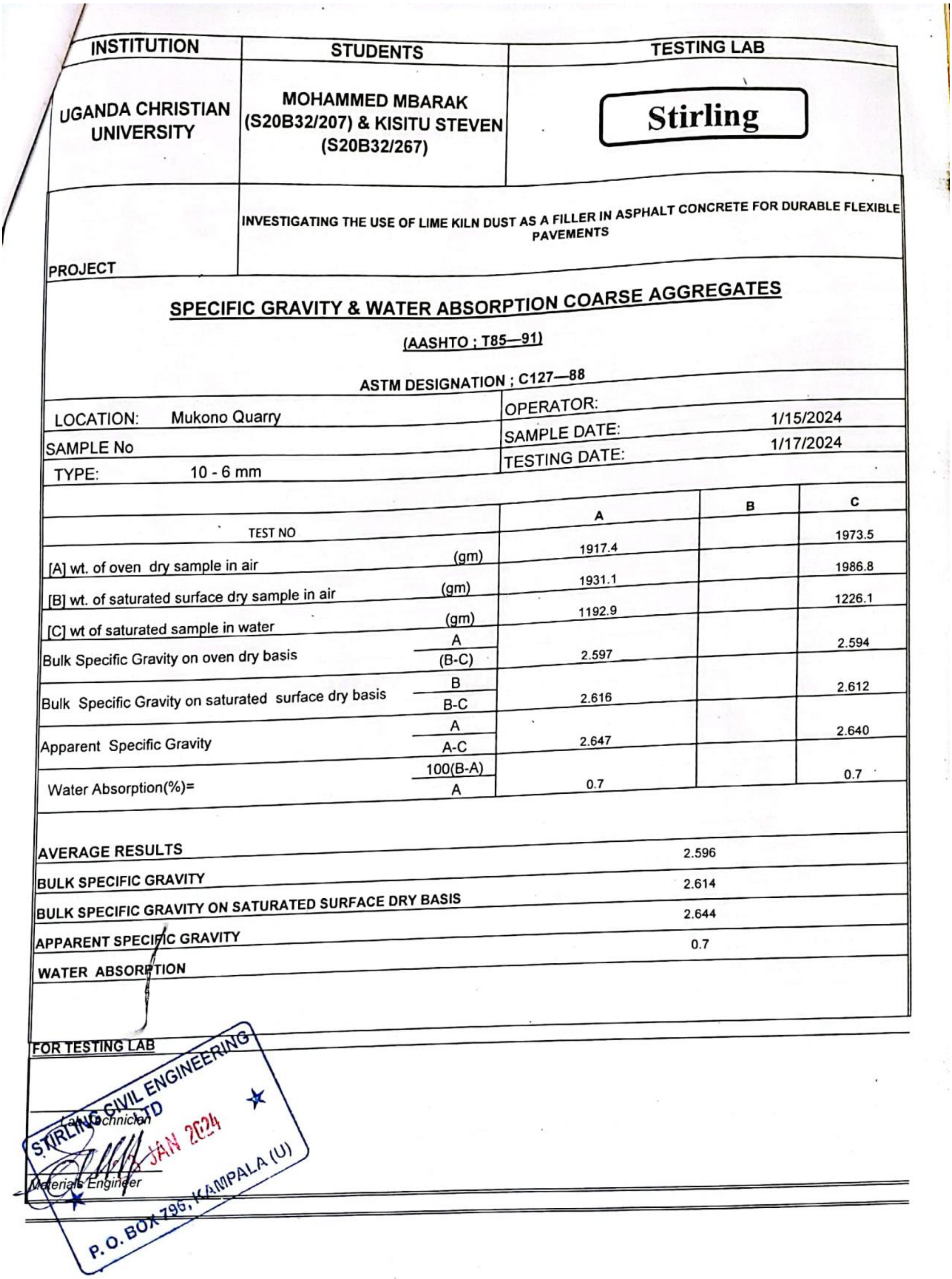
3 JAN 2024
P. O. BOX 796, KAMPALA (U)



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

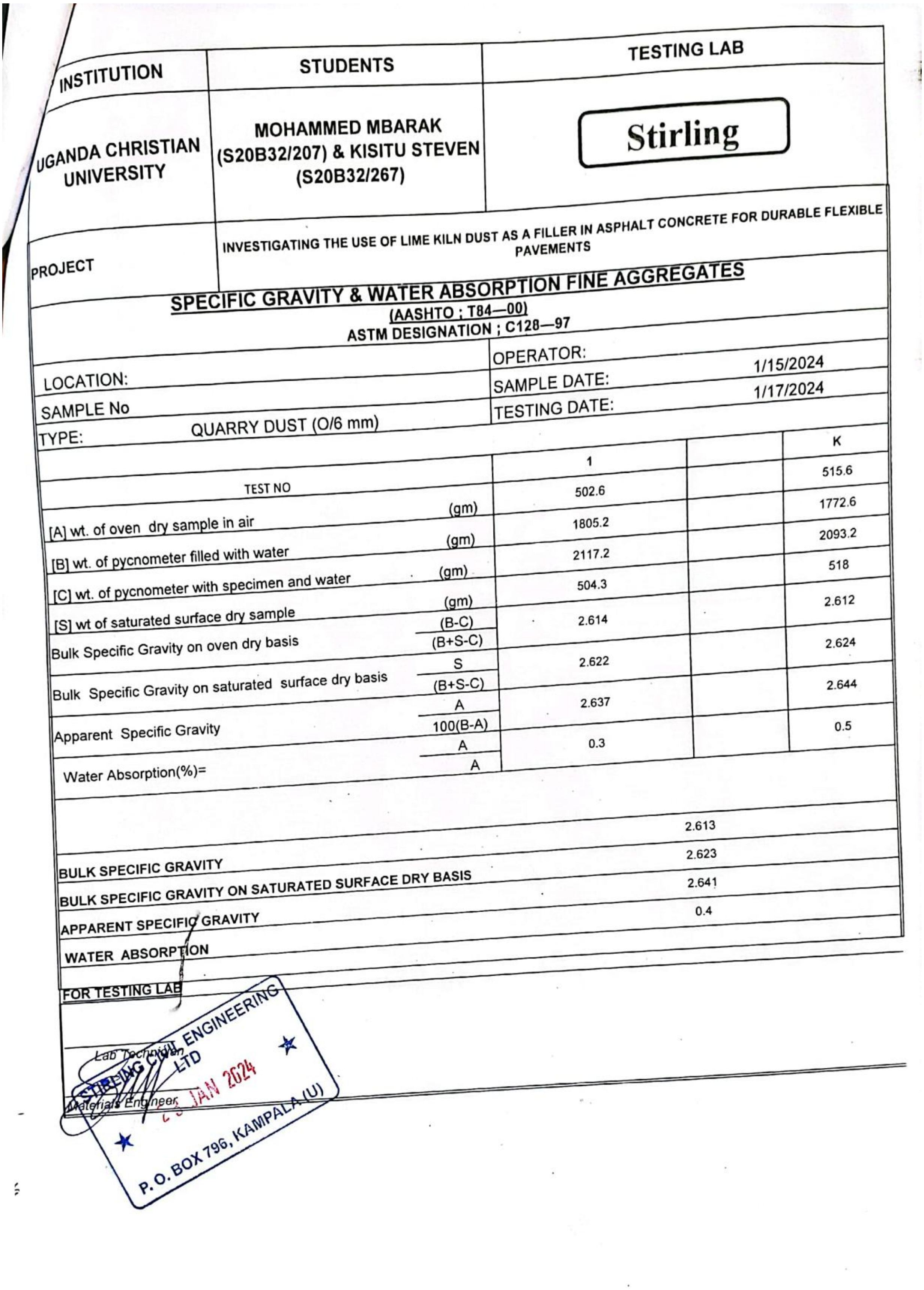
AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.596
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.614
APPARENT SPECIFIC GRAVITY	2.644
WATER ABSORPTION	0.7

FOR TESTING LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
JAN 2024
P.O. BOX 795, 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 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

FOR TESTING LAB

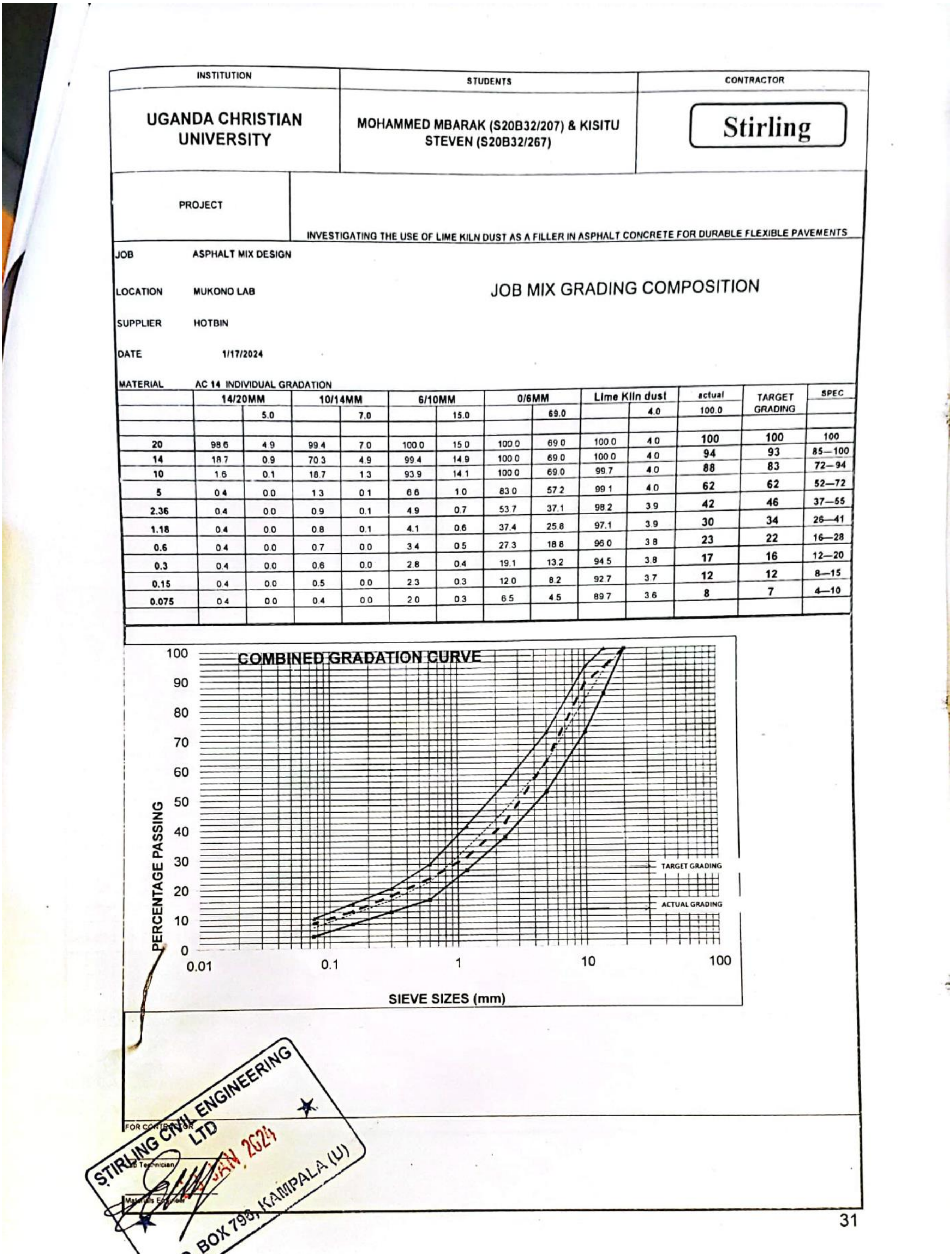
Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD

JAN 2024

P.O. BOX 796, KAMPALA (U)



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

Lab Technician

Materials Engineer

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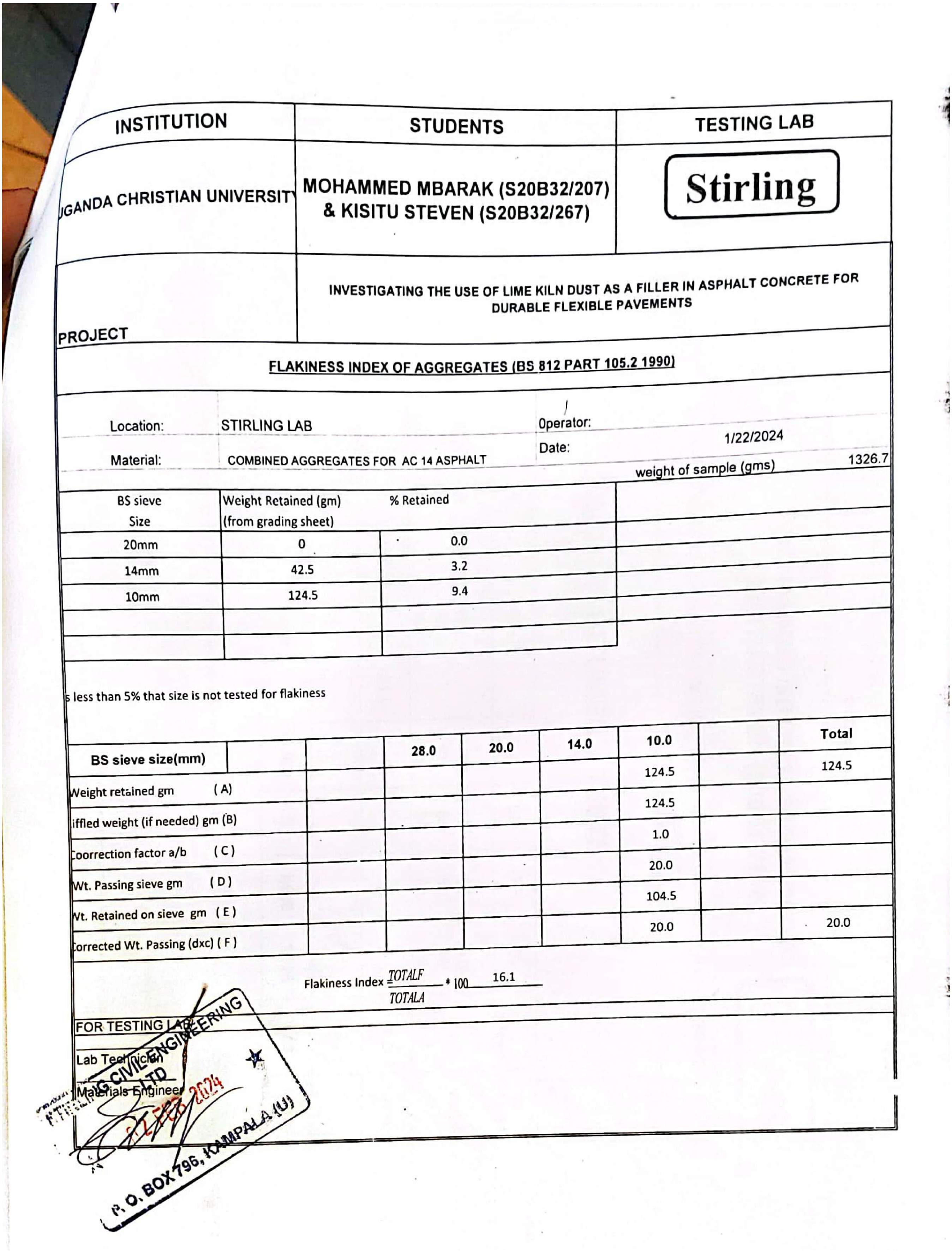


INSTITUTION	STUDENTS	TESTING LAB
JGANDA CHRISTIAN UNIVERSITY	**MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)**	**Stirling**
PROJECT	INVESTIGATING THE USE OF LIME KILN DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS	

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		
Vt. Retained on sieve gm (E)					104.5		
Corrected Wt. Passing (dxc) (F)					20.0		20.0

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

FOR TESTING LAB

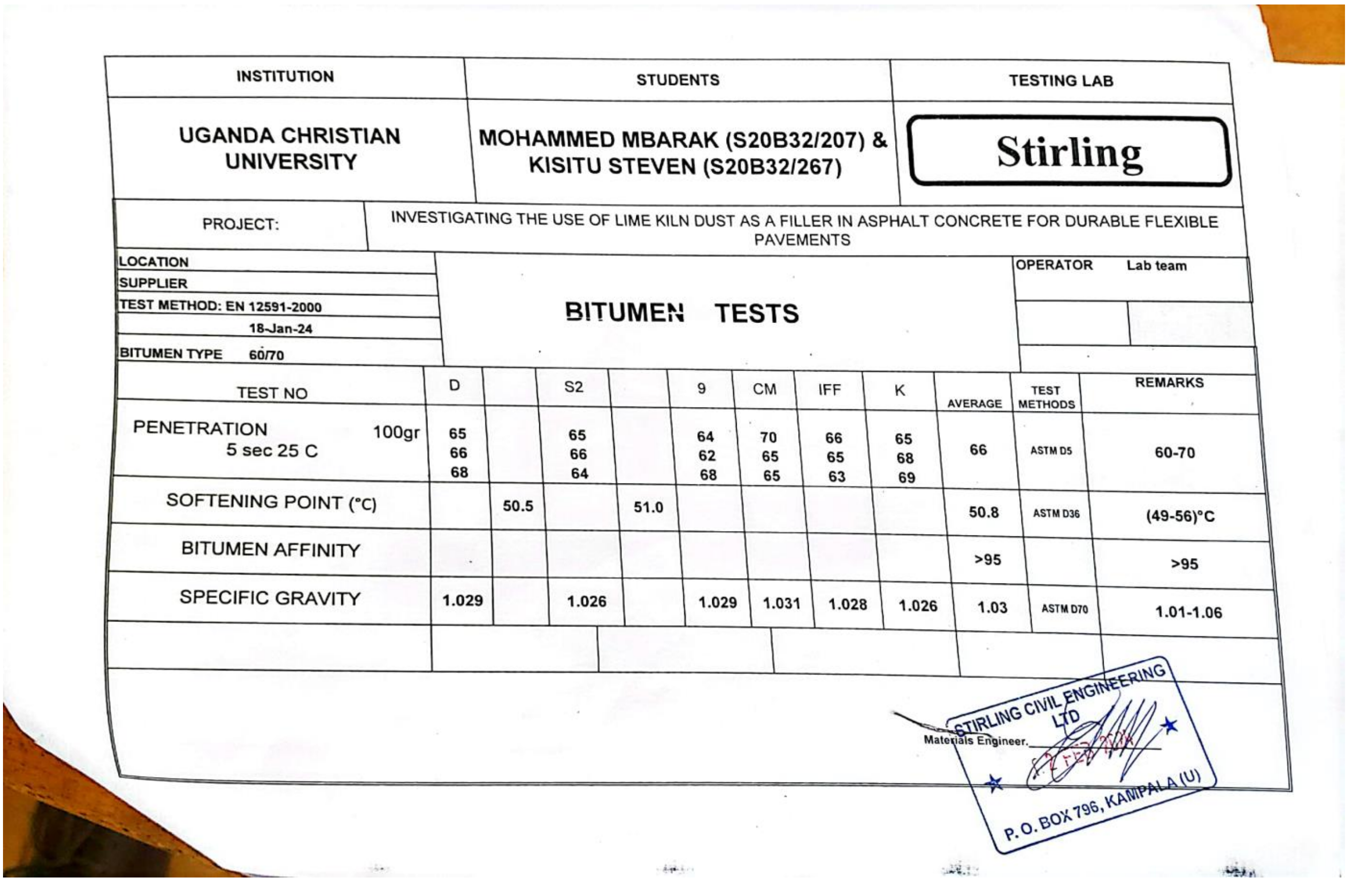
Lab Technician

Materials Engineer

G 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

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

BITUMEN TESTS

OPERATOR Lab team

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

Materials Engineer.

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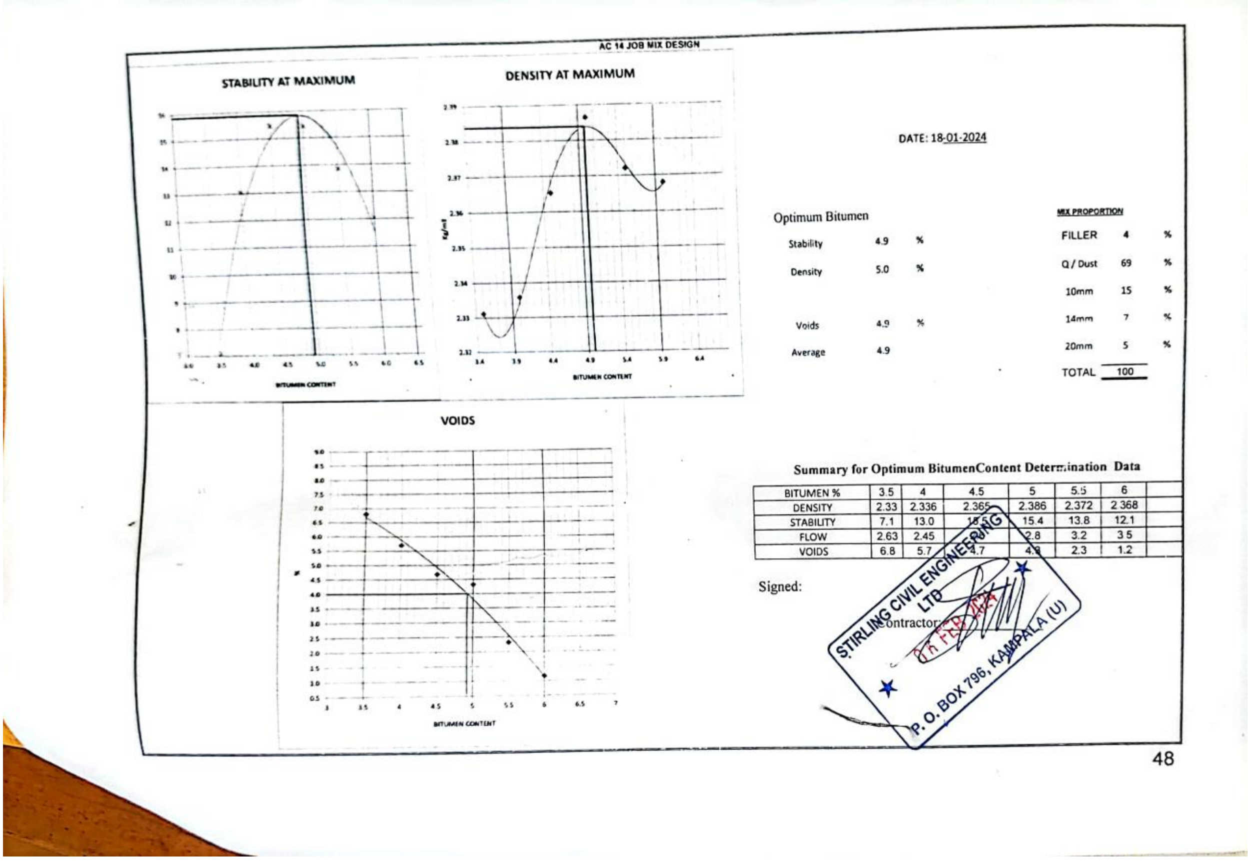
P.O. BOX 796, KAMPALA (U)



AC 14 JOB MIX DESIGN

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	

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	4.3	2.3	1.2	

Signed:

Contractor:

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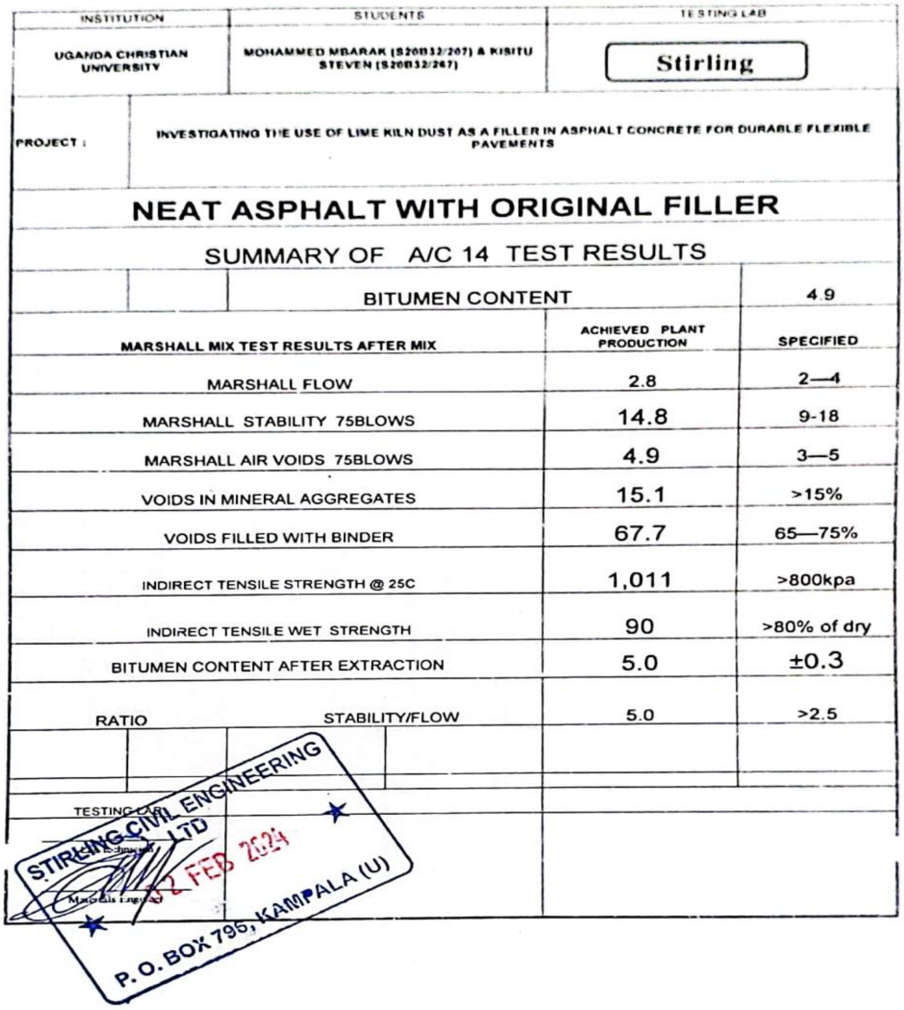
P. O. BOX 796, KAMPALA (U)

Annex B: results of the optimum bitumen content.



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

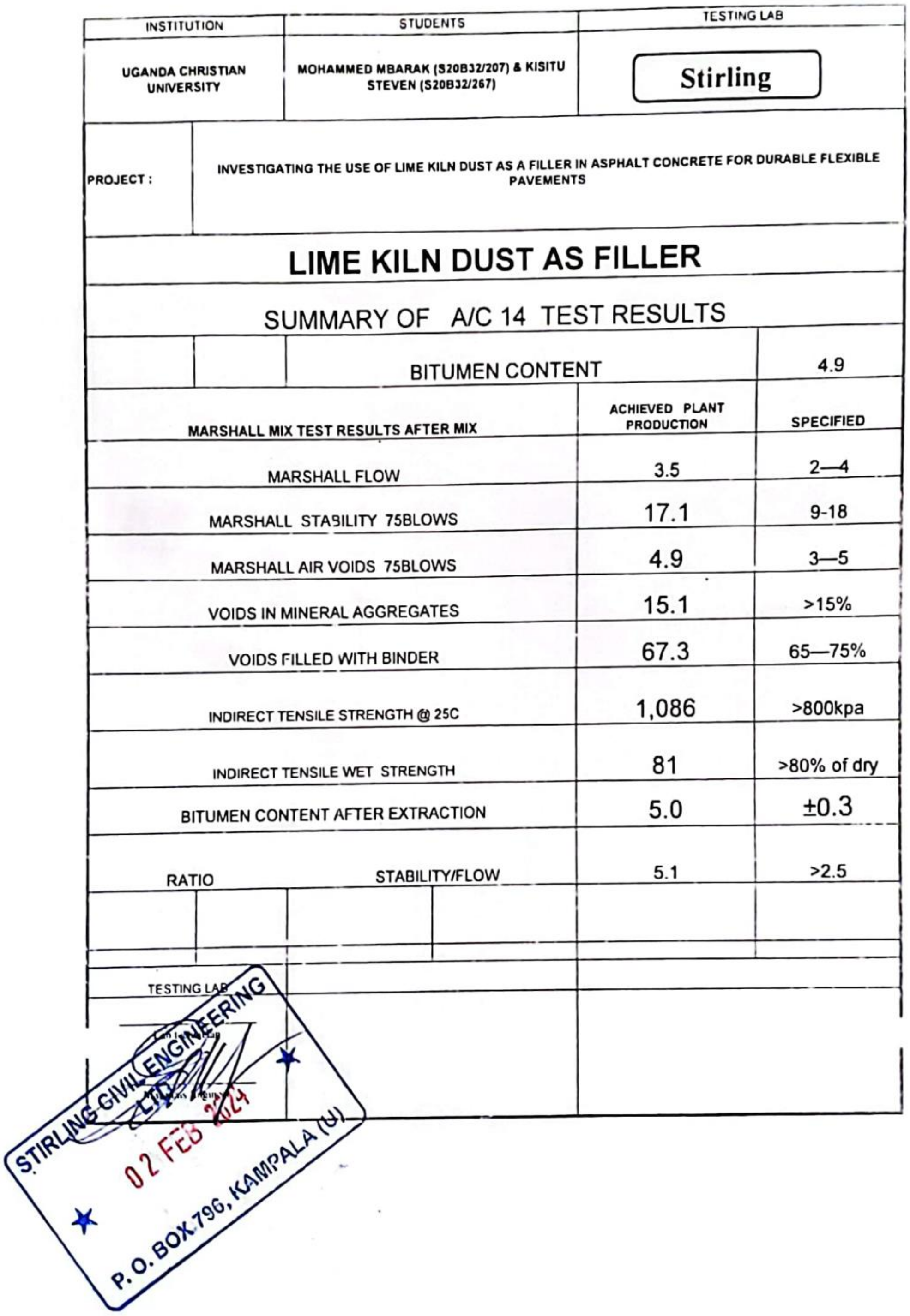
BITUMEN CONTENT		4.9
MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW	2.8	2—4
MARSHALL STABILITY 75BLOWS	14.8	9-18
MARSHALL AIR VOIDS 75BLOWS	4.9	3—5
VOIDS IN MINERAL AGGREGATES	15.1	>15%
VOIDS FILLED WITH BINDER	67.7	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,011	>800kpa
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 795, 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

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

STIRLING CIVIL ENGINEERING LTD

02 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. / **ASTM D6927Standard Method for Marshall Stability and Flow**

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	Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Stability (KN) Adjusted	Flow (mm)	Ratio (Stab./Flow)
1	1195.0	686.00	1196.50	2.341	2.330	4.9	15.2	67.5	65.4	65.3	65.4	65.4	0.95	14.0	13.26	3.07	4.318
2	1194.5	686.00	1196.00	2.342	2.331	4.9	15.1	67.8	66.4	66.0	65.4	65.9	0.95	15.0	14.23	2.60	5.473
3	1189.0	686.00	1194.50	2.338	2.327	5.0	15.2	67.1	64.5	65.2	65.2	65.0	0.96	15.4	14.77	2.91	5.077
4	1188.0	685.00	1191.50	2.346	2.334	4.7	15.0	68.4	66.2	65.1	66.4	65.9	0.95	15.0	14.23	2.80	5.082
Average Sample 1				**2.342**	**2.330**	**4.9**	**15.1**	**67.7**	Average Sample 1			**65.5**	**1.0**	**14.8**	**14.1**	**2.8**	**5.0**
-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average Sample 2									Average Sample 2								
Average Sample 1 & 2				2.342	2.330	4.9	15.1	67.7	Average Sample 1 & 2								

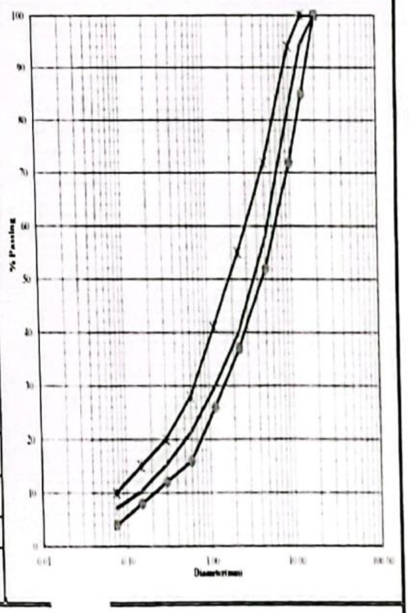
ASTM D 2172- Standard Test Method for Quantitative Extraction of Bitumen from Asphalt Mixtures

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 extracti	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			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	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				



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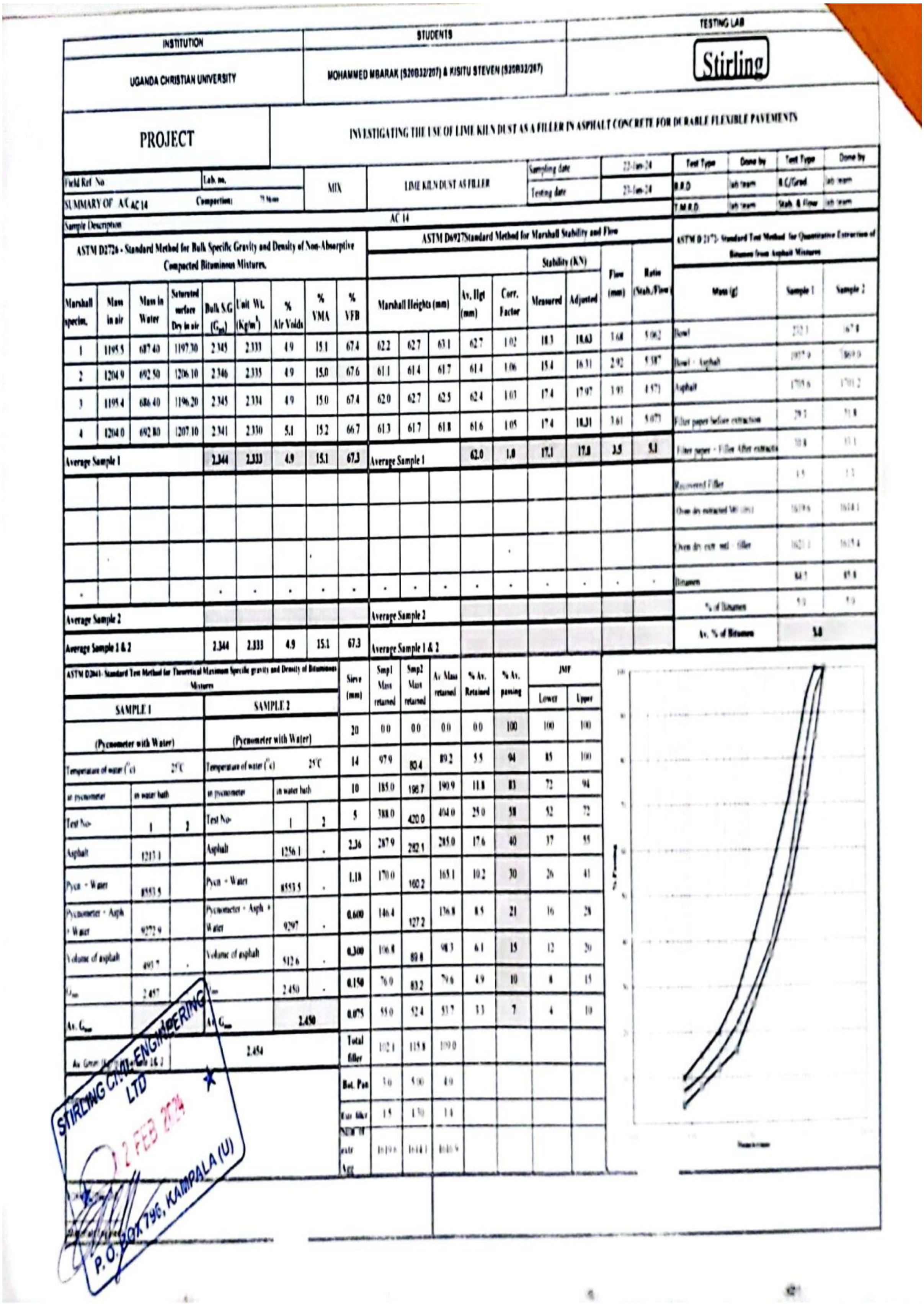

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

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

Field Ref No		Lab no.		MIX	LIME KILN DUST AS FILLER	Sampling date	22-Jan-24	Test Type	Done by	Test Type	Done by
SUMMARY OF A/C AC 14		Compaction:	75 blows			Testing date	23-Jan-24	B.R.D	lab team	B.C/Grad	lab team
								T.M.R.D	lab team	Stab. & Flow	lab team

Sample Description: AC 14

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	5.071
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 Mt (g)	1619.6	1614.1
Oven dry extr. mt + 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. G_{mm} (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				
Ext filler	1.5	1.30	1.4				
Mass of extr Agg	1619.6	1614.1	1616.9				

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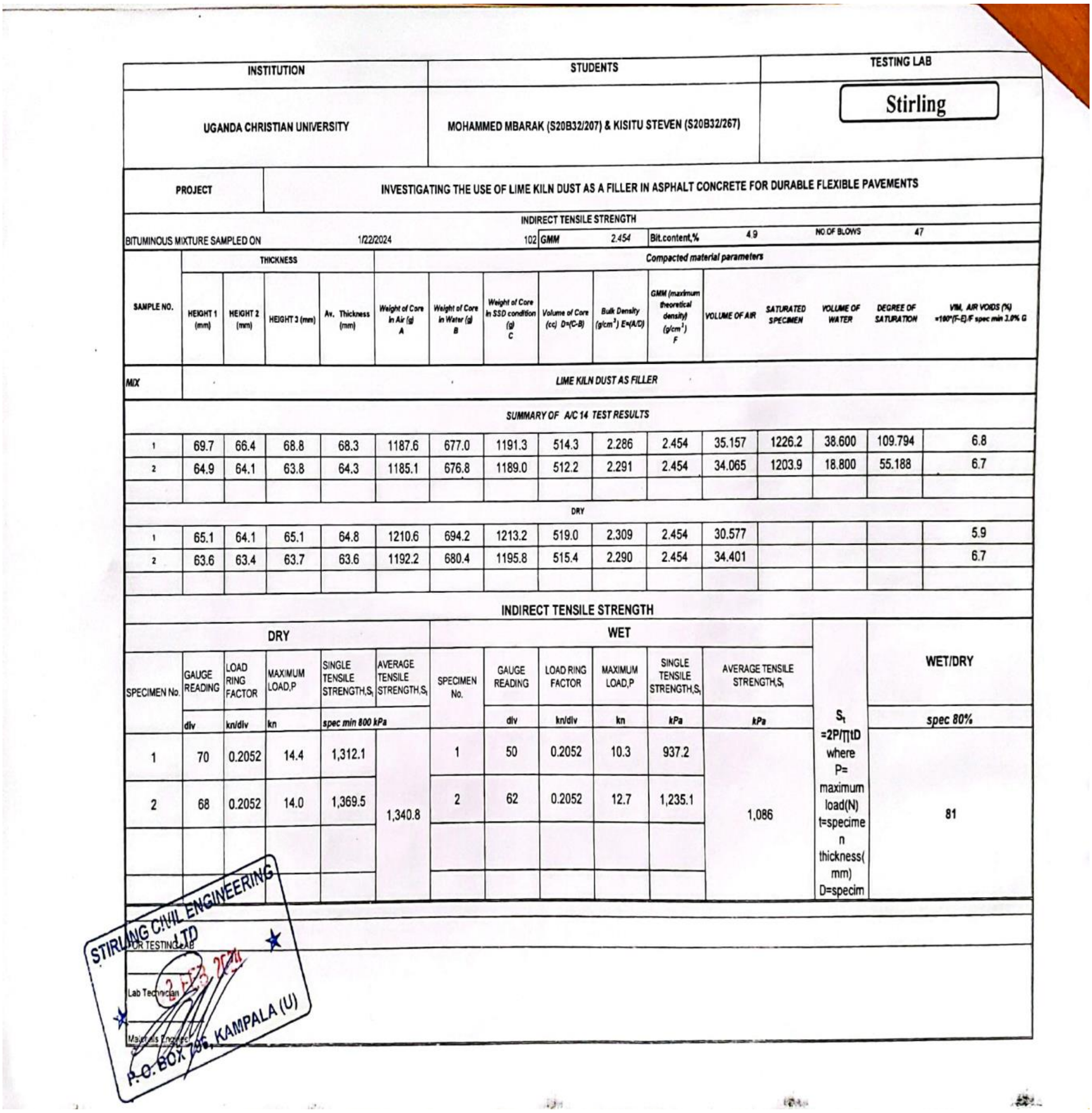
Annex C: results for the indirect tensile strength test.



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 3.0% 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							
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		WET/DRY
	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			

FOR TESTING LAB

Lab Technician

Materials Engineer

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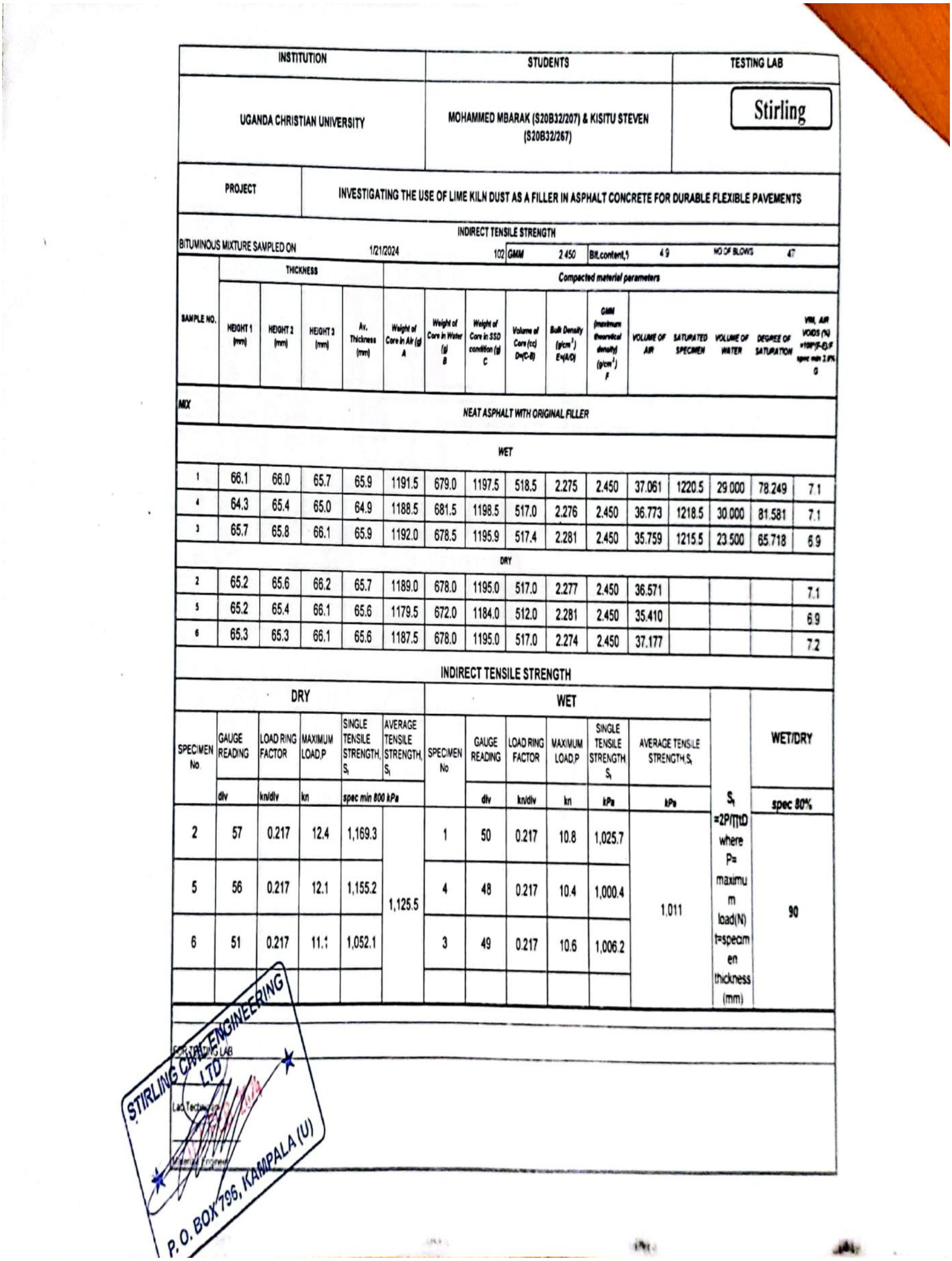

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MOHAMMED MBARAK (S20B32/207) & KISITU STEVEN (S20B32/267)	Stirling

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

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 2.0% 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							
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		WET/DRY
	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			

FOR TESTING LAB

Lab Technician

Materials Engineer

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