ASSESSING THE STIFFNESS PROPERTIES OF ASPHALT CONCRETE MODIFIED WITH WASTE DIESEL ENGINE OIL : A CASE STUDY OF KAMPALA- MASAKA ROAD

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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

This study explored the possibility of modifying bitumen with Waste Engine Oil (WEO) to help mitigate cracking in asphalt pavements. Laboratory investigations were conducted on bitumen of 50/70 penetration grade with WEO additions of 0-6%. In all experiments with WEO, the penetration increased from 62.2 to 73.4 mm, and all other physical properties measured decreased; notably the softening point (from 54.2 to 45.5° C) and density of the bitumen (from 1.018 to 0.999 g/cm^3). Marshall Mix Design implied that 4.6% was the optimal bitumen content, while the 3.5% WEO mixture had superior performance, workability and fatigue resistivity to the other mixtures. The results showed a very good moisture resistivity with a Tensile Strength Ratio of 92%. The findings from this study implied that for areas like Kampala-Masaka, Uganda, it is feasible to modify bitumen with up to 4% WEO to sustainably enhance pavement performance, improving the longevity of the pavement and delaying maintenance requirements. It is indicated that wide scale field studies be undertaken to monitor the impact of these laboratory studies in the field.

DECLARATION

I, Natangaza peace, hereby declare that this report titled "ASSESSING THE STIFFNESS PROPERTIES OF ASPHALT CONCRETE MODIFIED WITH WASTE DIESEL ENGINE OIL" is entirely my own work, except where I have duly acknowledged the use of other sources. All sources referred to have been acknowledged and cited properly. This report has not been submitted for any other academic purpose and all data and information presented herein are accurate to the best of my knowledge.

Signature…………………………………….

Date……………………………………………

APPROVAL

This is to certify that NATANGAZA PEACE did the work under this report and is ready for submission

Project supervisor:

Eng. AGUTI JOSEPINE

Signature…………………………………….

Date…………………………………………….

DEDICATION

I dedicate this report to the Department of engineering and environment of Uganda Christian University which has been there for every kind of support needed during my research.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to the Department of engineering and environment of Uganda Christian University especially my supervisor Eng. AGUTI JOSEPINE for her invaluable guidance, support, and constructive feedback throughout the development of this research. Their expertise and encouragement have been instrumental in shaping the direction and focus of this study.

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LIST OF ABBREVIATIONS

AIV	Aggregate Impact Value
BS	British Standard
FI	Flakiness Index
Gmb	Bulk Specific Gravity of Asphalt Concrete
Gmm	Maximum Specific Gravity of Asphalt Concrete
HMA	Hot Mixed Asphalt
ITS	Indirect Tensile Strength
LAA	Los Angeles Abrasion
OBC	Optimum Bitumen Content
TFV	Ten percent Fines Value
TSR	Tensile Strength Ratio
Va	Air Voids
WEO	Waste Engine Oil

CHAPTER ONE: INTRODUCTION

1.1 Background

Asphalt concrete is the most widely used pavement surface material in Uganda especially on highways and high traffic roads due to the fact that it is flexible and durable. It is predominantly utilized in flexible pavements to spread traffic loads over a number of layers with accommodation for small deformations without cracking. These types of pavements differ from the rigid pavements, which are largely built with concrete and crack upon being subjected to heavy loads in case they are not reinforced (Williams,2017).

Asphalt concrete is a composite material produced by blending a series of basic constituents together, generally at high temperatures of around 180°C. Asphalt Binder (Bitumen), a tacky and viscous liquid derived from crude oil, serves as the binding agent for the aggregate particles, providing flexibility and water resistance to the mixture. Aggregate Particles consisting of crushed stones, gravels, and sands provide strength and shape to the pavement. Since aggregates constitute the majority of asphalt concrete, they are graded to achieve optimum compaction and load distribution. Additionally, Filler typically produced from finely divided materials such as mineral dust, fills the small voids in the aggregate matrix and enhance the stability of the mixture as a whole (Ridmika, 2019). However, after 10-15 years of service, asphalt concrete will deteriorate via the process of oxidation and repeated exposure to environmental factors, e.g., heat that makes it stiffer and possess a lower relaxation capability. This causes the binder to become brittle and hence the formation of microcracks that propagate to create larger cracks at the binder-aggregate interface (Yildrim, 2007).

Studies have shown that incorporating diesel waste engine oil in to asphalt concrete offers various benefits including improved pavement performance and a reduction in aging issues. When used in proper proportions, diesel waste engine oil can restore flexibility to oxidized bitumen preventing the stiffness of the asphalt concrete and contributing to the constructability, cost effectiveness and sustainability of road construction and maintenance (Fuyu Wang et al., 2018). Stiffness in asphalt concrete is typically caused by prolonged oxidation which alters the chemical structure of the asphalt components and reduces its viscoelastic properties. To prolong the lifespan of the asphalt pavements, it is essential to rejuvenate aged asphalt binders. Research has shown that WEO is effective as a rejuvenator restoring the lost properties of aged bitumen (Williams, 2017).

1.2 Problem Statement

The pavement along the Kampala-Masaka Road between Km 97+000 and Km 102+000, stretching from Kamuwunga Trading Centre to Lukaya Town, is generally roadworthy, however, significant deficiencies have been noted. In particular, the air void content in the bitumen measures at 6.7%, exceeding the ideal limit of 5% (Costa Odwar, 2022). This excessive void content accelerates pavement deterioration by promoting extensive cracking, which disrupts traffic flow, elevates accident risks, and results in premature damage to vehicles (Tumwesigye & Kiggundu, 2019). Contributing factors likely include suboptimal compaction methods, inadequate material selection, and an imbalance in the asphalt mix design.

The financial burden associated with frequent repairs, especially when short-term durable materials are used, underscores the need for more resilient construction methods. Improving the performance of the asphalt pavement requires exploring solutions that address both material properties and mix design optimization. Potential remedies include enhanced compaction techniques, improved aggregate gradation, and the incorporation of additives that can rejuvenate the bitumen. Among these strategies, one promising approach is the modification of bitumen with Waste Engine Oil (WEO), which has been demonstrated to enhance the rheological properties of bitumen by reducing viscosity and improving temperature susceptibility (Osei, 2017).

Great attention has been given to the reuse of DWEO in asphalt concrete in terms of enhancing its rheological properties (Hassan et al. ,2014), and Choudhary et al. (2018) there is a necessity to investigate the effect of WEO on the stiffness properties of asphalt concrete and related pavement surface defects.

With numerous research studies being conducted, yet the effect of the incorporation of Diesel waste engine oil on asphalt concrete stiffness characteristics and other defects on pavement surface still remains inconclusive. It serves to explain that more work is needed so as to improve our understanding regarding how these types of asphalt concrete mixture's function.

Based on this analysis, the research applied WEO modification as a sustainable solution to mitigate the identified issues. By incorporating WEO, the modified bitumen exhibits improved flexibility and adhesion, ultimately reducing cracking and extending pavement life. This approach not only contributes to enhanced pavement performance under traffic and environmental stresses but also offers an environmentally benign method of recycling waste materials, thereby supporting longer-term durability and cost-effectiveness in road construction.

1.3 Research Objectives

1.3.1 Main Objective

To assess the stiffness properties of asphalt concrete modified with waste diesel engine oil.

1.3.2 Specific Objectives

1. To determine the engineering properties of the materials used in the asphalt mixture.
2. To determine the rheological properties of waste diesel engine oil modified bitumen.
3. To determine the optimal mix design for asphalt concrete modified with waste diesel engine oil.

1.4 Research Questions

1. What are the physical and chemical properties of the materials (aggregates, bitumen, and WEO) used for modifying asphalt?
2. How do the rheological properties of asphalt concrete vary when using neat bitumen compared to modified bitumen?
3. What is the optimal mix design for asphalt concrete modified with diesel waste engine oil and how does this design influence stiffness modulus and overall mechanical properties of the modified asphalt concrete?

1.5 Justification of the Study

Traditional asphalt mixes become more brittle over time, leading to reduced performance and increased maintenance costs (Mukasa et al., 2021). The incorporation of waste engine oil (WEO) into asphalt mixtures presents an innovative approach to improving asphalt concrete stiffness, offering potential environmental and economic benefits.

Reusing WEO not only provides a method of disposing of harmful waste that could otherwise cause environmental pollution but also serves as a cost-effective additive for enhancing the mechanical properties of bitumen. Previous studies have shown that the molecular structure of diesel WEO closely resembles that of asphalt, allowing it to form a coherent bond with bitumen components, as WEO (diesel) functional groups including the C-H bonds and carboxylic acids facilitates the compatibility with bitumen improving the blending properties and reducing viscosity, softening point thereby increasing penetration point of the bitumen hence improving the pavement's performance (Mohammad, 2018). Incorporating WEO in road construction not only offers a method of recycling waste materials but also provides a practical approach to addressing the issue of asphalt pavement aging and stiffness.

The findings might provide practical solutions for extending the lifespan of pavements, reducing maintenance costs in Uganda, and contributing to sustainable construction processes. It would also contribute to the wider global effort of recycling wastes and preserving natural environments by reducing demands on virgin bitumen and utilizing waste products in infrastructure projects.

1.6 Significance of the Study

The results of this study contributed significantly to both academic research and practical engineering by demonstrating that diesel waste engine oil (WEO) can be effectively used as an additive to modify asphalt concrete. This research provided detailed insights into how WEO improves the rheological properties of bitumen—enhancing its flexibility, adhesion, and workability while reducing viscosity and mitigating cracking—and established optimized modification levels for durable pavement performance. These findings offer a robust technical framework for improving asphalt mix designs, thereby addressing common issues such as excessive air voids and premature cracking in road pavements. By recycling waste engine oil, the research supports sustainability while offering cost-effective solutions to road deterioration problems. This integrated approach not only improves the structural integrity and longevity of asphalt pavements but also contributes new knowledge on balancing bitumen modification to achieve both enhanced flexibility and thermal stability, ultimately leading to more resilient and sustainable infrastructure.

1.7 Scope of the Study

The of this study was to evaluate the stiffness properties and performance of asphalt mixes made with both neat bitumen and WEO-modified bitumen at varying percentages. The study involved material testing, mix design and assessment of the properties of asphalt concrete produced using the two types of bitumen. The focus was on the kampala masaka road section between km 97+000 at kamuwunga and km 102+000 at lukaya, where significant pavement damage has been noted. The research was conducted over a span of eight months

CHAPTER TWO: LITERATURE REVIEW

2.1 Highway pavements

Highway pavements are engineered systems designed to support vehicular traffic and distribute loads to the underlying soil, ensuring smooth and durable transportation infrastructure. These pavements are constructed as layered structures comprising processed materials that collectively provide strength, flexibility, and longevity. The fundamental role of a pavement is to mitigate stress concentrations by gradually dispersing traffic loads into the subgrade, thereby preserving the integrity and extending the service life of the roadway (Tom & Rao, 1979).

Highway pavements are broadly classified into two main types: rigid and flexible pavements. Rigid pavements typically made of reinforced cement concrete, are known for their high flexural strength and long-term durability. They efficiently distribute loads over a large area due to their inherent stiffness and are particularly suited for environments with heavy, concentrated traffic while flexible pavements are composed of multiple layers of bituminous material and aggregates, which impart flexibility as well as strength. This layered design allows flexible pavements to adapt to deformations caused by temperature variations and traffic loading, making them ideal for highways, parking lots, and other transportation applications where responsiveness and ease of repair are critical (Prasad, 2024; Asiva Noor Rachmayani, 2022).

2.2 Flexible Pavements

Flexible pavements are multilayered systems designed to distribute vehicular loads over a large area of underlying natural soil, providing a resilient and adaptable roadway surface. Typically, these pavements consist of a wearing course, binder course, base course, subbase, and subgrade. The wearing course, constructed from dense-graded or open-graded asphalt concrete, provides a smooth, durable, and skid-resistant surface that withstands direct traffic loads and weathering. Beneath this, the binder course acts as a transitional layer, contributing to overall structural integrity while ensuring proper adhesion between the surface and the lower layers. The base course, composed of well-graded crushed stone, furnishes additional load distribution and structural support, and when necessary, an intervening subbase is added to reinforce a weak subgrade, which serves as the ultimate foundation ensuring stable drainage and load transfer.

2.2.1 Components of a flexible pavements

Typical flexible pavement is made up of several layers designed to distribute traffic loads effectively and ensure long term durability (Mazurowski, 2015).

The primary components include

Asphalt (AC) which is the mixture of bitumen aggregates and filler

Wearing course, the upper most layer designed to withstand weathering and traffic loads.

Binder course, the lower layer that provides structural strength and facilitates bonding with the base layer(Garcia and Hansen, 2001).

Base course, this layer distributes loads and provides structural support typically composed of well graded crushed stones (Testbook Edu Solutions, 2023).

Subbase course, this is a layer situated between the base and subgrade often used when the subgrade is weak and requires additional reinforcement.

Subgrade, the natural soil layer that is compacted and properly drained providing foundational support for the pavement structure.

The surfacing layer is the top most part of the flexible pavement designed to withstand traffic loads, resist environment impacts and offer a smooth skid resistant surface. It consists of two main sublayers that is the wearing course and binder course **(Garcia and Hansen, 2001)**.

The wearing course is the most upper layer of the pavement directly exposed to vehicle traffic, its key functions include providing a smooth and skid resistant surface for safety and comfort, protecting the underlying layers from water infiltration and oxidation and resisting rutting and abrasion caused by traffic loads. This layer is typically made from dense graded asphalt concrete or stone matrix asphalt depending on the desired durability and resistance to deformation.

The binder course is the intermediate layer positioned between the wearing course and the base. Its primary role is the enhance the structural strength of the pavement, improve load distribution to the base layer and serve as transition layer to prevent premature failure of the wearing course (Shen, 2013). It is composed of asphalt concrete with a coarser aggregate mix which improves resistance to deformation while maintaining flexibility.

The materials used in the surfacing layer include aggregates that provide strength and stability and skid resistance, bituminous binder that binds the aggregates offering flexibility and water proofing properties and filler materials such as limestone dust or minerals that improve adhesion and stiffness.

2.3 Types of asphalt concrete used in the surfacing layer

a) Hot Mix Asphalt (HMA)

This is produced by combining fine and coarse aggregates with filler materials then heating them together. After the materials are blended a specific percentage of bitumen is added. This process takes place at 150°C and the resulting mix is transported to the construction site by trucks (Gunkel, 2004).

b) Warm Mix Asphalt (WMA)

Warm mix asphalt shares similar materials with hot mix asphalt but the key difference is the mixing temperature. while hot mix asphalt is mixed at approximately 150°C, WMA is produced at lower temperatures. This temperature reduction provides several benefits including cost saving and enhanced durability (Zaumanis, 2014).

C) Cold Mix Asphalt (CMA)

CMA is created by blending aggregates, filler and bitumen at ambient temperatures meaning no heating is required. The process involves a straight forward mixing of the materials. CMA is typically used for repair and maintenance tasks such as fillinf pot holes, depressions and utility cuts (Omni Engineering, 2024).

2.4 Types of asphalt mixes used in the surfacing layer

The surface layer of flexible pavements plays a crucial role in providing smooth, durable and weather resistant driving surface. Several types of asphalt mixes are designed to meet specific performance needs considering factors like application, traffic load and environmental conditions. These mixes are intended to optimize durability, stability and resistance to deformation while also addressing noise reduction and drainage requirements. Common asphalt mixes used in surfacing include,

i. **Dense-Graded Asphalt Concrete (DGAC)**

Dense graded asphalt concrete is widely used asphalt mix due to its strength, affordability and versatility. It is made using a well graded combination of aggregates that reduces air voids, resulting in increased stability and durability. This mix is known for its low water permeability which improves its resistance to freeze thaw pavements especially in colder climates (EricksonAsphaltServices, 2022).

ii. **Stone Matrix Asphalt (SMA)**

SMA is a premium asphalt mix designed for maximum durability and resistance to permanent deformation under heavy traffic. It contains a high proportion of crushed, angular aggregates that create strong stone on stone contact forming an interlocking structure that offers superior stability and resistance to rutting. SMA typically incorporated polymer modified asphalt binders to enhance its durability, flexibility and ability to withstand temperature changes (Ilhan, 2024).

iii. **Open-Graded Friction Course (OGFC)s**

OGFC is a porous asphalt mix designed to improve road safety and environmental sustainability. It is characterized by large aggregate sizes and minimal fine aggregates resulting in a high air void content, this allows water to drain through the pavement surface reducing the risk if hydroplaning and improving skid resistance. OGFC also helps reduce noise pollution by absorbing tyre pavement noise (Mazurowski, 2024).

iv. Porous Asphalt Mix

Porous asphalt is designed to facilitate the passage of water through the pavement and into the underlying soil providing an environmentally friendly solution for storm water management. Its open graded aggregate structure and specializes asphalt binder allow water to flow through supporting sustainable urban drainage. A typical porous asphalt pavement consists of three layers that is to say surface course(50-100mm thick) for structural integrity and a smooth driving surface, filler course (50-75mm thick) to act as a transitional layer that filters water, the reservoir course (50-75mm thick) designed to temporarily store water before it infiltrates the subgrade (UNHSC, 2014).

2.5 Types of mix designs used in the surfacing layer

1. Stone Matrix Asphalt (SMA) is another mix type, which is used when pavement will be exposed to heavier traffic. The high rut resistance (due to stone-on-stone contact) and durability of SMA are made for the heavier loading conditions (Tashman, 2012).

2. Open-graded mixes like Open-Graded Friction Course (OGFC) offer improved safety for the user by allowing water to drain through the surface and reducing hydroplaning potential.

3. Warm Mix Asphalt (WMA) is a significant optional production temperature changes that can be used in any of these mix types. For concrete pavements, the mix deign is more focused on the overall properties for slabs and has surface texturing specifically for providing friction (Rohit, 2019).

4. Marshall Mix Design Method

The Marshall mix design method is one of the most commonly used techniques for designing dense graded hot mix asphalt mixtures. This method aims to determine the optimum binder content by balancing factors such as stability, flexibility and volumetric properties. This process involves compacting cylindrical samples of asphalt mixtures and performing mechanical rests to assess their load bearing capacity and deformation characteristics (White, 1985).

Steps involved in the Marshall Mix Design process

i. **Selection of Aggregate and Binder.**

This is the first step and it involves appropriate selection of aggregates and asphalt binders. Aggregates are chosen in such away that they meet target gradation, shape, and durability, while the asphalt binder is selected basing on performance grade specifications considering local standards and climatic conditions.

Specimen preparation.

The preparation is done using a predetermined gradation where asphalt binder is heated to meet the targeted mixing temperature. It also involves aggregate preheating to ensure uniform coating during mixing.

ii. **Compaction**

The mixture is then compacted in cylindrical molds using a Marshall compactor. The compactor applies predetermined number of blows to each side of the specimen, with the number of blows varying according to the traffic category. For instance, 50 blows per side are typically applied for light traffic, while 75 blows are used for heavy traffic conditions.

iii. **Specimen testing**

The specimens are tested for stability and flow.

2.6 Volumetric Analysis

This method involves determining the various volumetric properties of the mix such as: Bulk Density, Air Voids (Va), Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA).

2.6.1 Determining the Optimum Binder Content

This involves determining the binder content that satisfies Maximum stability, Acceptable flow values, Air voids within the desired range (typically 3-5%), Sufficient VMA and VFA to ensure durability.

2.7 Failures in flexible pavements

a) **Deterioration Due to Traffic**

- Rutting

Rutting is a permanent deformation of the pavement surface along wheel paths creating depressions. It occurs when traffic roads surpass the visco-plastic limit of asphalt mix resulting in plastic deformation. This issue is more prevalent in pavements with low stiffness or poorly compacted layers(Liley, 2018).

- Fatigue Cracking

Fatigue cracking is a progressive type of permanent failure caused by repeated traffic loads. Cracks typically develop at the bottom of the asphalt layer due to high tensile stresses eventually extending to the surface with continued loading. This form of damage is often seen in thinner pavements. Rigid pavements may also experience top down cracking as a result of surface embrittlement

Fatigue cracking refers to progressive form of pavement failure that results from application repeated traffic loads. Cracks appear at the bottom of the asphalt layer when there are high tensile stresses and propagate into the upper surface when there is continuous loading. This form of failure is commonly experienced in thin pavements. Aged pavements may also experience top-down cracking due to surface embrittlement (Harmelink, Shuler and Aschenbrener, 2008).

b) Thermal Cracking

Thermal cracking refers to cracks that appear perpendicular to the pavement's centreline, often at regular intervals. This cracks typically develop due to low temperatures causing thermal shrinkage, rapid temperature fractuations or significant daily temperature changes. Additionally, the aging of the binder or the improper selection of the asphalt grade can make the binder brittle. Thermal cracking occurs when the tensile stress caused by shrinkage exceeds the pavement's strength resulting into cracks(Admin, 2019).

c) Block Cracking

Block cracking consist of large interconnected rectangular cracks that generally appear in older pavements. These cracks are mainly caused by the aging and shrinkage of the asphalt binder. Other factors contributing to block cracking include lack of sufficient traffic loading to help densify the asphalt mix overtime and poor mix design particularly when the binder content is too low(Calnon, 2019).

d) Reflective Cracking

Reflecting cracks present themselves on the surfacing layer of the pavement due to movement or expansion of cracks in underlying layers.

2.8 Preventive measures for Cracking

Appropriate performance graded binders should be selected on the local climate and traffic conditions in the area of use.

Proper compaction, tack coating, and joint sealing must be ensured during construction.

Drainage systems should be implemented to effectively manage both surface and subsurface water.

For added strength, the use of geogrids, geotextiles or polymer modified binders is recommended.

2.9 Improving Asphalt Performance through Material Modification

In addition to conventional preventive maintenance practices, the long-term performance of asphalt pavements can be significantly enhanced through material modification techniques. These modifications focus on improving the properties of bitumen—the binder responsible for holding the aggregate together and resisting traffic and environmental stresses. By altering the rheological and physical characteristics of bitumen, engineers aim to reduce issues such as cracking, rutting, and moisture damage, which are common causes of premature pavement failure.

Various additives and modifiers have been explored to enhance asphalt performance, including polymers, rubber, nanomaterials, and industrial waste products. These materials are incorporated into the bitumen or asphalt mix to improve flexibility, reduce temperature susceptibility, and increase resistance to aging. Among the promising sustainable alternatives is the use of waste-derived products, which not only enhance performance but also support environmental conservation through recycling.

One such material gaining attention is Waste Engine Oil (WEO), a by-product of internal combustion engines. Its chemical compatibility with bitumen and its plasticizing effect make it a potential candidate for improving the workability, durability, and flexibility of asphalt concrete. The following section reviews existing studies on WEO as a bitumen modifier and evaluates its potential to enhance asphalt pavement performance.

2.10 Waste Engine Oil

WEO is a by-product of engine combustion consisting of a complex mixture of hydro carbons. Has the ability to rejuvenate aged bitumen by restoring some of the properties lost overtime. Research has shown that adding WEO to bitumen changes various properties such as reducing its viscosity. This alteration results in an improved mix and better compatibility during construction offering significant advantages in road construction, these benefits include faster project completion and improved workability of asphalt mix at high temperatures (Fuyu wang et al., 2028).

WEO modified bitumen out performs standard bitumen in terms of aging resistance. It increases the ratio of maltene to asphaltene helping to maintain flexibility in bitumen (Mohamad., 2018).

CHAPTER THREE: METHODOLOGY

3.0 Introduction

The chapter, outlines the materials, experimental standards, and test methods used to achieve the research objectives. It involved both visual inspections to assess pavement condition and laboratory testing to analyse factors contributing to pavement failure. By integrating empirical data from laboratory tests with mechanistic pavement behaviour, insights were gained into material properties and environmental impacts. The findings were utilized to explore strategies for enhancing resistance of bituminous mixtures to permanent deformation and improving overall pavement durability.

3.1 Research design.

This study used a quantitative approach, conducting experimental tests on aggregates and binders to identify the causes of premature deformation in road sections. The findings led to a proposed solution involving modifications to the asphalt binder. Descriptive and correlational analyses linked results from modified asphalt specimens to potential improvements in resistance to permanent deformation.

3.2 Primary data collection methods.

Laboratory tests were conducted on aggregates, bitumen, DWEO and modified bitumen. Following these tests, performance evaluations were carried to determine the optimal modified bitumen content that enhances the durability and flow of the resulting concrete.

3.2.1 Material Sourcing

Aggregates

Aggregates were sourced from Namawojja quarry, cleaned to remove contaminants and graded with sieve sizes ranging from; 0-3mm to 12-22mm. Before use they were tested meet the requirements for bituminous mixtures.

Waste engine oil (diesel) was collected from petrol fuel station Nyanama, using oil grade of 15W-40 from diesel engine, filtered to remove impurities and used at different percentages(0%,2%,4%, and 6% by weight of bitumen) to create uniform mixtures for testing.

Bitumen was got from kasangati being supplied by SB company by using the standard penetration grade of 50/70 which is commonly used in hot mix asphalt for paving, offering excellent adhesion and durability (Transport Research Laboratory, 1993).

3.3 Aggregate Test Methods

1. Aggregate grading tests (BS 812103-1:1985)

This process involved sieving to classify particle size distribution which helped in proportioning and blending different size fractions into a combined aggregate mix. This blending aimed to enhance asphalt mixture properties like air voids, VMA, and rutting resistance.

Sample preparation

This included heating and cooling a 2kg aggregate sample, then using a mechanical shaker with sieves to determine the mass retained on each sieve. The results provided cumulative percentage of material passing each sieve, aiding in the optimization of the aggregate mix.

Test procedure

- The set of sieves was mounted on a mechanical shaker in descending order of diameter, with a pan at the bottom. An oven dried aggregate sample was placed on the sieves and shaken until no more material passed through.
- The sample was then placed in a pan and with water to separate fines from coarser particles. The suspended fines were washed through a 75µm sieve.
- The washed aggregates and fines were dried in an oven at 105 ^{0}C ±5 for at least 12 hours, then cooled and weighed to determine M2.
- The mass passing the 75µm sieve was calculated as M1- M2.
- The percentage retained on each sieve was determined relative to the original mass M1.
- cumulative percentages were calculated for material passing each sieve, (% passing) = (% passing of previous sieve) – (% retained on this sieve)

2. Aggregate crushing Value (BS 812-110:1990)

The Aggregate Crushing Value test was conducted to assess the resistance of aggregates to crushing under a gradual compressive load. The test involved applying a load of 400kN to the aggregates and determining the ACV by measuring the material passing through 2.36mm sieve, following the standards outlined in BS 812: Part 110:1990. This process helps evaluate the strength and durability of aggregates for use in construction projects.

Sample preparation

The test sample consisted of an 8 kg aggregate riffle, sized between 14 mm and 10 mm. This was divided in to 3 equal portions, each placed on a tray. Each portion was heated at 105 ± 5^0C for about 4 hours to remove moisture, then cooled at room temperature before testing.

Test Procedure

- The aggregate sample was divided in to 3 layers of equal depth in a cylinder. Each layer was tamped with 25 blows using a tamping rod, ensuring excess material was removed and the surface levelled. by allowing the tamping rod to fall freely from a height of about 50 mm or more.
- The weight of the cylinder and aggregates was recorded as the mass of the test specimen.
- The specimen was placed in the test mold and plunger was positioned on top. This assembly was loaded uniformly to reach 400kN in 10 minutes.
- After releasing the load, crushed material was sieved through 2.36mm sieve. The weights of material passing (M2) and retained (M3) were recorded.
- This procedure was repeated for the second and third sample using the same sample mass.
- The ACV was calculated as a percentage using the recorded masses.

$$ACV = \frac{M2}{M1} \times 100\ \%$$ Equation 0.1

Where;

- M2 – Mass of material passing through 2.36mm sieve

- M1 – Mass of test specimen

The ACV obtained from each of the three samples was used to obtain the average. This was recorded as ACV of the aggregates recorded as a percentage.

3. Aggregate Impact value (BS 812-112:1990)

The aggregate impact value test was conducted to assess the aggregates resistance to sudden impact. It involved a fraction of aggregates that passed through a 14mm but were retained on 10 mm sieve tested in dry state. The procedure followed the guidelines set by BS 812: Part 112:1990.

Sample preparation

The test consisted of a 2 kg riffled sample of 14 to 10 mm aggregates which was then divided in to 3 roughly equal portions. Each portion was heated to 105 ± 5 ^{0}C for approximately 4 hours to remove all moisture, followed by cooling at room temperature before proceeding with the test.

Test Procedure

- The first test was put in a cylindrical steel cup in three layers, with each layer being tamping with 25 blows using a tamping rod. Excess aggregates were removed and the net mass was recorded (M1).
- The cup was secured on the impact machine and the hammer was dropped 15 times on to the aggregates. The crushed sample was then removed and weighed as M1.
- The crushed sample was sieved through a 2.36 mm sieve, the weight of mass passing (M2) and retained (M3) was recorded.
- The process was repeated other two samples to ensure consistency.

- The AIV was calculated for each sample using a specific formula below.

$$AIV = \frac{M1-M2}{M1} \times 100\% \qquad \text{Equation 0.2}$$

4. **Ten percent fines Value (BS 812-111:1990)**

Sample preparation

For dry condition

The test specimens were prepared by drying them in an oven at 105 ± 5°C for 4 hours and then cooling them before testing.

For soaked condition

The specimens were soaked in water for 24 hours, with air bubbles removed by gently lifting and dropping the baskets. After soaking, excess water was removed from the surface with a towel.

Test Procedure

- The aggregates were compacted in a cylinder in three layers by 25 strokes using a tamping rod.
- The plunger was pressed into aggregates at a uniform rate over 10 minutes ± 30 seconds recording maximum force(f).
- The crushed sample was sieved to separate fines and larger particles. The tray and aggregates were weighed and the mass of aggregate used (M1) was recorded. The whole sample was sieved on 2.36 mm sieve until no aggregates were passing. The masses of the fraction passing M2 and retained M3 were recorded.

$$m=\frac{M2}{M1} \times 100\%$$ Equation 0.3

if the fines percentage was not within the target range 7.5 % - 12.5 %, the test was repeated with adjusted force.

The force F (in kN), needed for 10 % fines was calculated from the equation:

$$F = \frac{14f}{m+4}$$ Equation 0.4

Where;

- The process was repeated for two more samples to find the average aggregate impact value.

5. **Water Absorption (BS 812-2:1975)**

The purpose for this test was to determine the relative densities of aggregates for asphalt mix design calculations.

The test aimed to assess the following;

1. Relative density on oven dry primarily need for asphalt mix design.

2. Relative density on a saturated surface-dry basis mainly used in concrete mix design.

3. Apparent relative density, is useful for production control to monitor variations in aggregate density.

4. Water absorption of the aggregates.

This test was conducted according to ASTM C127-88 and is applicable for aggregate sizes from 5mm to 40 mm.

Sample preparation

Two aggregate samples each weighing about 2-2.5 kg were used. These samples were washed through a 10mm sieve to remove finer particles like clay, silt and dust allowing them to drain. The samples were then placed in a wire basket and submerged in water for 24 hours. To remove trapped air, the basket was gently lifted and lowered under water with slight agitation.

Procedure

- The basket with the first sample was weighed in water and the mass C recorded.
- The aggregates were removed, placed on the dry cloth and gently surface- dried to remove visible water films. The mass A was then recorded.
- The aggregates were oven dried at 105 ± 5°C for 24 hours, cooled and then weighed to record mass D.
- The process was repeated for the second sample. The relative densities were determined using an equation and averaged from the two test results.

1. Relative Density at oven-dry basis = $\frac{D}{A-(B-C)}$ Equation 0.5

2. Relative Density on saturated surface dry basis = $\frac{A}{A-(B-C)}$ Equation 0.6

3. Apparent relative density = $\frac{D}{D-(B-C)}$ Equation 0.7

4. Water absorption = $\frac{(B-A)}{A} \times 100$ Equation 0.8

where;

- A is the mass of the saturated surface-dry aggregate in air (g)
- B is the apparent mass in water of the basket + sample of saturated aggregate (g)
- C is the apparent mass in water of the empty basket (g)
- D is the mass of the oven-dry aggregate in air (g)

6. Flakiness Index (BS 812-105:1989)

Flakiness Index test was performed to identify and quantify the flaky aggregates in the sample. Aggregates are considered flaky if their thickness is less than 60% of their nominal length. The presence of flaky particles is undesirable because they can weaken the aggregates, potentially leading to breakdown under heavy loads as noted in (BS 812-P105:1-1989).

Sample preparation

Three samples of about 2kg each were obtained by riffling and sampling the aggregates. These samples were washed to remove dust and then dried in an oven at 105˚C. After drying each sample was weighed and its mass was recorded.

Test procedure

- The sample was sieved through various sieve sizes 63mm, 50mm, 37.5mm,28mm,20mm, 14mm, 10mm and 6.3mm. material retained on 63mm sieve and passing 6.3mm sieve was discarded.
- The weights of aggregates retained on each sieve were determined and recorded as m1 and M2.

- Each fraction was measured using thickness gauge. All particles passing the guage were combined, weighed and recorded as m3.

The flakiness index was calculated using the formula,

Flakiness index = $\frac{m2}{m3} \times 100\%$ Equation 0.9

7. Los Angeles Abrasion (ASTM C131-2001)

The test was chosen to evaluate aggregate's resistance to wear and abrasion when used as a wearing course. The LAA value measures the degradation of mineral aggregates due to a combination of abrasion, impact and grinding.

This is achieved by rotating a specified number of steel spheres in a drum with the aggregates for a set number of revolutions, creating an abrasive action.

Sample preparation

A sample of aggregates was sieved through sieves 20, 12.5 and 10 mm to obtain two sets each weighing 5kg. The grading was chosen conform to AC20 specifications. The sample was the dried in an oven at 105˚C and allowed to cool at room temperature.

Test procedure

- The aggregate and charges were placed in the LAA testing machine.
- The machine was operated at 30-33 revolutions per minute for 500 revolutions. After the test, the material was discharged, sieved through a 1.70mm sieve and the retained material was weighed.

LAAV $= \frac{(W1 - W2)}{(W1 \text{ X } 100)}$ X 100% Equation 0.10

Where;

- W1 is the original weight of aggregate sample, (5000g)

- W2 is the weight of the sample specimen retained on 1.70 mm sieve.

3.4 Bitumen Tests

1. Penetration test (ASTM D5-86)

Sample preparation

The bitumen sample in the metallic bucket was carefully heated on a gas cooker until it became fluid. A portion of heated bitumen was scooped and poured into 4 labelled penetration tins to a depth sufficient for the needle to penetrate

The tins were loosely covered to prevent dust and allowed to cool at room temperature for an hour. They were the placed in a water bath at 25˚C for another hour to cure before starting the test.

Test procedure

- The cup with the bitumen sample was placed in a water bath at 25˚C which were then positioned on the base plate of the penetration apparatus. the needle was adjusted to just touch the surface of the sample.
- The needle was loaded for five seconds to penetrate the bitumen. The dial guage was adjusted to zero before loading and then read to measure the penetration distance.
- The process was repeated two more times to obtain 3 penetration readings for the same sample.
- The average was calculated and recorded as the penetration for the first sample.

2. Softening Point (ASTM D36)

Sample preparation

The bitumen was heated gradually in a metal container while stirring to prevent overheating until it became fluid enough to pour.

Two brass rings were placed on a metal plate, and heated bitumen poured into them in a smooth motion to avoid air bubbles and ensure a levelled surface.

The rings were left undisturbed for few minutes to allow the bitumen to set. The heat spatula was the used to trim excess material creating a flat surface. The rings were cooled at room temperature for 30minutes before proceeding with the test.

Test Procedure

A glass beaker was filled with distilled water, and the rings containing bitumen were placed on a metal support frame inside the beaker. A steel ball was carefully placed on top of each bitumen sample.

The set up was heated using controlled water bath, with the temperature increasing at a steady rate of 5˚C per minute.

As the temperature rose, the bitumen softened under the weight of the steel ball. The test was complete when the ball sunk completely through the bitumen and touched the bottom plate at which point the temperature was recorded.

The test was repeated twice more and the average of the three reading was taken as the softening point of bitumen.

$$SP = \frac{T_1+T_2}{2} \qquad \text{Equation 0.11}$$

Where:

SP = Softening Point (˚C)

T_1= Temperature recorded for the first sample (˚C)

T_{22} = Temperature recorded for the second sample (°C)

3. **Specific Gravity (ASTM D70)**

Test Procedure

- A clean dry pycnometer was weighed using digital balance and its mass was recorded as w1.
- The pycnometer was filled with distilled water ensuring no air bubbles remained. The weight of the water filled pycnometer was recorded as w2.
- A sample of bitumen was heated until fluid and carefully poured into the pycnometer to avoid air entrapment. The excess bitumen was removed and the weight of the pycnometer with bitumen was recorded as w3.
- The pycnometer containing bitumen was refilled with water until full. The weight of the pycnometer with both bitumen and water was recorded as w4.

$$SG = \frac{W_3 - W_1}{(W_2 - W_1) - (W_4 - W_3)} \quad \text{Equation 0.12}$$

4. **Ductility (ASTM D113-86)**

Test Procedure

- The conditioned bitumen specimen was placed in the ductility testing machine ensuring proper alignment. The machine's water bath was maintained at 27°C to control the temperature.
- The ends of the mould were slowly pulled apart at a uniform speed of 50mm/min using motorised machine. The bitumen elongated under tension until it broke.

- The total length from the original position to the breaking point was recorded as the ductility value. The test was repeated more two times to ensure accuracy. The average ductility value was calculated.

3.5 Waste Engine Oil Tests

1. Flash and Fire point

Test Procedure

- A clean dry brass test cup was filled with oil, stirred for uniformity and placed in the testing apparatus. A thermometer was inserted to monitor temperature.
- The oil was heated at a controlled rate of 5-6°C per minute while stirring to prevent overheating. A test frame was introduced at intervals to check for ignition.
- The flash point was recorded as the temperature were the oil vapours momentarily ignited but did not sustain combustion.
- Heating continued beyond the flash point. The fire point was recorded as the temperature where the oil ignited and sustained a frame for at least five seconds.

Kinematic Viscosity (ASTM D445)

Test procedures

- The preheated bitumen waste engine oil was poured into calibrated capillary viscometer tube upto the marked level.
- The viscometer was placed vertically at 135°C.
- The sample was allowed to stabilize in the bath foe at least 10minutes to ensure uniform heating.

- The time taken for the sample to flow between two marked points on the viscometer tube was recorded using a stop watch.
- The Kinematic Viscosity was calculated using the formula:
- $\gamma = C \times t$
- Where:
    - γ= Kinematic Viscosity
    - C= Calibration constant of the viscometer
    - t= Average flow time (seconds)

3.6 Waste engine oil modified bitumen test methods

1. Penetration Test

The penetration test was performed to assess the consistency and hardness of bitumen samples modified with 2%, 4%, and 6% WEO. The test measured the depth of penetration of the standard needle into the bitumen under controlled conditions.

Sample Preparation

The pure bitumen was heated to 120-150°C until fluid. The required amounts of waste engine oil (2%, 4% and 6% by weight) were added while stirring continuously to ensure uniform mixing.

The mixtures were kept at 140-160°C for 30 minutes to allow proper interaction between the components.

The mixtures were poured into metal cups to a depth of at least 10mm and left to cool at room temperature for at least one hour to solidify. The samples were then placed in a temperature-controlled water bath at 25°C for one hour before testing to ensure uniform temperature conditions.

Test Procedure

- The penetrometer apparatus was cleaned and the needle was checked for sharpness and alignment, the cup containing modified bitumen sample was inserted into the penetrometer.
- The needle was lowered to just touch the surface of the modified bitumen. It was then released for exactly five seconds to penetrate the sample under the applied load. The depth of the penetration was recorded using the penetrometer scale.
- This process was repeated for all the modified bitumen samples and three readings were taken at different locations, avoiding the edges.
- The average penetration value of each sample was calculated and the results were recorded.

2. Softening Point

Test Procedure

- Brass rings were cleaned and coated with glycerine and talc to prevent sticking of modified bitumen.
- Heated modified bitumen mixtures were poured into the rings without creating air bubbles.
- The rings were cooled at room temperature for 30 minutes then placed in a 5°C water bath for 15minutes to standardize the starting conditions.
- The rings were positioned in the softening point test apparatus with steel ball on top of each bitumen sample. The set up was placed in a beaker filled with distilled water which was heated at a controlled rate of 5°C per minute. The thermometer monitored the temperature.

- As the temperature rose the bitumen softened as the steel ball sunk. The softening point was recorded when the ball touched the bottom plate.
- The test was performed for all three modified bitumen samples and the results were recorded.

3. Density (ASTM D70)

Test procedure

- A clean dry pycnometer was weighed using a precision balance and its mass was recorded as A.
- The pycnometer was filled with water and its weight was recorded as B.
- The pycnometer was partially filled with bitumen -WEO and its weight was recorded as C.
- The pycnometer was then filed with distilled water at 25°C to its calibrated mark. The total weight of the pycnometer, bitumen-WEO sample, and water was recorded as D.
- The density and specific gravity of bitumen-WEO sample were calculated using specific formula based on recorded weights.

$$Relative\ Density = \frac{(C-A)}{(B-A)-(D-C)} \qquad \text{Equation 0.13}$$

4. Ductility

Test Procedures

- A standard ductility mode was cleaned and lightly greased with glycerine and talc to prevent sticking. Heated modified bitumen-WEO mixtures were poured into the moulds without trapping the air bubbles.

- The moulds were cooled at room temperature for 30minutes, then placed in a 25°C water bath for 90minutes to ensure uniforms cooling. Excess bitumen was trimmed using a hot spatula to create smooth surfaces.
- The mould sides were removed and the modified bitumen specimen was mounted in the ductility testing machine. Both ends were firmly clamped and the specimen was pulled apart at a uniform speed of 50mm/minutes.
- The elongation of the sample was observed as it stretched until it broke and measured.

3.7 Mix Design Tests

The Marshall mix design method was used to determine the proportions of aggregates and binder for both WEO-Modified and unmodified binder. Samples were prepared according to MS-2 Asphalt Mix Design Methods and tested for Marshall stability and flow (ASTM D1559). density voids analysis was conducted using ASTM D2726 and D2401 to calculate key properties like VFA and VMA. These results helped identify or determine asphalt bitumen content.

1. **Combined Grading**

- Different aggregate sizes of 0–3 mm, 3–6 mm, 6–12 mm, and 12–20 mm was collected and oven-dried at 110°C to remove moisture.
- The dried aggregates were then sieved ensuring proper gradation.
- The fine and coarse aggregates were proportioned based on the mix design requirements.
- 2Kg of aggregate was placed on the top sieve and mechanically shaken until there was no significant amount of aggregates passing through the sieve.

- The mass retained on each sieve was recorded, and the percentage passing was calculated using the formula

$$\%passing = \frac{Cummulative\ mass\ retained}{Total\ sample} \times 100 \qquad \text{Equation 0.14}$$

- The gradation curve was plotted to check compliance with standard grading envelopes.
- The proportions of each aggregate size were adjusted to achieve a continuous gradation that falls within the specified grading limits.
- The combined gradation was determined using the formula

$$P = \frac{A_1P_1 + A_2P_2 + A_3P_3 + A_4P_4}{A_1 + A_2 + A_3 + A_4} \qquad \text{Equation 0.15}$$

- Where:
    - P= Percentage passing for combined aggregates
    - A_n= Proportion of each aggregate fraction in the mix
    - P_n= Percentage passing of individual aggregate fraction
- The calculated combined gradation curve was compared against target gradation specifications for flexible pavement mixtures.
- If deviations were observed, the proportions of fine and coarse aggregates were adjusted accordingly.
- The results obtained were recorded.

2. **Marshall Test**

Sample Preparation

- The required quantity of aggregates and 50/70 penetration grade bitumen were collected.

- The aggregates were heated to 160°C, while the bitumen was heated separately to 145°C to achieve proper mixing.
- The heated aggregates and bitumen were then mixed thoroughly to ensure uniform coating.
- 3.5% by weight of Waste Engine Oil was added to the mix and blended homogeneously into the mixture.
- The mixed asphalt was then placed into a preheated Marshall mould, fitted with a baseplate and collar to maintain shape.
- The compacted mix was subjected to 75 blows per face using a standard Marshall hammer, simulating heavy traffic loading conditions.
- After compaction, the specimens were allowed to cool at room temperature for 24 hours before further testing.

3. Bulk Density Determination

- The mass of each specimen in air was recorded (W_1).
- Each specimen was then submerged in water and then weighed and recorded (W_2)
- To determine its saturated surface dry (SSD) mass, the submerged specimen was removed from the water and then the surface water wiped off, then the mass recorded (W_3).
- The bulk density of the specimen was calculated using the formula

$$Bulk\ Density = \frac{W_1}{W_3 - W_2}$$ Equation 0.16

4. **Stability and Flow Testing**

- The specimens were immersed in a water bath at 60°C for 30-40 minutes to simulate field conditions.
- After conditioning, the specimens were removed and placed in the Marshall testing machine.
- A compressive load was applied at a rate of 50 mm/min until the specimen failed.
- The maximum load was recorded, indicating the strength of the mix.
- Simultaneously, the flow value was measured at the point of failure.
- The Marshall Stability was obtained as the peak load-bearing capacity of the mix.
- The flow value represented the plastic deformation under load.
- The results obtained are shown in the table below

3.8 Obtaining Indirect Tensile strength

Determining the percentage of Air voids

Test procedures

- A compacted asphalt specimen was prepared using the standard Marshall compaction method and allowed to cool to room temperature.
- The mass and dimensions of the specimen were measured, and the volume was calculated.
- The specimen was then saturated using the water displacement method to obtain the Saturated Surface-Dry (SSD) weight.
- The bulk specific gravity (Gmb) was calculated from the measured mass and volume.

- A separate sample was processed under vacuum conditions using a pycnometer to determine the theoretical maximum specific gravity (Gmm) of the mix.
- The air voids percentage (Va) was calculated using the formula:

$$\boldsymbol{Va} = \left(\frac{\boldsymbol{G_{mm}} - \boldsymbol{G_{mb}}}{\boldsymbol{G_{mm}}}\right) \times \mathbf{100}$$ Equation 0.17

Indirect Tensile strength

- A cylindrical asphalt specimen was conditioned at a controlled temperature.
- The specimen was then placed in the indirect tensile strength testing apparatus.
- A compressive load was applied along the diametrical plane at a constant loading rate until the specimen failed.
- The maximum load (P) at failure was recorded.
- The indirect tensile strength (ITS) was calculated using the formula:

$$ITS = \frac{2P}{\pi t D}$$ Equation 0.18

- The Tensile Strength Ratio was calculated from

$$TSR = \frac{Tensile\ strength\ Wet}{Tensile\ Stength\ Dry} \times 100$$ Equation 0.19

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Results showing the Characterization of the materials.

4.1.1 Aggregates test methods

1. Flakiness Index

Table 0-1: Flakiness index

Sum of Mass retained	G	2101.3
Sum of Corrected Mass passing slots	G	417.7
Flakiness Index FI = (M_3/M_2) *100	%	**19.9**
Maximum allowable FI	%	**35**

The obtained flakiness index of 19.9% as indicated in table 4-1 and it is noted to be below the maximum allowable limit of 35%, indicating that the aggregate particles used are relatively less flaky. According to BS 812-105.1:198), lower flakiness values are preferred because flaky particles tend to break under loading and contribute to poor compaction and reduced structural strength.

Since the flakiness index directly influences the workability and strength of asphalt mixtures, the obtained value suggests that the aggregate will provide good interlocking, improved load distribution, and better resistance to deformation.

2. LOS ANGELES ABRASION

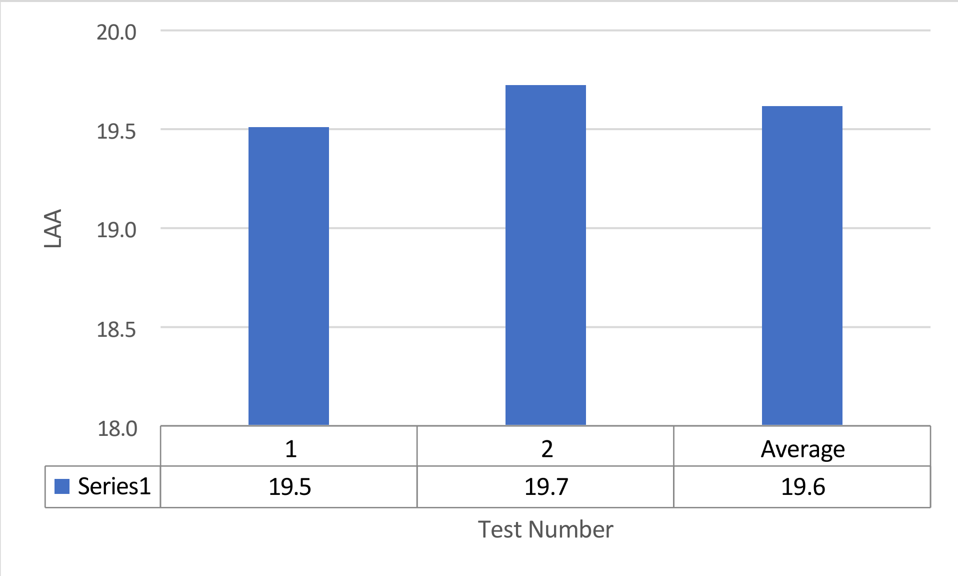


Figure 0-1: A graph of Los Angeles Abrasion test

On comparison of the three values from the test, the average value of abrasion calculated was 19.6% from figure 4-1 which is below the maximum required value of 30% according to ASTM.

With this value of abrasion, the aggregates are able to avoid abrasion due to loads provided by the tyres of the cars that experience friction resistance as they interact with the asphalt concrete pavement.

The flexible pavement surfacing layer is able to retain its thickness and bitumen will not be exposed leading early ageing and hardening to bitumen that makes its tend towards experiencing fatigue cracks.

3. AGGREGATE IMPACT VALUE

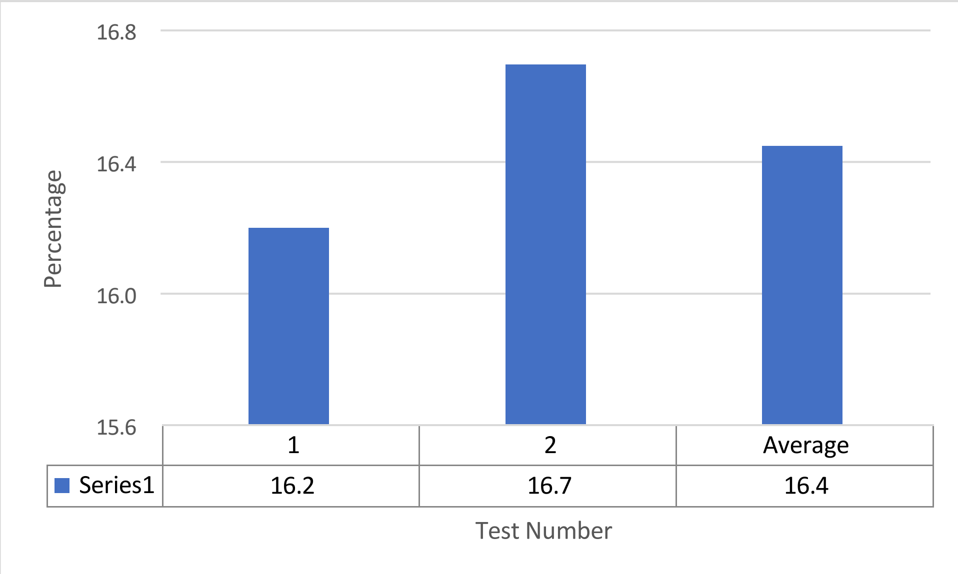


Figure 0-2: A graph of AIV test results

The calculated average value for this test is 16.4% which is within the standard range of < 20% as required by BS 812 – 112 as shown in the figure 4-2.

For cases of heavy loading by heavy traffic, aggregates that are able to give an AIV value with in that that is required are able to resist the impact imposed on them by the existing traffic when in use.

These impacts can be dynamic in nature, and some can be caused due to break and start reactions from cars.

4. AGGREGATE CRUSHING VALUE

From the test an average Aggregate Crushing Value was 13% which is below the required 10-15% in reference to BS 812-110.

With this value, the aggregates are able to withstand traffic loads on the road without undergoing crushing, therefore they are able to serve durably without failing due to loading and this also reduces risks due to rutting that is usually an irreversible effect.

5. TEN PERCENT FINES VALUE

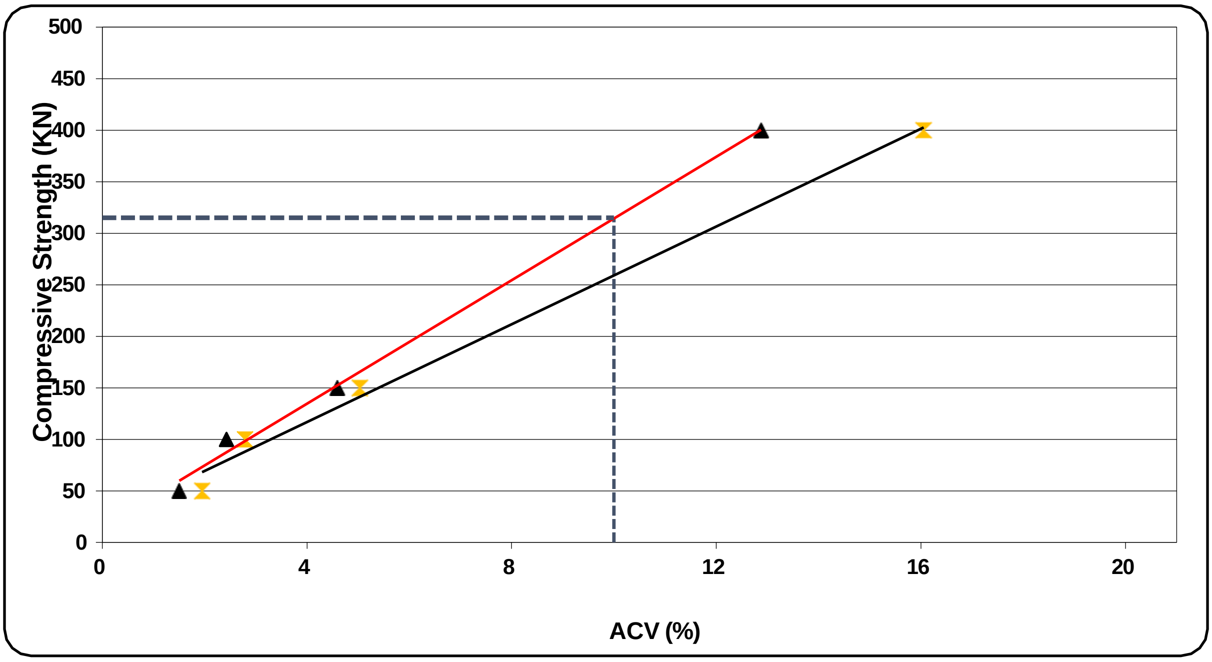


Figure 0-3: A graph of TFV Dry and Wet results

Considering the wet to dry TFV value of 83% gotten as an average which is within the required standards of > 75% as in reference to BS 812-111.

From the figure 4-3, indicates that the aggregates are able to experience interactions with moisture and not be damaged and hence can be able to withstand weathering without sustaining significant damage. This is a crucial factor in helping the material serve durably while incorporated within the asphalt concrete in the wearing course.

6. Grading of aggregates

Table 0-2: Grading of 0-3 aggregates

Sieve Size (mm)	Weight Retained (gm)	Cum. Wt. Retained (gm)	Cumulative % Retained	% of Passing
20.0	0.0	0.0	0.0	100.0
14	0.0	0.0	0.0	100.0
10	0.0	0.0	0.0	100.0
5	0.0	0.0	0.0	100.0
2.36	176.5	176.5	11.2	88.8
1.18	298.5	475.0	30.2	69.8
0.60	239.1	714.1	45.4	54.6
0.300	327.5	1041.6	66.3	33.7
0.150	261.0	1302.6	82.9	17.1
0.075	149.7	1452.3	92.4	7.6
Pan	119.0			

Table 0-3: Particle size distribution for aggregate size 3-6

Sieve Size (mm)	Weight Retained (gm)	Cum. Wt. Retained (gm)	Cumulative % Retained	% of Passing
20.0	0.0	0.0	0.0	100.0
14	0.0	0.0	0.0	100.0
10	0.0	0.0	0.0	100.0

5	592.9	592.9	18.1	81.9
2.36	2655.6	3248.5	99.2	0.8
1.18	3.6	3252.1	99.3	0.7
0.60	0.9	3253.0	99.3	0.7
0.300	1.3	3254.3	99.4	0.6
0.150	1.4	3255.7	99.4	0.6
0.075	1.6	3257.3	99.5	0.5
Pan	17.4			

Table 0-4: Particle size distribution for aggregate size 6-12

Sieve Size (mm)	**Weight Retained (gm)**	**Cum. Wt. Retained (gm)**	**Cumulative % Retained**	**% of Passing**
20.0	0.0	0.0	0.0	100.0
14	41.0	41.0	1.0	99.0
10	859.6	900.6	22.0	78.0
5	3049.8	3950.4	96.4	3.6
2.36	132.6	4083.0	99.6	0.4
1.18	2.6	4085.6	99.7	0.3
0.60	1.1	4086.7	99.7	0.3
0.300	1.4	4088.1	99.7	0.3
0.150	1.2	4089.3	99.8	0.2
0.075	1.7	4091.0	99.8	0.2

Pan	8.1			

Table 0-5: Particle size distribution for aggregate size 12-20

Sieve Size (mm)	**Weight Retained (gm)**	**Cum. Wt. Retained (gm)**	**Cumulative % Retained**	**% of Passing**
20.0	431.6	431.6	11.1	88.9
14	1737.6	2169.2	55.9	44.1
10	1410.1	3579.3	92.3	7.7
5	276.2	3855.5	99.4	0.6
2.36	10.5	3866.0	99.7	0.3
1.18	1.1	3867.1	99.7	0.3
0.60	1.2	3868.3	99.7	0.3
0.300	2.5	3870.8	99.8	0.2
0.150	1.2	3872.0	99.8	0.2
0.075	2.4	3874.4	99.9	0.1
Pan	4.0			

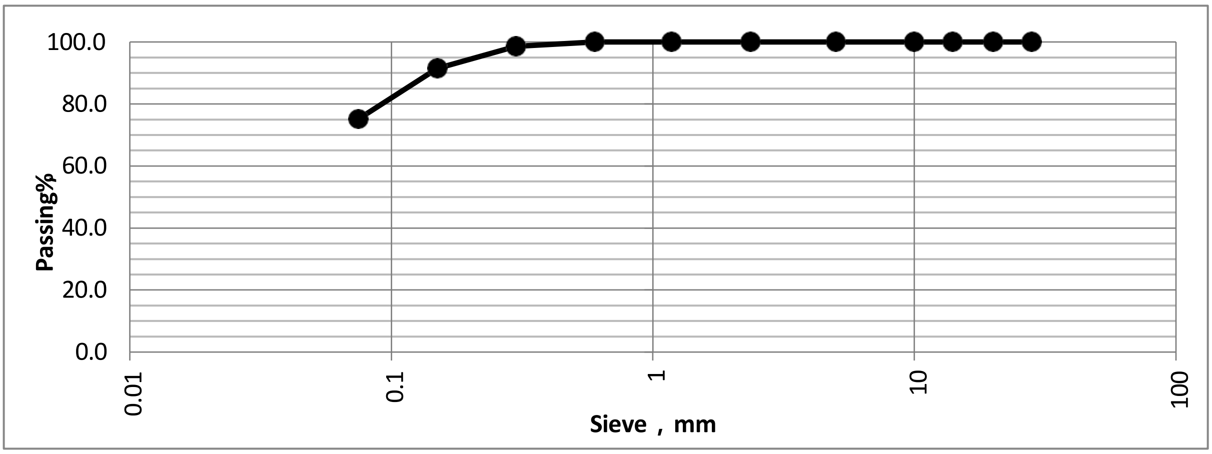


Figure 0-4: Grading of Filler

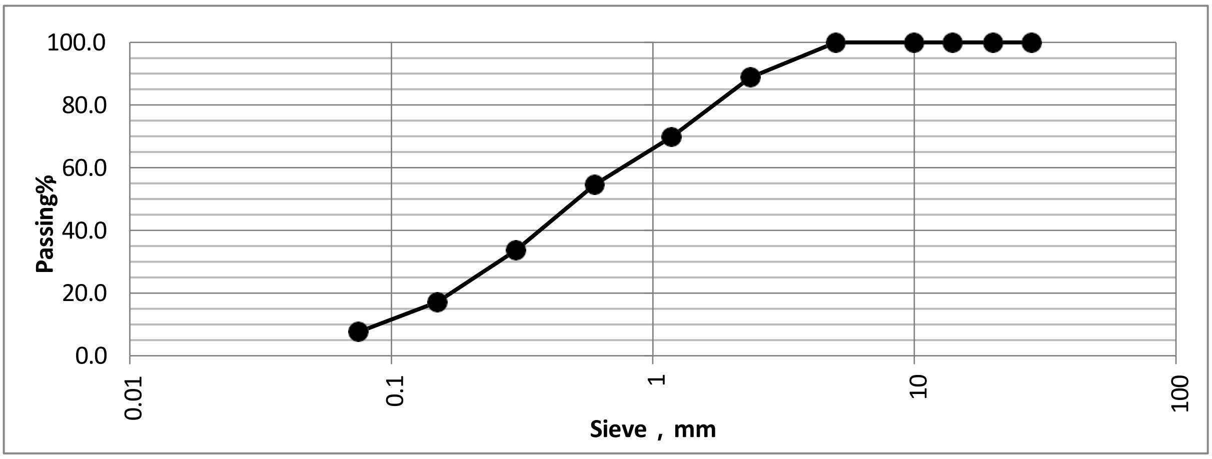


Figure 0-5: Grading of 0-3mm aggregates

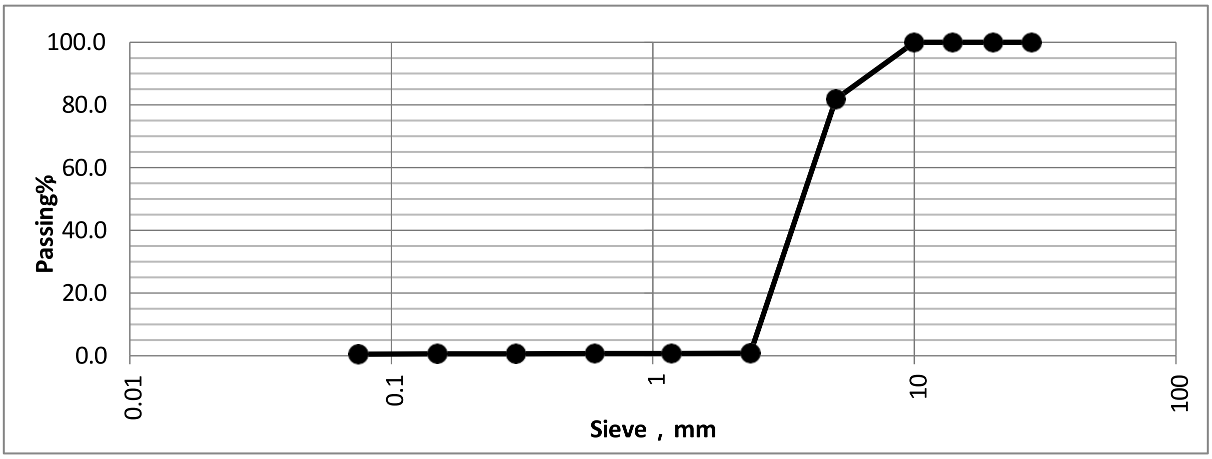


Figure 0-6: Grading of 3-6mm aggregates

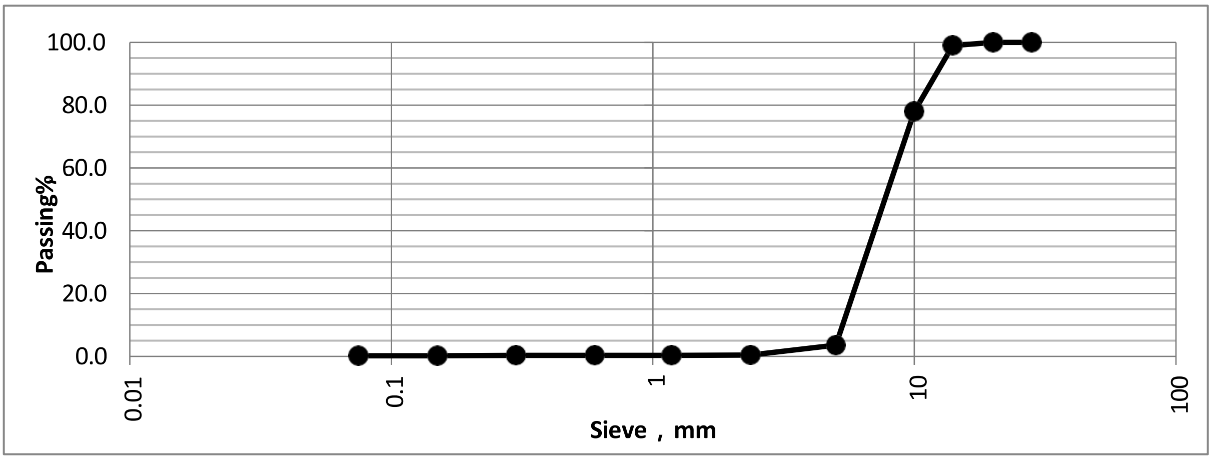


Figure 0-7: Grading of 6-12mm aggregates

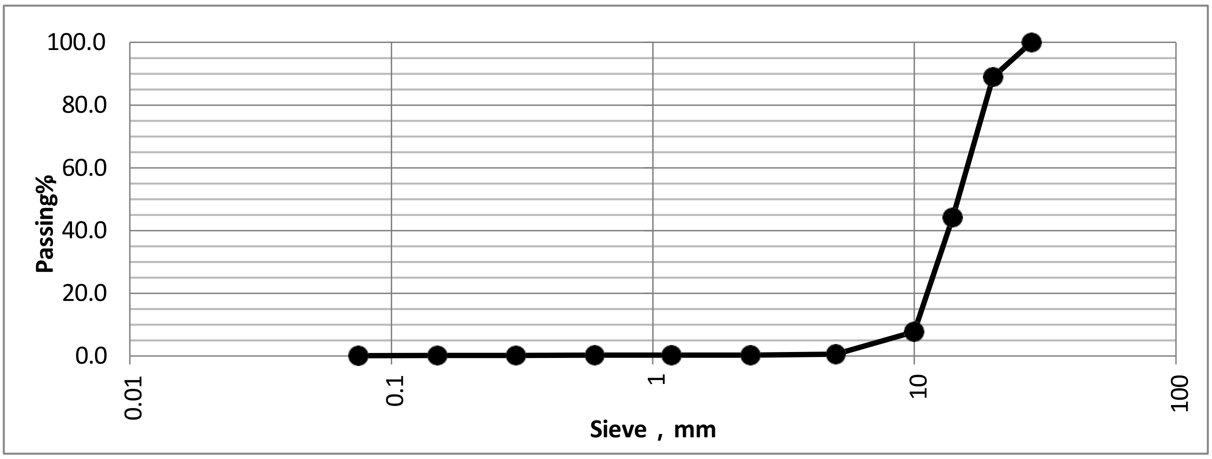


Figure 0-8: Grading of 12-20mm aggregates

7. Specific gravity and water absorption

Table 0-6: Relative density and water absorption for aggregates (0-3)

Specimen reference			1	2	Average
Mass of saturated surface-dry aggregate in air	A	g	415.1	447.0	
Mass of Pycnometer + sample + water	B	g	2039.7	2053.9	
Mass of Pycnometer filled with water only	C	g	1777.5	1771.6	
Mass of oven-dry aggregate in air	D	g	410.3	441.7	
Particle density on an oven-dry basis	$P_d = \frac{D}{A-(B-C)}$	Mg/m^3	2.683	2.682	2.683
Particle density on a saturated and surface-dry basis	$P_s = \frac{A}{A-(B-C)}$	Mg/m^3	2.715	2.714	2.714
Apparent Particle density	$P_a = \frac{D}{D-(B-C)}$	Mg/m^3	2.770	2.771	**2.771**
Water Absorption	$W_{abs} = 100x\left(\frac{A-D}{D}\right)$	%	1.170	1.200	**1.2**

Table 0-7: Relative density and water absorption for aggregates (3-6)

Specimen reference			**1**	**2**	**Average**
Mass of saturated surface-dry aggregate in air	A	g	788.1	789.4	
Mass of Pycnometer + sample + water	B	g	2040.6	2042.1	
Mass of Pycnometer filled with water only	C	g	1547.6	1547.6	
Mass of oven-dry aggregate in air	D	g	783.5	785.6	
Particle density on an oven-dry basis	$P_d = \frac{D}{A-(B-C)}$	Mg/m^3	2.655	2.664	2.659
Particle density on a saturated and surface-dry basis	$P_s = \frac{A}{A-(B-C)}$	Mg/m^3	2.671	2.677	2.674
Apparent Particle density	$P_a = \frac{D}{D-(B-C)}$	Mg/m^3	2.697	2.699	**2.698**
Water Absorption	$W_{abs} = 100x\left(\frac{A-D}{D}\right)$	%	0.587	0.484	**0.5**

Table 0-8: Relative density and water absorption for aggregates (6-12)

Specimen reference			**1**	**2**	**Average**
Mass of Saturated Surface-dry aggregates in air	A	g	2482.1	2510.3	
Mass of basket + Sample in Water	B	g	1795.0	1812.5	
Mass of basket in Water	C	g	238.3	238.3	
Mass of Oven-dryaggregates	D	g	2473.8	2501.0	
Particle density on an oven-dry basis	$P_d = \frac{D}{A-(B-C)}$	Mg/m^3	2.673	2.672	2.672
Particle density on a saturated and surface-dry basis	$P_s = \frac{A}{A-(B-C)}$	Mg/m^3	2.682	2.682	2.682
Apparent Particle density	$P_a = \frac{D}{D-(B-C)}$	Mg/m^3	2.697	2.699	**2.698**
Water Absorption	$W_{abs} = 100x\left(\frac{A-D}{D}\right)$	%	0.336	0.372	**0.4**

Table 0-9: Relative density and water absorption for aggregates (12-20)

Specimen reference			**1**	**2**	**Average**
Mass of Saturated Surface-dry aggregates in air	A	g	2783.5	2858.9	
Mass of basket + Sample in Water	B	g	1986.0	2031.8	
Mass of basket in Water	C	g	238.3	238.3	
Mass of Oven-dryaggregates	D	g	2775.3	2850.7	
Particle density on an oven-dry basis	$P_d = \frac{D}{A-(B-C)}$	Mg/m^3	2.679	2.676	2.678
Particle density on a saturated and surface-dry basis	$P_s = \frac{A}{A-(B-C)}$	Mg/m^3	2.687	2.683	2.685
Apparent Particle density	$P_a = \frac{D}{D-(B-C)}$	Mg/m^3	2.701	2.696	**2.699**
Water Absorption	$W_{abs} = 100x\left(\frac{A-D}{D}\right)$	%	0.295	0.288	**0.3**

An absorption value of water of 1.2% for the aggregates was as result of a density that is apparent of 2.772 Mg/m^3 with an SSD of 2.643 but varied with aggregates sizes as in reference to BS 812-112.

This value was generally low and gives a picture of how little the water that was absorbed by the aggregates and with this result, segregation, ravelling and distresses will not be expected to take place because aggregates have a high cohesion towards the bitumen because it absorbs less water that usually alters the bitumen-aggregate bond that is susceptible to moisture damages.

4.1.2 Bitumen test methods.

1. Penetration test

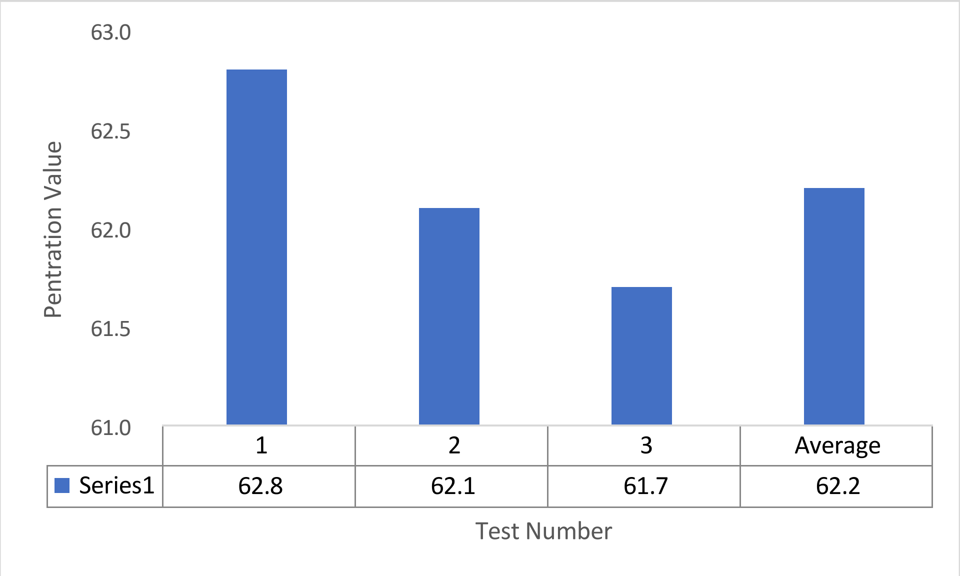


Figure 0-9: Penetration test of neat bitumen

From the results compiled, an average value of 62.2 mm was recorded. The required value for a bitumen grade 50/70 is 50-70 mm. as required by ASTM D-5.

With this value of penetration, the bitumen is suitable for application on the flexible pavement wearing course and this value implies that the binder is not soft or even stiff for its application and this eases workability during mixing, but also application of the binder and also makes the binder not stiffen during its service hence resisting cracking.

2. Softening point

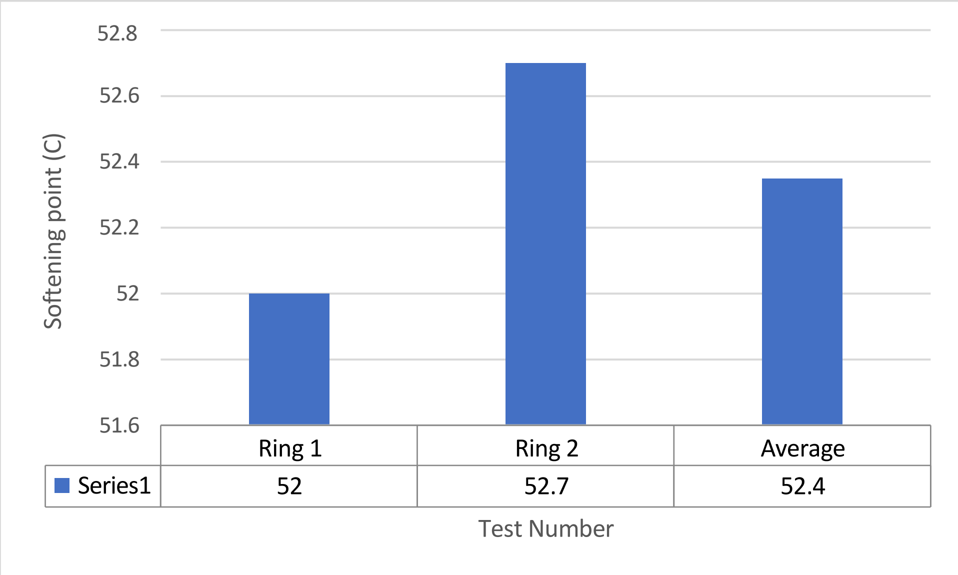


Figure 0-10: Softening Point of neat Bitumen

An average softening point of 52.4 degrees Celsius gotten was in line with the softening point required from the standard of ASTM D36 as indicated in figure 4-10. With this value the bitumen will not melt at a temperature less than 52.4. Meaning basing of the surrounding temperatures in the region that is usually around 38 degrees Celsius which could also rise up to about 40 degrees Celsius, the bitumen in the asphalt concrete will not be able to easily melt and be soft.

This avoids chances of distresses like rutting which usually occur when bitumen melts easily, consequently softening and resulting into continuous deformations in the wheel path as the cars use the flexible pavement.

3. Density

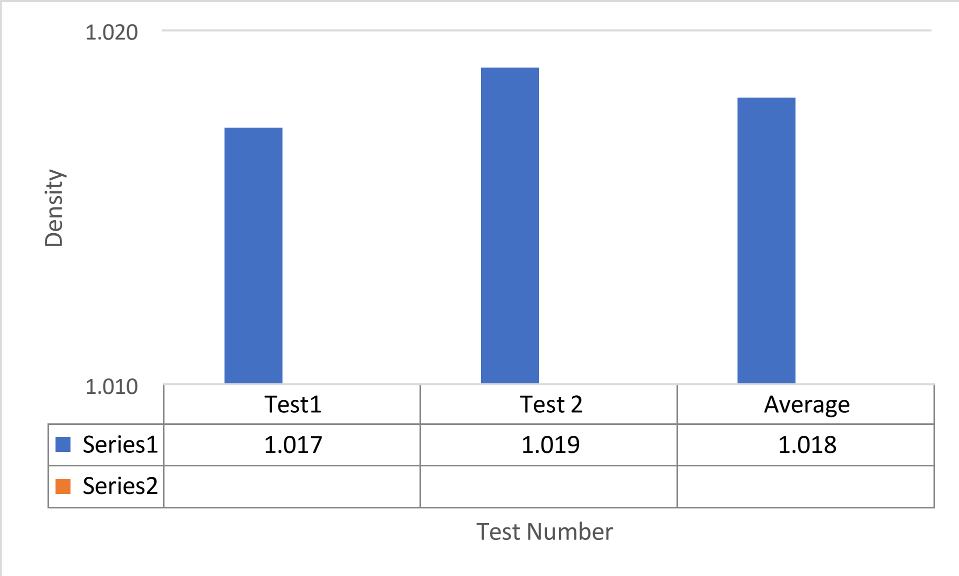


Figure 0-11: Density of Neat Bitumen

From the results, the resulting average density from the tests is 1.018 g/cm^3 which is above 1 that is a requirement according to D8188.

With this value, bitumen in terms of its constituents gives a good picture of what is constitutes, these being well distributed to give a a density greater than 1. These include well distributed saturated compounds like propane, aromatic compounds that usually include a benzene ring, resins and asphaltenes necessary for the fluidity. With these, bitumen in asphalt concrete is able to take up an average molecular mass weight that will be able to withstand loads.

4. Ductility

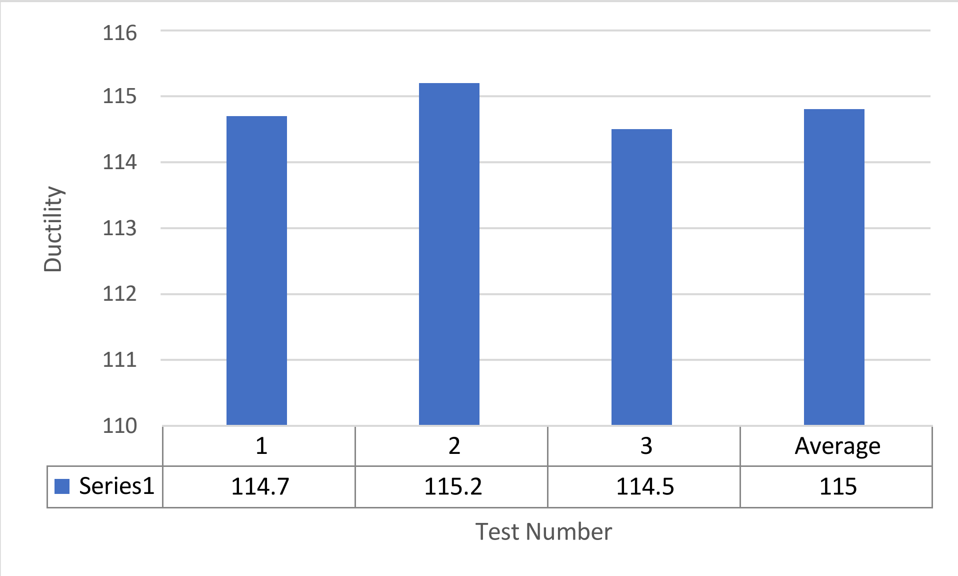


Figure 0-12: Ductility of Bitumen

At 0% waste engine oil, the ductility is 115 cm, which increases to 120 cm at 2% waste engine oil. This value is above the minimum value specified by standards of BS EN 1427 as shown in figure 4-12.

This happens because of an increase in flexibility that is as result of softening of the bitumen softening of the bitumen due to the replaced fractions of the maltene fractions content that is caused by the existence of the waste engine oil in the bitumen.

When ductility is to increase, the asphalt concrete becomes able to withstand changes due to loading from vehicles using the road through its ability to stretch. With this ability of bitumen in asphalt concrete, when modified, and this makes asphalt concrete resistant to crack due to its inability to stretch.

4.1.3 Waste Engine oil test methods.

1. Kinematic Viscosity

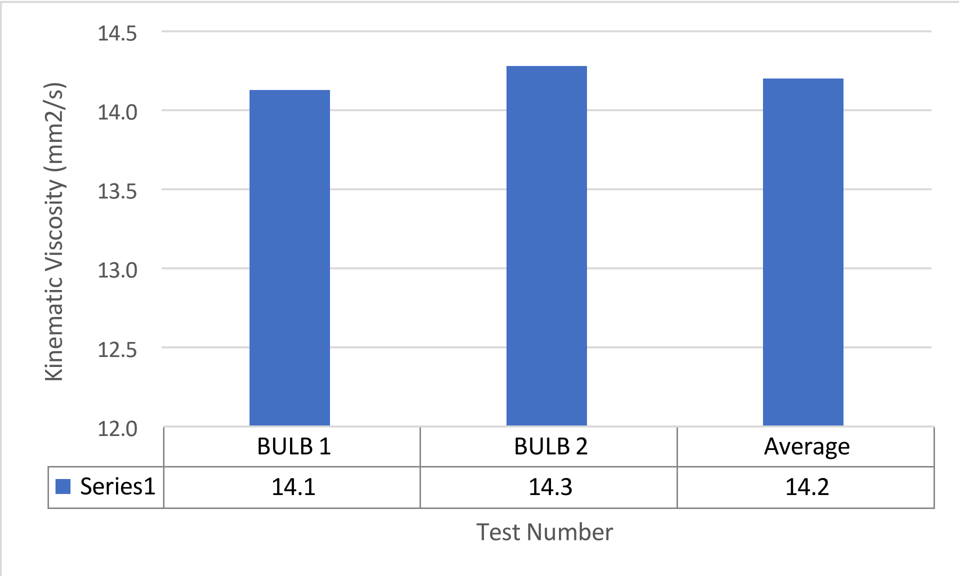


Figure 0-13: Kinematic Viscosity of WEO

The average kinematic viscosity value that resulted from the testing of waste engine oil is 14.2 mm^2/s which is within the standards according to EN 12595.

With this value of viscosity, bitumen is able to flow easily without resistance in itself. This is necessary for its stretching ability because when subjected to both and heavy loads, it will be able to stretch enabling it to distribute the loads along the whole pavement limiting failure of a single section. Usually, this failure is a cracking distress due to stiff and un-stretchable asphalt concrete.

2. Flash and fire point

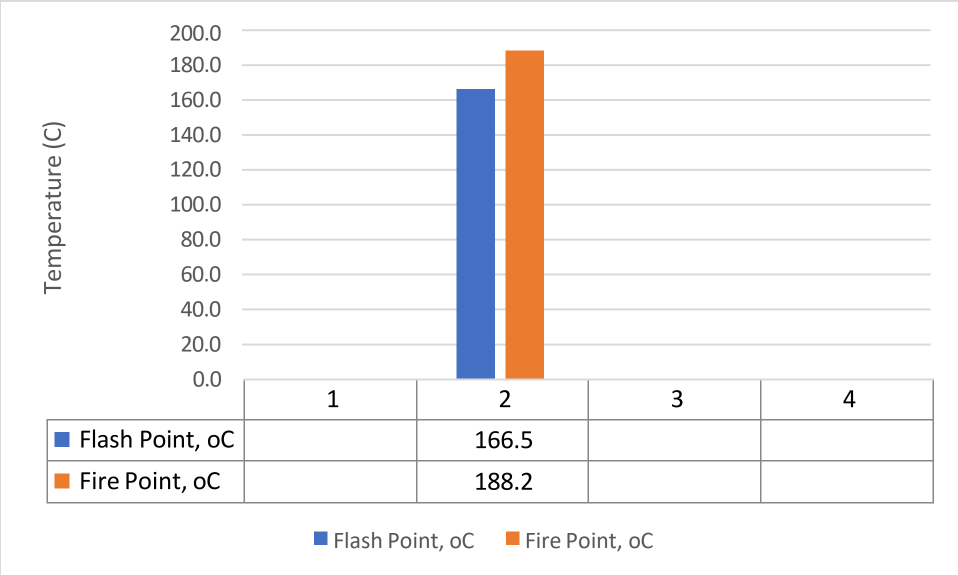


Figure 0-14: Flash and fire point of WEO

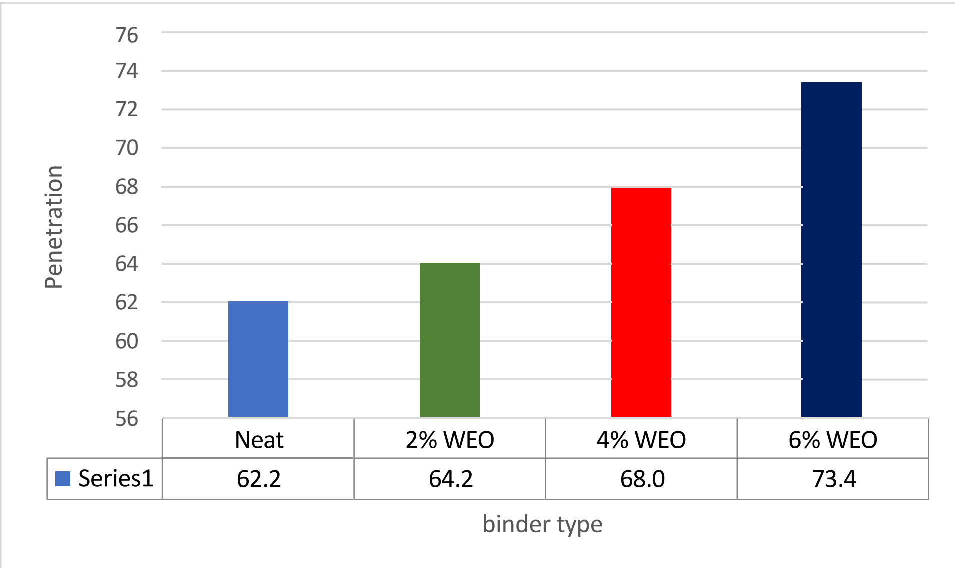
As a result of tested flaming in presence of a thermometer, the average values for flash and fire point were 166.5 degrees Celsius and 188.2 degrees Celsius respectively which is within standards according to ASTM D92 as shown in figure 4-14.

Now, before a flame is ignited and lasts continuously (fire point) it first undergoes short while-ignition and this means that if it meets the standards, then the bitumen is not likely to be ignited in case of fire outbreaks on roads, meaning that in terms of fire accidents, the bitumen performs in resistance to them.

4.2 Results showing neat and modified bitumen test methods.

4.2.1 Bitumen Test Methods

1. Penetration Test

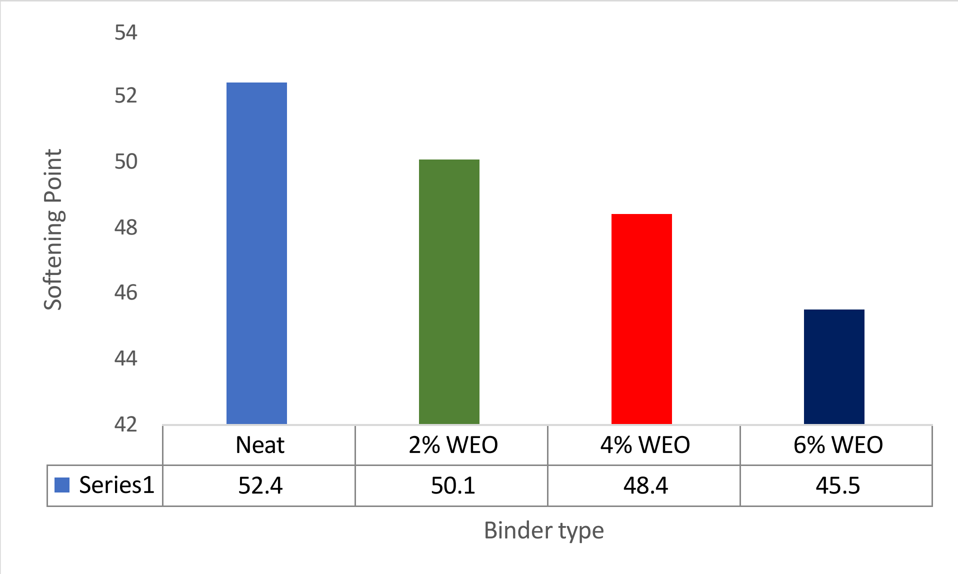


We see that the penetration at 0% WEO in bitumen is 62.2 and this increases to 64.2 at 2% WEO that is within the standards according to (standard).

This happens because the waste engine oil contains more asphaltenes, resins and saturated compounds that aid in increasing the softening ability of the bitumen, hence making the needle penetrate more.

This means that bitumen will be able to adjust more to pavement distresses that lead to cracking since it is no longer stiff and is less susceptible.

2. Softening point



Softening point showed that adding WEO to bitumen lowers its softening point, making it softer and more flexible. As the softening point decreased from 54.2˚C for neat bitumen to 45.5˚C with 6% WEO. This reduction indicates improved ductility and crack resistance but also increases the risk of rutting in the binder becomes so stiff.

The optimum balance was found at 4% WEO offering better crack resistance without compromising high temperature stability.

3. Density

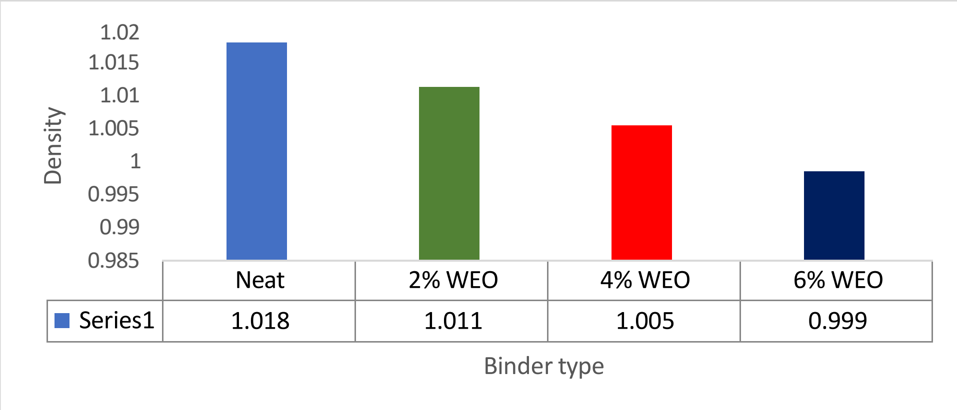


Figure 0-15: Density

The density of the bitumen decreased as the waste engine oil content increased, from 1.018g/cm³ for neat bitumen to 0.999g/cm³ at 6% WEO. This decrease is due to lighter components in WEO diluting the heavier asphaltene content making the binder softer and more flexible as it makes WEO less dense than bitumen reducing bitumen's molecular weight hence increasing its volume. An optimal balance was observed at 4% WEO, were the density was 1.005g/cm³ improving ductility without compromising stability.

4. Ductility

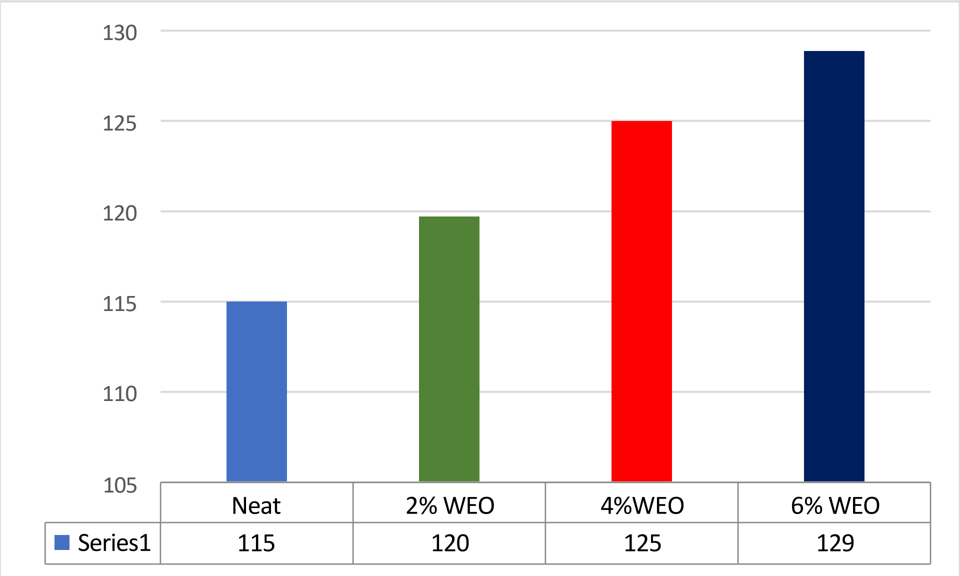


Figure 0-16: Ductility

With these results of figure 4-16, the bitumen shows a trend that with increase in the WEO content, the ductility also increases. Thus, is evident at 0% WEO with a ductility value is 115 cm, 2% WEO with a ductility value of 125 cm of ductility which is above that specified by standards as 100 cm ASTM D113.

This is as a result of the contents of asphaltenes, resins among others that contribute to the stretching ability of the bonds through their ability to make bitumen fluid.

4.3 Marshal mix design test methods.

1. Combined grading

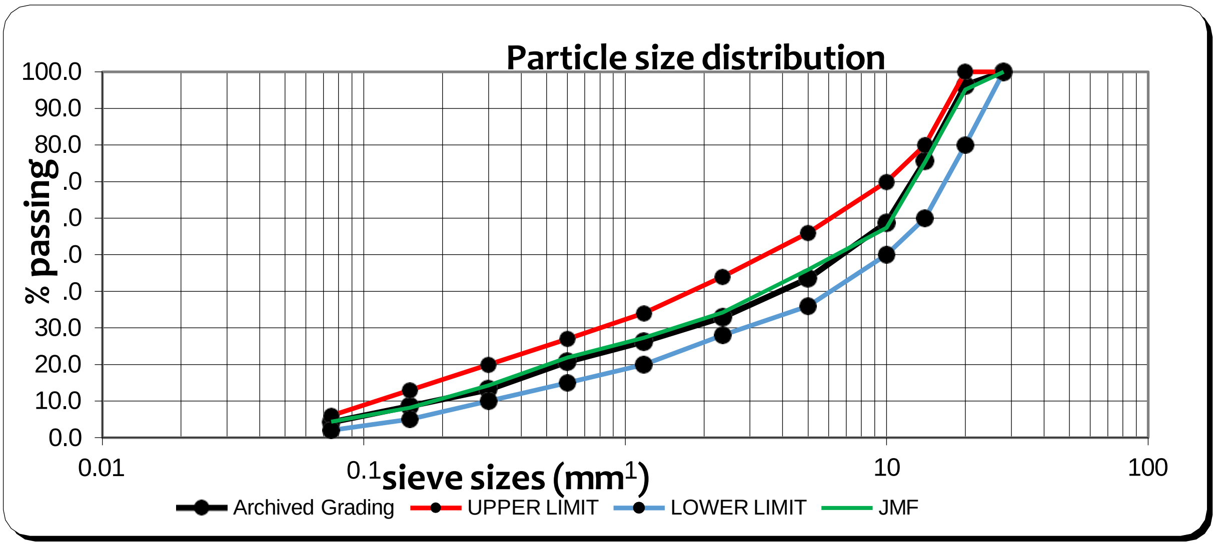


Figure 0-17 A graph showing combined grading of aggregates

The combined aggregate gradation curve above indicate results of a well-graded mixture suitable for asphalt mix design. The cumulative retained percentages show a gradual distribution of particle sizes, ensuring proper interlocking and mechanical stability. The passing percentage values align well with the standard grading limits, suggesting that the aggregate blend falls within the acceptable range for asphalt mixtures. Coarse aggregates, ranging from 28 mm to 5 mm, constitute a significant portion of the mix, with 56.5% retained at the 5 mm sieve. This distribution enhances the load-bearing capacity and structural integrity of the mix. Additionally, the intermediate aggregates (2.36 mm – 0.6 mm) contribute to compaction and workability, with 67.1% retained at 2.36 mm, ensuring the mix has sufficient fines to prevent segregation while maintaining stability.

The fine aggregates, particularly those passing through the 0.075 mm sieve, account for 4.3%, which is within the acceptable range to prevent excessive dust while maintaining cohesion. A balanced proportion of course and fine particles is essential for achieving an asphalt mix those resists rutting and fatigue cracking. The relatively low fine content helps maintain good drainage, reducing the risk of moisture-related damage and improving durability. Overall, the grading results suggest a well-optimized aggregate structure that supports strong adhesion with bitumen, ensuring a durable and long-lasting pavement structure.

2. Optimum Bitumen Content

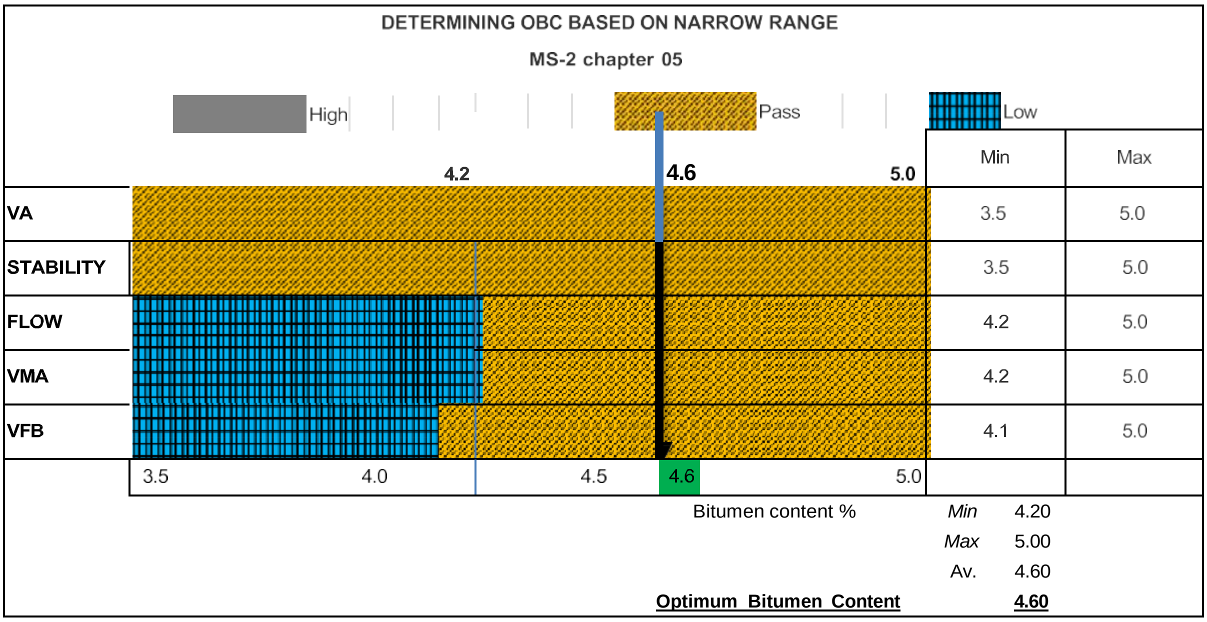


Figure 0-18: Determination of Optimum Bitumen Content

The results shows in figure 8-18 that the Optimum Bitumen Content for the tested asphalt mix is 4.6%, was determined using the Marshall Mix Design method. At this content, all critical parameters align with specifications the air voids of 4.62% fall within the 3-6% target, stability peaks at 15.56 kN well above the 8 kN minimum, flow is optimal at 3.05 mm within the 2–4 mm range and density reaches its maximum 2.403 g/cm³. Trends show air voids decrease and flow increases with higher bitumen, while stability and density peak at 4.5% before declining. This balance ensures durability, resistance to deformation, and proper compaction.

Lower bitumen content results in excessive air voids and low flow which may risk moisture damage and brittleness. Conversely, 5.0% bitumen pushes flow to the upper limit, increasing rutting risk while stability drops. Both extremes are non-ideal. For long-term performance.

3. Marshall Stability and Flow

Table 0-10: Marshall stability and flow

Test Number	1	2	3	Average
Marshall Stability (KN)	15.33	16.03	15.08	15.48
Correction Factor	1	1	1	1.00
Corrected Marshall Stability (KN)	15.33	16.03	15.08	15.48
Flow (mm)	2.26	2.20	2.30	2.25

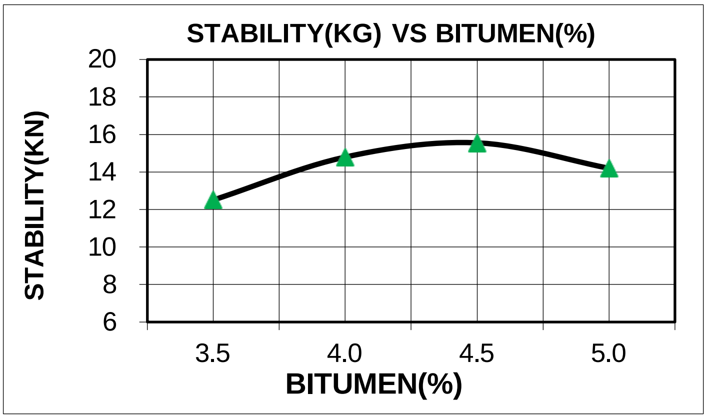


Figure 0-19: Marshall Stability

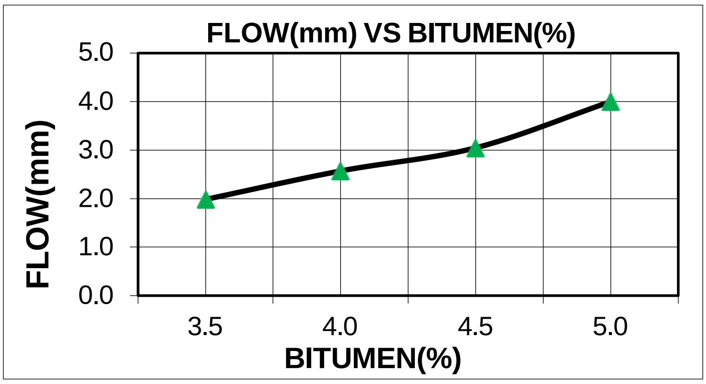
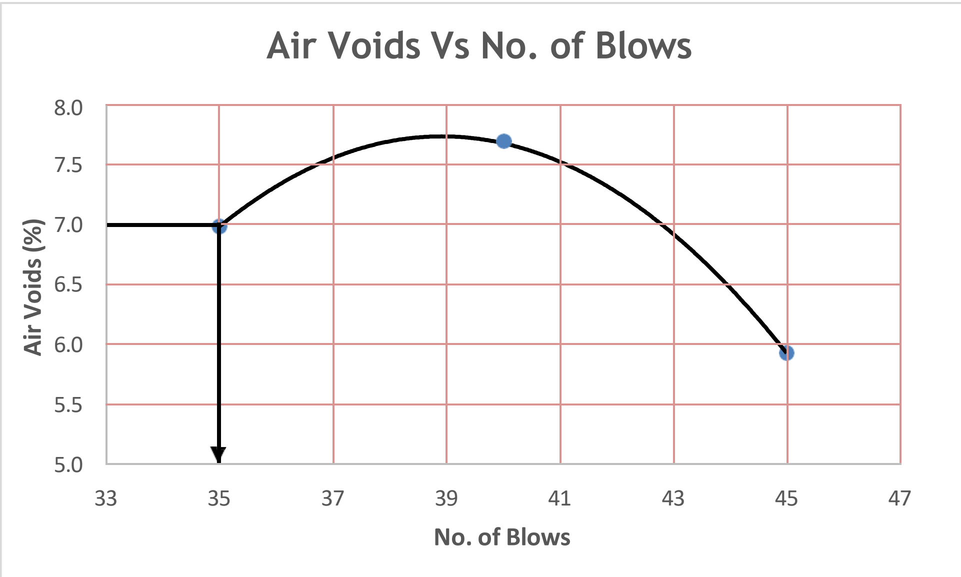


Figure 0-20: Marshall Flow

Air voids



4.4 Indirect tensile strength.

Table 0-11: Indirect Tensile strength results with WEO

	Unit	Code	DRY			WET		
No. Blows			35			35		
Diameter	Mm	D	101					
Thickness	Mm	t	65.9	65.8	65.5	65.3	64.8	66.0
Weight in Air	Gr	A	1237.6	1235.6	1234.6	1236.9	1234.4	1229.6

Weight in water after soaking	Gr	B	1238.3	1236.1	1235.0	1237.3	1235.3	1230.3
Weight in air after soaking	Gr	C	709.9	708.8	708.6	709.9	708.8	706.4
Volume	Cc	E	528.4	527.3	526.4	527.4	526.5	523.9
BULK DENSITY	gr/cc	F	2.342	2.343	2.345	2.345	2.345	2.347
Correction Factor	-	C'	1.000					
Corrected Specific Gravity	gr/cc	F'	2.342	2.343	2.345	2.345	2.345	2.347
Max, Specific Gravity	Gmm	G	2.515	2.515	2.515	2.515	2.515	2.515
Air Voids, (100 x (G-F')/G)	%	H	6.9	6.8	6.7	6.7	6.8	6.7
Volume of Air Voids, (H x E/100)		I	36.3	36.0	35.5	35.6	35.7	35.0
Load reading	KN	P	16.85	15.18	16.65	16.54	14.30	13.61
Tensile strength, 2xP/(π x t x D)	Kpa		1612.5	1454.9	1603.1	1597	1392	1300
Average Tensile Strength	Kpa		1557			1430		
Tensile Strength Ratio	%		92					

From table 4-27, it showed that the Tensile Strength Ratio of the Asphalt Concrete mixture, modified with 3.5% Waste Engine Oil and containing 4.6% binder compacted with 35 blows, was determined at 92%. This value exceeds the minimum threshold of 80%, indicating that the addition of WEO has significantly improved the adhesion between the binder and the aggregates, as well as the cohesion within the bitumen enhancing improved stiffness properties. The rejuvenating effect of WEO likely replenishes the lost maltenes in aged binders, resulting in a softer, more flexible binder that adheres more effectively to the aggregate particles. As a result, the mixture demonstrates enhanced resistance to tensile stresses generated by traffic loads and environmental factors.

4.5 DESIGN

Considerations

2 – lane road, $l_f = 1$

One directional traffic to Masaka

Formulae

$F_0 = lf \times ADT$ Equation 0.1

$F_p = F_0(1+r)^y$ Equation 0.2

$G = (1+r)^{0.5y}$ Equation 0.3

$T_i = 365x\,F_p xWxGxYx10^{-6}$ Equation 0.4

ESAL = 50.0 msa (T (0) Heavy Traffic) Equation 0.5

Information from TRL report (Otto, 2019)

For, Subgrade CBR = 15%

Resilience modulus = $2555 \times CBR^{0.64}$ =14457.37psi Equation 0.6

Initial Performance serviceability index = 4.5

Terminal Performance serviceability index = 2.5

Change in P_{si} = 2.0

Standard deviation

Reliability = 90% (interstate highways)

DSN = $a_1D_1 + a_2D_2m_2 + a_3D_3m_3$

From graphs $\mathbf{DSN_{min}}$ = 4.2

$\mathbf{DSN_{actual}}$ = a1D1+a2D2m1+a3D3m2

With

a_1 = 0.35 (interstate highway)

a_2 = 0.12 (Natural or Crushed gravel)

a_3 = 0.11 (Natural Gravel)

$m_1 = m_2$ = 0.8 (Fair drainage)

D_1 = 150 mm (Surfacing layer thickness)

D_2 = 300 mm (Road base thickness)

D_3 = 300 mm (Subbase thickness)

Considering material depth of 1000mm, subgrade layer thickness=250mm.

<u>Quantification calculations</u>.

Batch mass of aggregates = 1180g.

5% bitumen content, mass of bitumen = 0.035/95x1180 = 43.4g optimum WEO of 3.5% was mixed in 4.6% bitumen = 0.035x43.4 = 1.52g

Volume of the Marshall Mould used for the mix; V is equal to;

$$\frac{22}{7}x0.0508^2x0.0635 = 0.000515m^3 \quad \text{Equation 0.7}$$

The Marshall mould requires, volume conversion to g, multiplication with 1000000 gives 515g

This is was used as a mix for real application on the road.

4.6 Data analysis methods.

These results of this research were analysed using computer Microsoft excel. This tool help in the creation of graphs which explain the behaviour of the material in relation to various conditions.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

- The results of this study demonstrated that modifying 50/70 penetration grade bitumen with Waste Engine Oil (WEO) improved its rheological behavior. Specifically, the penetration value increased from 62.2 mm to 73.4 mm with 6% WEO, indicating enhanced softness and reduced stiffness. Simultaneously, the softening point and density decreased, confirming greater flexibility in the binder. These findings suggest that WEO effectively enhances the workability of bitumen, making it more suitable for asphalt concrete production.
- At 3.5% WEO content, the modified asphalt mix achieved an optimum bitumen content (OBC) of 4.6%, compared to 4.7% for the unmodified mix. This reduction in OBC highlights the improved efficiency of the WEO-modified binder in coating aggregates and achieving desired performance metrics. Additionally, a tensile strength ratio (TSR) of 92% confirmed that moisture resistance was not compromised by the inclusion of WEO, which is crucial for long-term pavement durability.
- Marshall Stability and flow results further supported the suitability of the modified mix. The average stability of 15.48 kN and average flow of 2.25 mm fell within acceptable limits, indicating the mix maintained structural strength and adequate flexibility. Overall, the inclusion of WEO improved binder performance, enhanced flexibility, reduced air void content, and provided a sustainable alternative to traditional bitumen modification.

5.2 Recommendations

- It is recommended that WEO be incorporated into asphalt mixtures at an optimal content of approximately 3.5%. At this dosage, the binder exhibits improved flexibility and workability while maintaining stability and durability. This can contribute to longer-lasting pavements with reduced maintenance demands and better resistance to cracking under traffic loading.
- Further studies should be undertaken through long-term field trials to assess the real-world performance of WEO-modified asphalt. These studies should investigate the effects of environmental conditions, aging, and traffic stress on the structural integrity and durability of the modified pavement mixtures.
- Research into combining WEO with plastomeric additives, such as recycled waste plastics, is encouraged to counterbalance softening effects in hotter climates and promote even greater sustainability in pavement technologies.

5.2.1 Recommendations for further studies.

- WEO is shown to reduce stability as its percentage of modification increases. Therefore, careful consideration is required to balance factors of stability, workability and environmental concerns while determining the optimal waste engine oil content.
- Finally, national and regional road authorities should consider establishing technical guidelines for the use of WEO in bituminous mixes.

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Appendices

Appendix A: Pictorial

Gradation of aggregates

Stability and flow test

Marshal testing

Marshals

APPENDIX B: Laboratory Results

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
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P.O.Box 29285 KAMPALA
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Email: cscecjiangbo@gmail.com

Location:	Zirobwe Quarry	Sampling Date:	11-Dec-2024
Material Source:	Kasangati Asphalt Plant	Tested Date:	17/12/2024

SUMMARY OF TEST RESULTS FOR ASPHALT AGGREGATES

Sample Size			Filler	0-3	3-6	6-12	12-22
Particle density on an oven-dry basis		Mg/m^3	3.077	2.683	2.659	2.672	2.678
Particle density on a saturated and surface-dry basis		Mg/m^3	/	2.714	2.674	2.682	2.685
Apparent Particle density		Mg/m^3	/	2.771	2.698	2.698	2.699
Water Absorption		%	/	1.18	0.54	0.35	0.29
TFV	DRY	KN	315.0			BS 812 Part 111 : 1990	
	Ratio	%	83.2				
ACV		KN	12.9			BS 812 Part 111 : 1990	
F I		%	19.9			BS 812: Part 105.1 1990	
AIV		%	16.4			BS 812 Part 112:1990	
LAAV		%	19.6			ASTM C131-2001	

Remarks:

Representatives

Group member	Materials Technician (CSCEC)	Materials Engineer(CSCEC)
Sign	Sign:	Sign:
Date	Date: 17/12/2024	Date: 20/01/2025

STATE CONSTRUCTION ENGINEERING P.O.Box 29285 Kampala 20 JAN 2025

cSCEc	**CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD** Block 36, Plot 95, 11&711,Kitebi Kibuga Kampala,Sssuna II Road, Nyanama Zone Mutundwe, Lubaga Division P.O.Box 29285 KAMPALA Tel: +256(0)755046031/708898888 Email: cscecjiangbo@gmail.com

Summary of Bitumen Test Results

Bitumen type:	*50/70(Neat)*	*Supplier/ Origin: SB Company*	
Testing date:	*31/Dec/24*	*Sample Date:*	*22/Dec/24*

Penetration value		62.2		ASTM D 5
Softening(Ring & Ball)		52.4		ASTM D36/ AASHTO T 053
Density (g/cm3)		1.02		ASTM D70
Ductility(cm)		115		AASHTO T051-94
Remarks:				

	Representatives	
Group Member	**Lab Technician (cscec)**	Materials Engineer (CSCEC)
Sign	**sign** [signature]	**Sign** [signature]
Date:	**Date** 31/12/24	**Date** 21/1/2025

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21 JAN 2025
(CSCEC)

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Summary of Test Results For Bitumen Grade 50/70 With Waste Engine Oil at Different Percentages

Sampling Location	Lab at Campsite (Nyanama)	Date of sampling	22/12/2024
Source of Materials	SB Company	Date of Testing	18/01/2025
Bitumen Grade	50/70		

Test Parameter	Standard Specifications	Unit	Specifications Limits for 50/70 Bitumen	Test Results of Bitumen with % of Waste Engine Oil			
				0%	2%	4%	6%
Penetration depth of a 100g needle	AASHTO T049-96	mm	50 - 70	62.2	64.2	68.0	73.4
Ductility	AASHTO T051-94	cm	Min 100	114.8	119.7	125.0	128.9
Softening Point	ASTM D36/ AASHTO T 053 -96	•C	46 - 54	52.4	50.1	48.4	45.5
Specific Gravity	ASTM D70 - 97	g/cc	Min 1.00	1.02	1.01	1.00	1.00

Remarks:

Representatives

Group Member	Lab Technician (CSCEC)	Materials Engineer (CSCEC)
Sign	sign	Sign
Date:	Date 18/01/25	Date 21/[illegible]/2025

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Penetration Test for Bitumen

Testing Method ASTM D 5

Bitumen type:	*50/70*	*Supplier/ Origin: SB Company*	
Testing date:	*31/Dec/24*	*Sample Date:*	*22/Dec/24*

Measurement no.	1	2	3	Remarks
Penetrometer dial reading				
Initial reading	0.13	0.13	0.10	
Final reading	6.41	6.34	6.27	
Penetration value	62.8	62.1	61.7	
Average penetration value		62.2		

Remark:

Representatives		
Group member	Laboratory Technician (CSCEC)	Materials Engineer (CSCEC)
Signature:	Sign [signature]	Signature: [signature]
Date:	Date 31/12/24	Date: 21/01/2025

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Summary of Bitumen Test Results

Bitumen type:	*2% WEO*	*Supplier/ Origin: SB Company*	
Testing date:	*18/Jan/25*	*Sample Date:*	*22/Dec/24*
Penetration value	64.2		ASTM D 5
Softening(Ring & Ball)	50.1		ASTM D36/ AASHTO T 053
Density (g/cm3)	1.01		ASTM D70
Ductility(cm)	120		AASHTO T051-94
Remark			
Group Member	Lab Technician (CSCEC)	Materials Engineer (CSCEC)	
Signature:	Sign [signature]	Sign [signature]	
Date:	Date 18/01/25	Date 21/01/2025	

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ABSTRACT OF MARSHALL MIX DESIGN TEST VALUES

Neat Bitumen Content%	Density (g/cm³)	Air Voids% (va)	VMA %	VFB %	Stability (KN)	Flow (mm)
3.5	2.375	6.50	13.88	59.12	7.92	1.98
4.0	2.392	5.71	13.74	64.32	9.69	2.57
4.5	2.403	4.48	14.60	68.74	11.97	3.05
5.0	2.397	4.18	15.04	73.18	12.80	4.00
Spec.Limits	N/A	3 - 6%	Min. 14%	65-75%	8-18 KN	2-4mm

Trends and Relations of the Test data

The test property curves plotted as described above have been found to follow as reasonably consistent pattern for Bitumen mix. Trends generally noted are outlined below.

a.)The stability value initially increases as bitumen improves cohesion and adhesion but decreases beyond the OBC.

b.) The flow value increases with increasing BT content

c.) The Density value increases with increasing BT content up to a maximum after which the density decreases due to iver saturation

d.) The % of Air voids decreasing with increasing BT content.

e.)VMA slightly increases initially as bitumen increases film thickness but may decrease due to aggregate packing adjustiments.

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ANALYSIS OF TEST RESULTS

BITUMEN(%)	3.5	4.0	4.5	5.0
DENSITY	2.375	2.392	2.403	2.397
BITUMEN(%)	3.5	4.0	4.5	5.0
AIR VOIDS(%)	6.50	5.71	4.48	4.18
BITUMEN(%)	3.5	4.0	4.5	5.0
STABILITY(KN)	7.92	9.69	11.97	12.80
BITUMEN(%)	3.5	4.0	4.5	5.0
FLOW(mm)	1.98	2.57	3.05	4.00
BITUMEN(%)	3.5	4.0	4.5	5.0
VMA(%)	14.64	14.49	14.55	15.20
BITUMEN(%)	3.5	4.0	4.5	5.0
VFB(%)	55.59	60.44	69.00	72.27

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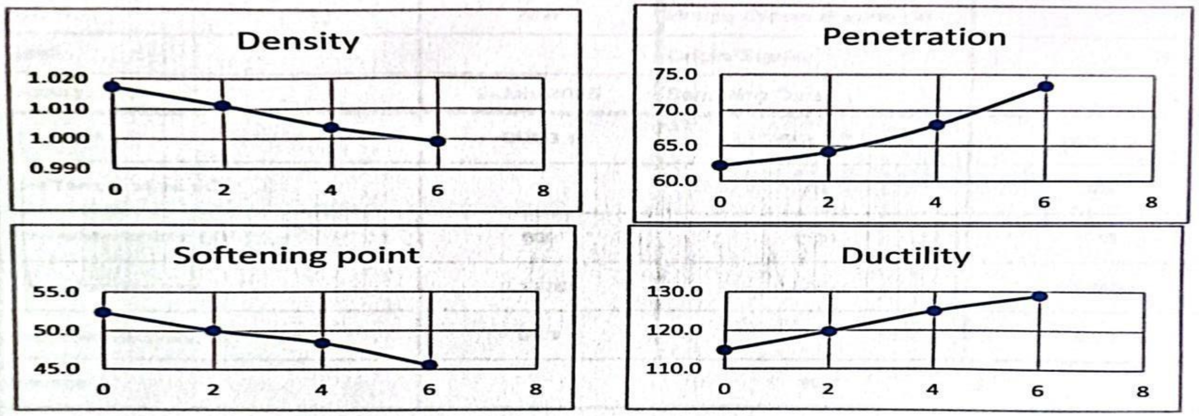
Relationship Btn Neat Bitumen and Modified Bitumen				
%age of WEO	0	2	4	6
TEST				
Penetration	62.2	64.2	68.0	73.4
Softening point	52.4	50.1	48.4	45.5
Density	1.017	1.011	1.004	0.999
Ductility	114.8	119.7	125.0	128.9



Key Observations:

1. At 2% WEO:

Slight changes in all properties.
Improved workability and flexibility.
Still suitable for heavy and light traffic roads.

2. At 4% WEO:

Noticeable softening and reduced heat resistance.
Suitable for light traffic in moderate climates.

3. At 6% WEO:

Significant softening, reduced stability, and lower compaction quality.
Not ideal for heavy loads or hot climates.

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Kinematic Viscosity Test

Testing Method ASTM D 2170-01

Ref. No.	*N/A*	*Waste Diesel Engine Oil*	*WEO*
Type		*Origin/Suplier*	*Workshop*
Testing date	*9-Jan-2025*	*Sampling Date*	*22-12-24*

Sample No.	BULB 1	BULB 2	BULB 3	SPECIFICATION
Test Temperature oC	40	40	40	
Time taken to flow (s)	809	1101	976	
calibration constant	0.11755	0.08641	0.09824	
Kinematic viscosity, mm^2/s (cSt)	95.1	95.1	95.9	
Average	95.4			

Comments:

Representatives

Group Member	Materials Technician (CSCEC)	Materials Engineer (CSCEC)
Sign:	Sign	Sign
Date:	Date 9/01/25	Date

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Kinematic Viscosity Test

Testing Method ASTM D 2170-01

Ref. No.	*N/A*	*Waste Diesel Engine Oil*	*WEO*
Type		*Origin/Suplier*	*Workshop*
Testing date	*9-Jan-2025*	*Sampling Date*	*22-12-24*

Sample No.	BULB 1	BULB 2	BULB 3	SPECIFICATION
Test Temperature oC	60	60	60	
Time taken to flow (s)	120	165	145	
calibration constant	0.11771	0.08653	0.09824	
Kinematic viscosity, mm^2/s (cSt)	14.1	14.3	14.2	
Average	14.2			

Comments:

Representatives

Group member	Materials Technician (CSCEC)	Materials Engineer (CSCEC)
Sign:	Sign	Sign
Date:	Date 9/01/25	Date 21/01/2025

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Flash and Fire Point

Testing Method ASTM D 92

Type	*Waste Engine Oil*	*Supplier/ Origin*	*Workshop*
Testing date	*1/9/2025*	*Sample Date:*	*12/22/2024*

***Note: Temperature rise** for PG 76-10 up to 295 °C is 14 - 17 °C per minute ; 295 °C up to the end is 5 - 6 °C per minute .*

Measured Flash Point, °C	164.3
Measured Fire Point, °C	186
Measured Barometric Reading, P, mmHg	31.5

Correction for Barometric Reading = 0.003 X (760 - P)	2.186

Corrected Flash Point, °C	166.5
Corrected Fire Point, °C	188.2

Remark

Group Member	Materials Technician(cscec)	Materials Engineer (CSCEC)
Sign:	Sign	Sign
Date:	Date 9/01/25	Date

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD ★ P.O.Box 29285 Kampala 21 JAN 2025 (CSCEC)

Viscosity Test of Oil

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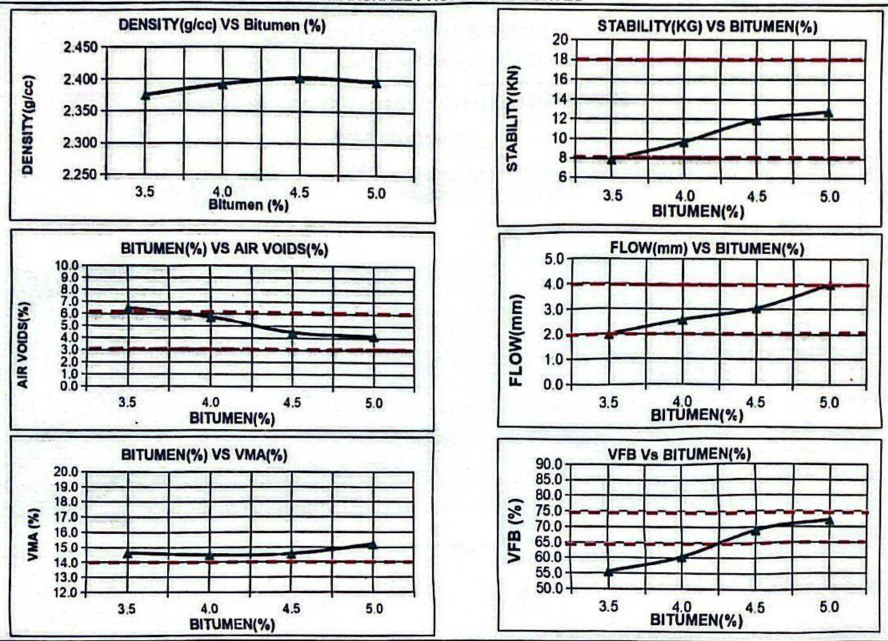
MARSHALL PROPERTIES CURVES



Group Member	Laboratory Technician	Materials Engineer
Sign	Sign [signature]	Sign: [signature]
Date	Date 26/01/2025	Date 26/01/2025

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD (CSCEC) P.O.Box 29285 Kampala 26 JAN 2025

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
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Email: cscecjiangbo@gmail.com

Kinematic Viscosity Test

Testing Method ASTM D 2170-01

Ref. No.	*N/A*	*Waste Diesel Engine Oil*	*WEO*
Type		*Origin/Suplier*	*Workshop*
Testing date	*9-Jan-2025*	*Sampling Date*	*22-12-24*

Sample No.	BULB 1	BULB 2	BULB 3	SPECIFICATION
Test Temperature oC	40	40	40	
Time taken to flow (s)	809	1101	976	
calibration constant	0.11755	0.08641	0.09824	
Kinematic viscosity, mm^2/s (cSt)	95.1	95.1	95.9	
Average		95.4		

Comments:

Representatives

Group Member	Materials Technician (CSCEC)	Materials Engineer (CSCEC)
Sign:	Sign	Sign
Date:	Date 9/01/25	Date 21/01/2025

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD ★ P.O.Box 29285 Kampala 21 JAN 2025 (CSCEC)

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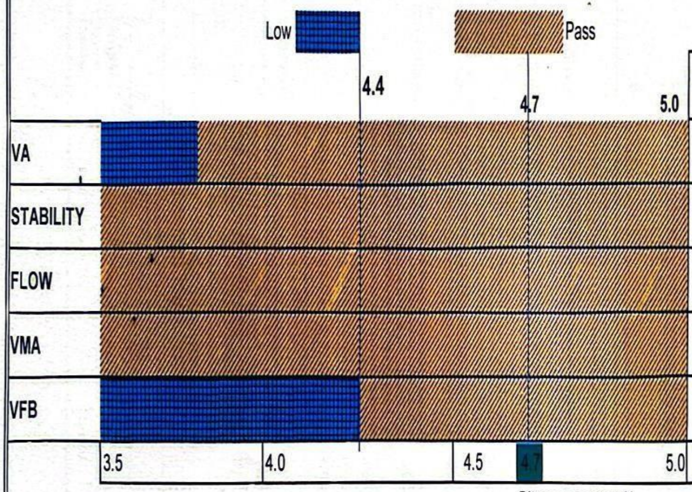
DETERMINING OBC BASED ON NARROW RANGE

MS-2 chapter 05



	Min	Max
VA	3.7	5.0
STABILITY	3.5	5.0
FLOW	3.5	5.0
VMA	4.3	5.0
VFB	4.4	5.0

Min 4.40
Max 5.00
Av. 4.70

Optimum Bitumen Content **4.7**

Group Member	Laboratory Technician	Materials Engineer
Sign:	Sign	Sign:
Date:	Date 26/01/2025	Date: 26 JAN 2025

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SUMMARY OF THE TEST RESULTS ON ASPHALT CONCRETE SURFACING (AC20)
using 50/70 Bitumen

Road Name:	/				Sample Ref .	N/A		
Chainage / Location	LAB				Sampling Date:	23/Jan/2025		
Mixture Source	Lab Mix				Test Date:	26/Jan/2025		
Hot bin Propotions	Agg. Size	12/20mm	6/12mm	3/6mm	0/3mm	Filler	Bitumen Content OBC %	4.7
	%age	44	9	9	36	2		

Test Parameter		Unit	Test Method	Specifications	AC20
Marshall	Va	%	ASTM D1559-89	3 - 5	4.0
	VMA	%		Min 14	14.9
	VFB	%		65-78	72.9
	Stability	KN		8-18	12.7
	Flow	mm		2-4	3.33
	Bulk Specific gravity	g/cc		NA	2.401
Maximum Specific Gravity of Mix	Gmm	g/cc	ASTM D2041-95	NA	2.509
ITS	Dry	g/cc	ASHTO T 283	MIN 800	1651.0
	Ratio	g/cc		<80	90.5

Remark:

Representative(CSCEC)

Group Member	Lab Technician	Materials Engineer
Sign:	Sign [signature]	Sign: [signature]
Date:	Date 26/01/2025	Date: 26/01/2025

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
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26 JAN 2025
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ABSTRACT OF MARSHALL MIX DESIGN TEST VALUES

3.5%WEO & 50/70 Bitumen Content%	Density (g/cm³)	Air Voids% (va)	VMA %	VFB %	Stability (kN)	Flow (mm)
3.5	2.396	5.81	13.88	58.13	12.84	1.74
4.0	2.413	4.94	13.74	63.86	15.19	1.89
4.5	2.401	4.67	14.60	67.77	15.56	2.18
5.0	2.402	4.26	15.04	71.25	14.20	2.52
Spec.Limits	N/A	3 - 6%	Min. 14%	65-75%	8-18 KN	2-4mm

Trends and Relations of the Test data

The test property curves plotted as described above have been found to follow as reasonably consistent pattern for Bitumen mix. Trends generally noted are outlined below.

a.)The stability value initially increases as bitumen improves cohesion and adhesion but decreases beyond the OBC.

b.) The flow value increases with increasing BT content

c.) The Density value increases with increasing BT content up to a maximum after which the density decreases due to iver saturation

d.) The % of Air voids decreasing with increasing BT content.

e.)VMA slightly increases initially as bitumen increases film thickness but may decrease due to aggregate packing adjustiments.

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05 FEB 2025
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ANALYSIS OF TEST RESULTS

BITUMEN(%)	3.5	4.0	4.5	5.0
DENSITY	2.396	2.413	2.401	2.402
BITUMEN(%)	3.5	4.0	4.5	5.0
AIR VOIDS(%)	5.81	4.94	4.67	4.26
BITUMEN(%)	3.5	4.0	4.5	5.0
STABILITY(KN)	12.51	14.80	15.56	14.20
BITUMEN(%)	3.5	4.0	4.5	5.0
FLOW(mm)	1.74	1.89	2.18	2.52
BITUMEN(%)	3.5	4.0	4.5	5.0
VMA(%)	13.88	13.74	14.60	15.04
BITUMEN(%)	3.5	4.0	4.5	5.0
VFB(%)	58.13	63.86	67.77	71.25

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD ★ P.O.Box 29285 Kampala 05 FEB 2025 (CSCEC)

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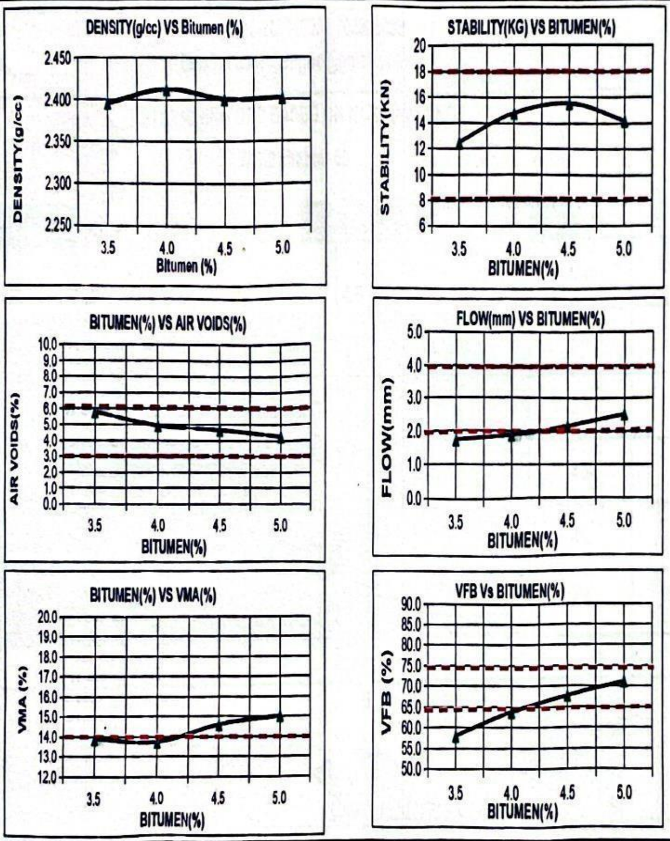
Mutundwe, Lubaga Division
P.O.Box 29285 KAMPALA
Tel: +256(0)755046031/708898888
Email: cscecjiangbo@gmail.com

MARSHALL PROPERTIES CURVES



Group Member	Laboratory Technician		Materials Engineer
Sign	Sign	[signature]	Sign:
Date	Date	03/02/2025	Date 03/02/2025

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
P.O.Box 29295 Kampala
03 FEB 2025
(CSCEC)

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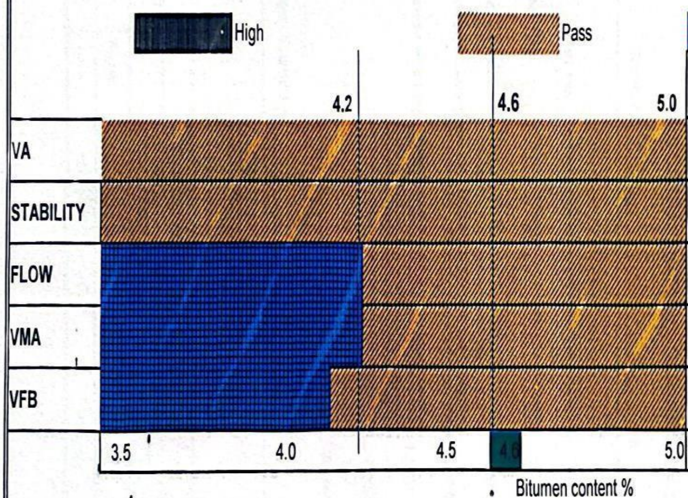
DETERMINING OBC BASED ON NARROW RANGE

MS-2 chapter 05



	Min	Max
VA	3.5	5.0
STABILITY	3.5	5.0
FLOW	4.2	5.0
VMA	4.2	5.0
VFB	4.1	5.0

Min 4.20
Max 5.00
4.60

Optimum Bitumen Content **4.60**

Group Member	Laboratory Technician	Materials Engineer
Sign:	Sign [signature]	Sign: [signature]
Date:	Date 05/02/2025	Date: 05/02/2025

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD (CSCEC) P.O.Box 29285 Kampala 05 FEB 2025

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SUMMARY OF THE TEST RESULTS ON ASPHALT CONCRETE SURFACING (AC20)
using 50/70 Bitumen with 3.5% Waste Engine Oil

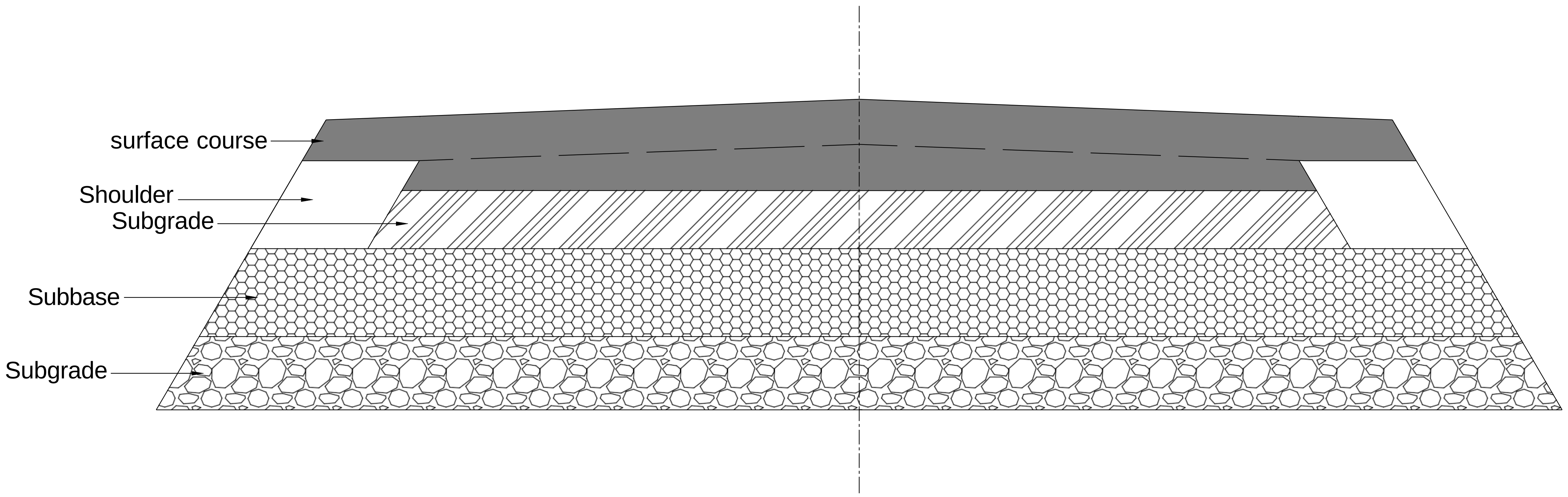
Road Name:	/				Sample Ref .		Modified Bitumen	
Chainage / Location	LAB				Sampling Date:		23/Jan/2025	
Mixture Source	Lab Mix				Test Date:		5/Feb/2025	
Hot bin Propotions	Agg. Size	12/20mm	6/12mm	3/6mm	0/3mm	Filler	Bitumen Content OBC %	4.6
	%age	44	9	9	36	2		
Test Parameter		Unit	Test Method				Specifications	AC20
Marshall	Va	%	ASTM D1559-89				3 - 5	4.5
	VMA	%					Min 14	15.0
	VFB	%					65-78	69.6
	Stability	KN					8-18	15.5
	Flow	mm					2-4	3.33
	Bulk Specific gravity	g/cc					NA	2.402
Maximum Specific Gravity of Mix	Gmm	g/cc	ASTM D2041-95				NA	2.515
ITS	Dry	g/cc	ASHTO T 283				MIN 800	1556.8
	Kpa	g/cc					>80	91.8

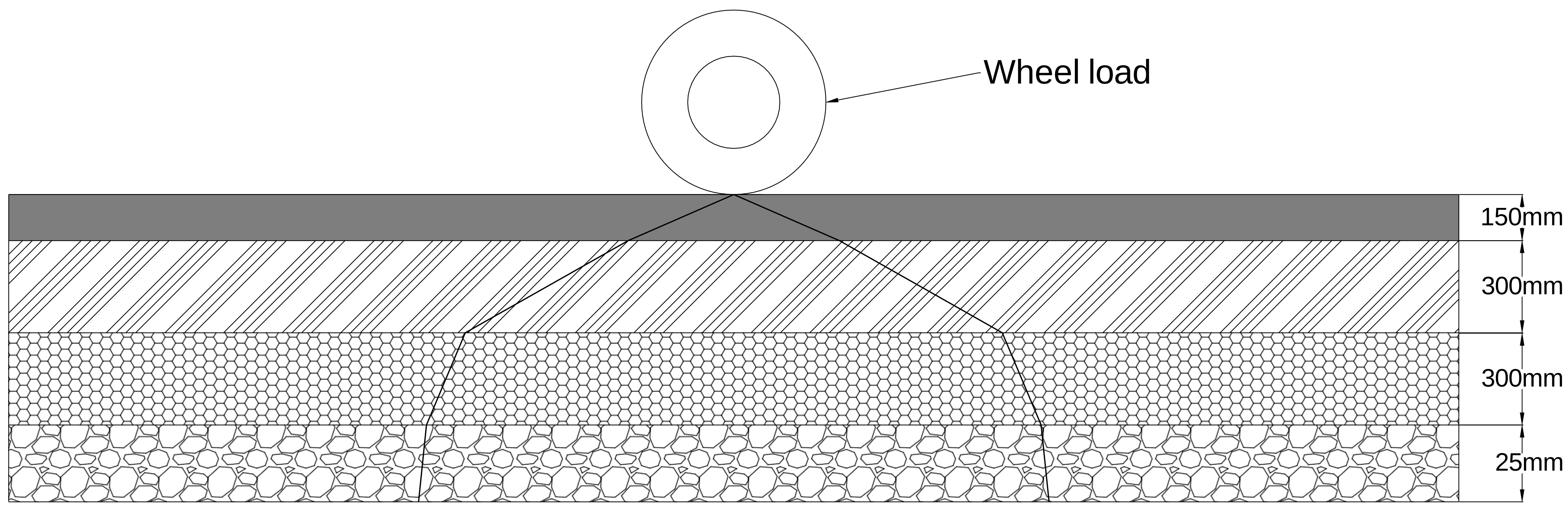
Remark:

Representative(CSCEC)

Group Member	Lab Technician	Materials Engineer
Sign:	Sign [signature]	Sign: [signature]
Date:	Date 05/02/2025	Date 5/2/25

CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD (CSCEC) P.O.Box 29285 Kampala 05 FEB 2025





TITLE	ROAD CROSS SECTION DESIGN
NAME	NATANGAZA PEACE REG No. S21B32/100
SCALE	1:50
DATE	12/4/2025