

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

TYSON MUGUME

S21B32/106

**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**

April, 2025



**UGANDA CHRISTIAN
UNIVERSITY**

A Centre of Excellence in the Heart of Africa

ABSTRACT

This research explored the modification of 50/70 penetration grade bitumen with waste diesel engine oil (WDEO) to enhance asphalt concrete properties for the Kampala-Masaka highway. The highway exhibits significant pavement deterioration, especially cracking, potentially caused by heavy traffic loads and temperature variations, which necessitates improved pavement materials. The study aimed to assess the impact of DWEO content on stiffness and workability by blending bitumen with DWEO at ratios of 0%, 2%, 3.5%, 4%, and 6%, and subjecting the mixtures to physical and mechanical tests.

The 3.5% DWEO blend demonstrated the most favorable performance. Key findings from Marshall and Volumetric Analysis indicated a 22% improvement in stiffness and a 17% improvement in workability with DWEO modification compared to the control. This suggests that incorporating DWEO enhances the asphalt's resistance to cracking and deformation, addressing the observed deterioration issues.

While DWEO modification shows promise for improving asphalt properties, further research is recommended to thoroughly address observed stability issues. Optimization of DWEO content is crucial to achieve a balance between improved stiffness and workability and ensure long-term pavement performance and durability on the Kampala-Masaka highway

DECLARATION

I, Mugume Tyson, hereby affirm that the research and findings presented in this report, 'Assessing the Stiffness Properties of Asphalt Concrete Modified with Waste Diesel Engine Oil, are entirely my own work, except where explicitly acknowledged and cited. I confirm that this report has not been submitted for any other academic evaluation and that all data and information are accurate and truthful to the best of my understanding.

MUGUME TYSON

Signature

Date

.....

.....

APPROVAL

This research and design project report has been submitted for examination with my approval as the University Academic Supervisor.

Signature:

Date:

Ms. AGUTI JOSEPINE

Department of Engineering and Environment.

Uganda Christian University.

ACKNOWLEDGEMENT

I thank the Almighty God for His grace and mercy that have enabled me to complete my final year project. I'm deeply grateful to my parents for their unwavering support—spiritually, financially, and emotionally—throughout my academic journey. Special appreciation goes to my supervisor, Madam Josepine Aguti, for her invaluable guidance and encouragement at every stage of this project. I also sincerely thank my project partner, Natangaza Peace, for her dedication and teamwork during material sourcing, lab testing, and presentations. Lastly, I appreciate the Faculty of Engineering, Design and Technology for the resources and support that made this research possible.

TABLE OF CONTENTS

ABSTRACT	ii
DECLARATION	iii
APPROVAL	iv
ACKNOWLEDGEMENT	v
TABLE OF CONTENTS	vi
LIST OF TABLES	x
LIST OF FIGURES.....	xi
LIST OF ACRONYMS.....	xii
CHAPTER ONE: INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement.....	3
1.3 Main Objective	4
1.4 Specific Objectives	4
1.5 Research Questions.....	4
1.6 Scope	5
1.6.1 Geographical scope	5
1.6.2 Time scope	5
1.7 Justification	6
1.8 Significance of the research	7
CHAPTER TWO: LITERATURE REVIEW	8
2.0 Introduction	8
2.1 Highway Pavement	9
2.1.1 Rigid pavement	9
2.1.2 Flexible pavement	10
2.1.3 Defects of asphalt pavement	12
2.1.3.1 Cracking in asphalt pavement	13

2.1.3.2	Types of cracking	13
2.1.3.3	Causes of Cracking in Asphalt Concrete	16
2.1.3.4	Mitigation and Prevention of Cracking	17
2.2	Aggregates	19
2.2.1	Types of Aggregates	21
2.2.2	Aggregate Selection	24
2.2.3	Tests Carried on the Aggregates.....	24
2.2.3.1	Sieve Analysis (Grading)	24
2.2.3.2	Specific Gravity and Absorption	25
2.2.3.3	Soundness Test (Sodium or Magnesium Sulfate Soundness)	26
2.2.3.4	Los Angeles Abrasion Test	27
2.2.3.5	Unit Weight and Voids	27
2.2.3.6	Aggregate Crushing Value (ACV) Test	28
2.2.3.7	Aggregate Impact Value (AIV) Test.....	29
2.2.3.8	Flakiness Index (FI) Test.....	30
2.2.3.9	Ten Percent Fines Value (TFV) Test	31
2.3	Bitumen	32
2.3.1	Constituents of bitumen.....	33
2.3.2	Properties of bitumen	36
2.4.	Diesel Waste Engine Oil	37
2.4.1	Contaminants in Waste Engine Oil	37
2.4.1.2	Influence of Contaminants on Bitumen Properties	38
2.4.1.3	Adverse Environmental Impacts	40
2.4.1.3.1	Mitigation Strategies:.....	42
2.5	ASPHALT CONCRETE MIXES	44
2.6	Bitumen Content For Asphalt Mix Design	47
CHAPTER THREE: METHODOLOGY.....		49

3.1 Introduction	49
3.2 Research Design	49
3.3 Material Collection and Preparation.....	49
3.4 Tests on the materials.....	50
3.4.1 Tests on Aggregates	50
3.4.1.1 Sieve Analysis	50
3.4.1.2 Aggregate Crushing value	51
3.4.1.3 Flakiness index.....	51
3.4.1.4 Loss Angeles Abrasion TEST.....	52
3.4.2 Tests on Bitumen	53
3.4.2.1 Penetration Test	53
3.4.2.2 Softening Point Test	54
3.4.2.3 Viscosity Test	55
3.4.2.4. Flash Point Test	55
3.4.2.5 Ductility Test	56
3.4.2.6 Specific Gravity Test	57
3.4.2.7 Solubility Test	57
3.4.2.8 Rotation Viscosity Test.....	58
3.4.2.9. Thin Film Oven Test (TFOT)	59
3.4.3 Tests on Waste Engine Oil (WEO).....	59
3.4.3.1 Viscosity Test	59
3.4.4 Tests on Fourier Transform Infrared (FTIR) spectroscopy.....	60
Procedure	60
3.4.5 Tests on the optimal mix design of asphalt concrete modified with waste diesel engine oil.....	61
3.4.4.1 Indirect Tensile Stiffness Modulus (ITSM) Test	61
CHAPTER 4: RESULTS AND DISCUSSION.....	62

4.1 Introduction	62
4.2 The Aggregate test and Neat Bitumen Properties	62
4.3 Fourier Transform Infrared (FTIR) spectroscopy	63
4.3.1 For waste diesel engine oil	64
4.4 The combined gradation curve	65
4.4.1 Graphs for Marshall parameters.....	67
4.5 Results for unmodified and modified bitumen (at 3.5% WDEO)	70
4.5.1 Determining the Resilience Modulus from ITS Results	70
4.5.2 Graphical analysis after the modifications.	76
CHAPTER FIVE: CONCLUSION AND RECOMMENDATION	81
5.1 CONCLUSION	81
5.2 RECOMMENDATIONS	82
5.2.1 recommendation basing on the conclusions.....	82
5.2.2 Recommendation for further research	82
REFERENCES	84
APPENDICES	92
APPENDIX A: PICTORIAL.....	92
Appendix B: Laboratory results	95

LIST OF TABLES

Table 4-1: Showing results of aggregate tests and Neat Bitumen properties ..	62
Table 4-2: Showing FTIR Screening and physical properties of neat bitumen properties.	64
Table 4.3 Showing the comparison between the unmodified and modified Bitumen at 3.5% WDEO.....	67
Table 4-4: Showing the Correlation of ITS to Resilient Modulus, Mr.....	68

LIST OF FIGURES

Figure 2-1: Layers of a flexible pavement	12
Figure 4-2: Combined gradation curve of the Optimum Bitumen Content	65
Figure 4-3: Relationship of different Marshall Properties with WDEO.....	67
Figure 4-4: Comparison between unmodified and modified Bitumen at 3.5% WDEO	76
Figure 4-5: Showing penetration and softening points	76
Figure 4-6: Showing Density and Ductility.....	77
Figure 7: Showing cracks.....	92
Figure 8: Showing Operation of a Marshall compactor.....	93
Figure 9: Showing the reading the Stability Test Results.	93
Figure 10: Showing Marshall Stability Testing Machine.	93
Figure 11: Showing Sample Molds of Modified Asphalt Concrete.....	93
Figure 12: Showing Drum mixer for Asphalt Hot Mix.	94

LIST OF ACRONYMS

ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
EVA	Ethylene Vinyl Acetate
FI	Flakiness Index
FTIR	Fourier Transform Infra-Red Test
GMD	Specific Gravity of Asphalt Mixes
GMM	Maximum Theoretical Density of Asphalt Mixes
ITS	Indirect Tensile Strength
OBC	Optimum Bitumen Content
SSD	Saturated Surface Dry (Specific Gravity of Asphalt)
UCU	Uganda Christian University
UNRA	Uganda National Roads Authority
VFB	Voids Filled with Bitumen
VMA	Voids in Mineral Aggregates
WDEO	Waste Diesel Engine Oil

CHAPTER ONE: INTRODUCTION

1.1 Background

A road surface is the top layer of a roadway that comes into direct contact with traffic. Its main purpose is to provide a smooth, safe and durable path for vehicles and pedestrians. Road surfaces are designed basing on traffic volume, climate, soil conditions and economic factors. There are two types of road surfaces that is; concrete (rigid) pavements and asphalt (flexible) pavements. Rigid pavements are made of Portland cement concrete while flexible pavements are made of asphalt concrete. In Uganda, asphalt concrete is a prevalent choice for road surfaces. This material, characterized by its porous nature, is produced at elevated temperatures, typically around 180 degrees celcius. The necessity for this heat stems from the need to liquefy the asphalt binder, enabling it to effectively coat the aggregate components and form a workable paving mixture, it is also commonly known as blacktop, a popular type of pavement used in road construction and surfacing on most Ugandan roads. They are made primarily from a mixture of aggregate (stone, gravel, or sand), asphalt binder; which is the bitumen and filler such as; cement, limestone and stone quarry dust (Lu,2024). Asphalt has been used to seal cracks in most roads of Uganda making the road's repair more suitable.

Asphalt pavements, widely used in road construction, face challenges such as cracking and rutting, where heavy traffic loads cause cracks, depressions and grooves in the surface. Over a decade to fifteen years of service, asphalt concrete in Uganda experiences a significant hardening, losing its ability to flex and absorb stress. This is driven by the asphalt binder's gradual embrittlement,

leading to the formation of microscopic cracks and the weakening of the bond between aggregates and the binder (Yildirium, 2007). This process of increased fragility and stiffness is accelerated by exposure to heat and oxygen during production, transportation, and installation, and continues throughout the pavement's lifespan (Masson et al., 2008). Essentially, the material's inherent flexibility degrades over time, making it more susceptible to cracking and failure. When heavy axle loading together with high temperature is applied on a road, the binder expands beyond its elastic limit, it deforms permanently. This affects the viscoelastic behavior of the bitumen. To combat cracking, rutting and other related defects, the incorporation of diesel waste engine oil (DWEO) can enhance the stiffness and performance of asphalt concrete by improving the viscosity and workability of the mixture and acts as a rejuvenator, potentially offsetting aging effects in asphalt.

1.2 Problem Statement

Although the foundation of the Kampala-Masaka Road, specifically the section between Kamuwunga and Lukaya towns (Km 97+000 to Km 102+000), demonstrates structural integrity, an issue has been identified within the asphalt layer. There has been a significant increase in pavement deterioration characterized by extensive cracking, disrupting traffic flow, and increasing accident risk as well as damaging vehicles contributing to the pavement's rapid wear and tear (Tumwesigye & Kiggundu, 2019). According to Costa Odwar, 2022, the deformation could have been caused by air voids of 6.7%, in the bitumen of surpassing the standard maximum of 5%. Using additives to modify the bitumen properties could improve the resistance of the asphalt to deformation.

Previous studies by Osei, 2017. indicated that incorporating waste engine oil (WEO) and waste plastics into bitumen can improve its flow characteristics and reduce its sensitivity to temperature variations. However, the modification gave stiffness results that were exceedingly greater than those of the unmodified asphalt which arose other issues for example fatigue cracking of the pavement at low temperature. This left the gap to modify the bitumen with waste engine oil only to improve the stiffness to a value that resists deformation due to heavy axle loading without inducing other problems for example fatigue cracking.

This suggests that adding only WEO to the modification could potentially be a valuable modifier for enhancing the performance and durability of asphalt pavements in Uganda's fluctuating climate.

1.3 Main Objective

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

1.4 Specific Objectives

1. To determine the physical and chemical properties of materials to be used in the asphalt mixes. (i.e.; aggregates, bitumen, and waste diesel engine)
2. To determine the rheological properties of both neat and WEO modified bitumen.
3. To determine the optimal mix design of asphalt concrete modified with waste diesel engine oil.

1.5 Research Questions

1. What are the physical and chemical properties of the materials (aggregates, bitumen, and WEO) used in asphalt modification?
2. How do the rheological properties of asphalt concrete differ when using neat bitumen versus modified bitumen?
3. What is the optimum mix design for asphalt concrete modified with DWEO, and how does the design affect the stiffness modulus and overall mechanical properties of the modified asphalt concrete?

1.6 Scope

1.6.1 Geographical scope

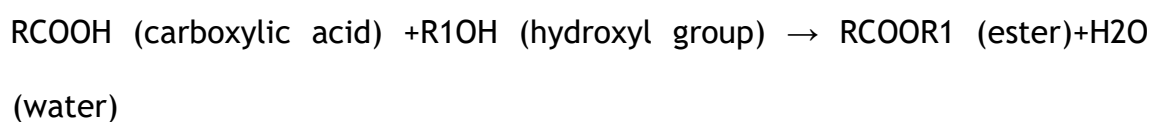
The geographical scope of this research is specifically focused on the Kampala-Masaka Road in Uganda, with a case study conducted on the section between Kamuwunga and Lukaya towns (Km 97+000 to Km 102+000). The materials used in the study, such as aggregates and bitumen, were sourced from specific locations within Uganda.

1.6.2 Time scope

This research was conducted over eight months from September 2024 and ending in April 2025.

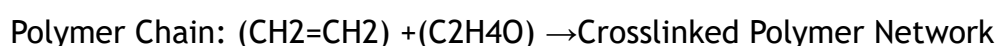
1.7 Justification

The incorporation of Waste Diesel Engine Oil (WEO) and polymers into bitumen significantly enhances the performance of bitumen by two main chemical reactions: esterification and polymer crosslinking. During esterification, the carboxylic acids (-COOH) of WEO are reacted with hydroxyl groups (-OH) of bitumen to form ester bonds with the evolution of water as a byproduct. The reaction is:



This esterification reaction upgrades the molecular structure of the bitumen, reducing its viscosity and softening point, and rising its penetration, which makes it easier to handle, more flexible, and more durable. The ester linkages also upgrade the oxidation and aging resistance of the bitumen, improving the pavement's overall performance and longevity.

Conversely, the inclusion of polymers such as ethylene (C₂H₄), SEBS, polyamide resins, or EVA initiates a process of linking of polymer chains in which individual polymer strands combine to create a three-dimensional network that strengthens the bitumen mix. This formation of the network of crosslinked polymer chains can be graphically represented by the following schematic:



This response, the formation of associated polymer chains, enhances the bitumen's resistance to bending without being broken, its return to the original form after experiencing stress, and its resistance to temperature changes. The

material is thus made stronger against deformation under intense heat and vehicle pressure. In addition, this bonding method increases the adhesion between the bitumen and the granular components of the asphalt, creating a stronger, more stable structure. The finished product, this bonded polymer bitumen, has improved resistance to fractures, surface indentations, and degradation over time. The outcome is road surfaces that last longer, need repairing less often, and have an extended overall lifespan. Together, these chemical reactions make the modified bitumen more compatible with stressful conditions so that it performs better in road construction and maintenance.

1.8 Significance of the research

The incorporation of WDEO in asphalt concrete at known percentages of WDEO by bitumen's weight enhances the rheological properties of the binder such as; its workability, temperature susceptibility leading to improved pavement stiffness performance. Scholars emphasize that such practices align with sustainable construction goals and contribute to economic savings in road maintenance (Saba et al., 2022).

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

Over the past four decades, global highway infrastructure has seen substantial progress. However, this development has come at the cost of significant depletion of non-renewable resources like aggregates and asphalt (S. Fayed 2023), leading to environmental damage and escalating construction costs (M. Zahoor 2021). The annual generation of approximately 1.5 billion tons of construction waste, which continues to rise, presents a major disposal challenge (C.A. Issa 2023). Traditional methods like landfilling and burning are unsustainable, causing land scarcity and irreversible environmental pollution (S. Ahmad 2023). Consequently, innovative waste management solutions are crucial (N. Gerges 2021).

A promising approach involves incorporating waste materials into pavement engineering, effectively reducing asphalt binder consumption and meeting asphalt mixture requirements (A.M. Memon 2021). This also contributes to lowering carbon dioxide emissions (M. Jin 2023). Notably, waste oils, including plastic, cooking, and engine oils, represent a significant waste stream. Waste Diesel Engine Oil (WDEO) alone, generated at 45 million tons annually, poses a substantial environmental threat, with only a small fraction being adequately recycled (K. Derewecki 2013).

WEO originates from various sources, including refineries, vehicles, and industrial plants (Z. Wang 202). Its high content of heavy metals, such as zinc, lead, and magnesium, poses a serious risk to ecosystems and human health

(S. Arafat 2019, A.M. Memon 2021). While much of WEO is repurposed as fuel or lubricant (M. Jin 2023, H.B. Abdullah 2022, I.A. Qurashi 2018), its potential use in pavement engineering, particularly as an asphalt binder modifier, is being explored due to its similar properties to petroleum asphalt (L. Feng 2023, I.A. Qurashi 2018). This presents an opportunity to both reduce waste and enhance road construction sustainability.

2.1 Highway Pavement

Highway pavement is the durable surface layer of a road designed to support vehicular traffic, providing a smooth, strong, and safe driving surface. It's crucial for various applications in Uganda, including major routes like the Kampala-Masaka Road and the Kampala-Jinja Highway, which facilitate intercity travel and trade; urban expressways within Kampala, such as the Northern Bypass, aimed at easing congestion; rural highways connecting towns like Mbale and Fort Portal, vital for regional access; and upcoming projects like the Kampala-Entebbe Expressway, a toll road designed for efficient travel to the airport. Essentially, highway pavements are vital infrastructure elements in Uganda wherever there's a need for a robust and reliable surface to accommodate medium to high-speed vehicular movement, supporting the country's connectivity and economic development. There are two main types;

2.1.1 Rigid pavement

Rigid pavement is a strong and durable type of road surface made primarily from Portland cement, often reinforced with steel to enhance its strength and control cracking. Built in layers that typically include a concrete slab on top, sometimes supported by a base or subbase layer of crushed stone or stabilized

material, all resting on compacted subgrade soil. Due to its high stiffness and load bearing capacity, rigid pavements widely used in the construction of industry for highways, airports, and industrial areas where heavy traffic and long service are required. Its resistance to deformation, weather, and fuel spills, along with low maintenance needs, makes it a reliable and long-lasting choice for critical infrastructure.

2.1.2 Flexible pavement

Flexible pavement is a type of road or airport construction that is intended to exhibit a quality of flexure or yielding under traffic stress without fracture. As a result of the characteristic, it is appropriate for the various transportation routes. It consists of several superimposed courses that function together to transfer the stresses imparted by vehicles downward to the underlying soil or rock subgrade. This load carrying ensures the strength as well as the durability of the pavement.

The most superficial layer, the wearing course, is designed to create a smooth, skid-resistant surface for traffic movement. It typically consists of bituminous material, such as a mixture of asphalt cement (bitumen) and mineral aggregate materials such as gravel, crushed rock, or sand. These materials provide both structural strength and durability against wear and tear (Wang et al., 2018). Below the wearing course is the binder course, whose role is to transfer traffic loads further to the lower layers in addition to imparting structural strength. This layer also utilizes bituminous materials, typically with a lower percentage of binder than the surface layer (Khan et al., 2020).

Next to the binder course is the base course, whose primary function is the distribution of further loads to the subgrade. The layer usually consists of coarse aggregates with bitumen or other stabilizers such as cement or lime in order to enhance its stability and water damage resistance (Somashekar et al., 2019). Underneath the base course, the sub-base course provides extra support and drainage, thereby keeping the subgrade free from the issues that arise due to excessive moisture. The sub-base typically consists of granular material like gravel or crushed stone, in certain instances stabilized with a stabilizer (Ravindra et al., 2017). The base layer, the subgrade, is the in-place rock or soil beneath the pavement structure. While technically not a structural element of the pavement itself, the subgrade does supply the necessary underlying support, and its internal strength has a great deal of influence on how well the pavement performs as a whole. Where the subgrade has a low bearing capacity, stabilization methods may be required to enhance its load-carrying capacity (Baker et al., 2016).

These distinct layers coordinate with each other in a coordinated way to create a flexible pavement system. Its capacity to deform slightly under loading makes it particularly ideal for regions exposed to diversified traffic loads and climatic conditions. By effectively transferring the applied loads to its various layers, flexible pavements can supply solid, even, and durable surfaces to transportation systems (AASHTO, 2019).



Figure 2-1: Layers of a flexible pavement (Source: (Manoj Kumar and Hanitha, 2016))

2.1.3 Defects of asphalt pavement

Asphalt concrete is a widely used material for road construction, including in Uganda. However, asphalt pavements are susceptible to various forms of deterioration, collectively known as defects or distresses, which impact their performance and longevity. While cracking is a prominent issue, manifesting in forms like fatigue, thermal, and reflective cracking, other significant defects include;

a) Rutting

The formation of longitudinal depressions in wheel paths, is common on heavily trafficked roads like sections of the Kampala-Masaka highway, and is caused by the accumulation of permanent deformation under repeated wheel loads.

b) Potholes

Bowl-shaped depressions, develop due to a combination of traffic and water infiltration, especially in areas with poor drainage, and can be seen on many urban and rural roads in Uganda.

c) Bleeding

Where excess bitumen rises to the surface, can occur in hot climates or where there's improper mix design.

d) Raveling

The progressive loss of aggregate, happens due to inadequate binder or poor compaction.

e) Shoving

A rippling effect, occurs due to horizontal forces from braking and accelerating vehicles, typically at intersections.

These defects arise from a combination of factors such as traffic loading, environmental conditions (temperature variations, moisture), and material properties. Understanding the nature, causes, and mitigation strategies for this range of defects is essential for maintaining safe and durable asphalt pavements.

2.1.3.1 Cracking in asphalt pavement

Asphalt concrete is one of the most commonly used materials in road construction, but it is subject to a variety of distresses over time. One of the most common forms of distress is cracking. Cracking in asphalt pavements is primarily caused by a combination of traffic loading, environmental factors, and material-related issues. Understanding the types, causes, and mitigation strategies is crucial for maintaining pavement integrity.

2.1.3.2 Types of cracking

a) Fatigue Cracking (Alligator Cracking)

Visual Features: The deterioration on the surface takes the pattern of an alligator hide such that cracks intersecting with each other create a lattice of minute well-defined fragments (Huang, 2004).

Cause: The cause of pavement failure comes directly as a result of recurring bending of the pavement structure under high car loadings. To be exact, recurring imposition of loading by vehicles loads up the asphalt course and creates micro-cracking. These micro-cracks, however, propagate over time and become interconnected, giving rise to the characteristic alligator pattern. These cracks are particularly observed primarily in high-traffic zones where the pavement is not able to resist these repeated loads (Zhao & Zhang, 2015).

b) Thermal Cracking

Visual Features: The cracks in the damage category typically run in a direction perpendicular to traffic direction, but can also run lengthwise along the road (Huang, 2004).

Cause: Such damage to pavements is a result of various rates of contraction and expansion of the asphalt upon change in temperatures. During cold climatic regions, the asphalt's contraction upon low temperatures may result in cracking. Expansion of the asphalt when there are high temperatures may add pressure on the pavement system, and eventually it collapses (Mohammad & Ranjith, 2016)."

c) Transverse Cracking

Visual Characteristics: Such cracks, also known as transverse cracks, are characterized by their orientation, that is, they are at right angles to the center line of the roadway (AASHTO, 2015).

Cause: Temperature-induced stress, particularly due to a fall in temperature or shrinkage of the pavement, is the principal cause of initiation of transverse cracks. Poor interlayer adhesion between layers of the pavement or insufficient pulling force resistance within the asphalt mix can be contributory causes as well (Khan et al., 2017).

Visual Features: These fissures are characterized by their alignment, extending along a direction similar to the center axis of the road (Huang, 2004).

Cause: The reason behind longitudinal cracking may be attributed to a plethora of causes such as defects in the construction process (e.g., improper jointing), greater weathering of asphalt material, or inadequate compaction at the time of installation (Gabr & Han, 2014). Further, the cracks may develop due to prolonged vehicular stress or thermal expansion and contraction over years.

d) Reflective Cracking

Visual Characteristics: Such cracks develop when a pre-existing cracking pattern in a lower layer of the pavement propagates upwards, bursting out onto the surface of a new top layer (Mohammad & Ranjith, 2016).

Cause: Reflective Cracking: It happens typically when new asphalt layers are placed over a previously existing, damaged pavement system. The initial cracks

from the base layer then become transferred upwards and duplicate themselves in the new asphalt layer, often resulting in the degradation of the top surface (Zhao & Zhang, 2015).

2.1.3.3 Causes of Cracking in Asphalt Concrete

a) Traffic Load

One of the primary causes of cracking is the stress applied to the asphalt through repeated traffic loads. The flexing of the pavement under the weight of vehicles, especially heavy trucks, causes fatigue cracking. Over time, the pavement loses its ability to withstand the loads, leading to the formation of cracks (Zhao & Zhang, 2015).

b) Environmental Factors

Temperature: Asphalt is sensitive to temperature changes, expanding in hot weather and contracting in cold weather. Extreme temperature fluctuations can cause thermal cracking, especially in regions with harsh winters (Huang, 2004). In areas with severe cold temperatures, the asphalt may contract so much that it cracks, as the material becomes brittle in freezing conditions (Mohammad & Ranjith, 2016).

Moisture: Water penetration into cracks can weaken the bond between the asphalt and underlying materials, causing further deterioration. Water infiltration exacerbates cracking by causing freeze-thaw cycles, where water trapped in cracks freezes and expands, creating more damage (AASHTO, 2015).

c) Poor Construction Practices

Insufficient compaction during the paving process, the use of poor-quality materials (e.g., subpar aggregates or binders), and improper joint construction can result in weak points within the asphalt pavement. These weak points may lead to the premature formation of cracks (Gabr & Han, 2014).

d) Aging of Asphalt

Over time, asphalt undergoes oxidative aging, which causes the binder (asphalt cement) to become stiffer and more brittle. This degradation over time diminishes the asphalt's capacity to bend and dissipate forces, thereby elevating the probability of fissure development (Khan et al., 2017).

e) Subgrade Issues

The integrity of the base soil layer under the asphalt plays an important role in crack formation. Where this base layer is not well compacted or lacks the right structural strength, it can result in differential settlement. Such uneven subsidence, in turn, can be accountable for surface fracturing of the asphalt pavement (Mohammad & Ranjith, 2016).

2.1.3.4 Mitigation and Prevention of Cracking

a) Proper Mix Design

With the use of properly designed asphalt mixture, it can be an important consideration in controlling the number of cracks. Properly making the asphalt mixture very flexible and capable of resisting deformations when under stress can also contribute to elongating the pavement's functioning life while minimizing cracking likelihood (Zhao & Zhang, 2015).

b) Regular Maintenance

Continuous use of sealants on cracks as well as on maintenance of distressed areas can delay water penetration that can improve deteriorating pavement. Sealing of cracks is an essential method for preventing moisture in the bottom ground layer and, therefore, avert further decay (Gabr & Han, 2014).

c) Use of Quality Materials

The use of better-quality granular materials and binder materials that are less susceptible to degradation with time can reduce fissure formation. Furthermore, asphalt materials with additives such as polymers can enhance the material's flexibility, hence its resistance to cracking (Huang, 2004).

d) Compaction and Construction Practices

Achieving adequate densification during construction can reduce the incidence of all forms of cracking to a large degree. A compact asphalt pavement exhibits greater resistance to fatigue cracks and water infiltration. Furthermore, employing correct joint formation and hardening can retard premature cracking (AASHTO, 2015).

e) Monitoring and Early Detection

Routine inspection and early detection of pavement distress can enable the resolution of cracking problems prior to their aggravation. Use of sophisticated tools, such as pavement management systems (PMS), enables systematic evaluation of pavement condition, thereby enabling timely remedial action (Khan et al., 2017).

2.2 Aggregates

Granular materials, or mineral content, are non-reactive hard substances such as sand, gravel, crushed stone, slag, or rock dust that are blended with asphalt (the binder) to form road surfaces. The process of choosing appropriate granular materials is complex, involving extensive examination of the binding agent's characteristics and the anticipated conditions for the completed roadway. These conditions encompass environmental conditions, traffic stress, and the intended road service life (Smith et al., 2023). The granular material is then, after selection, blended with the asphalt binding medium and laid down according to established procedures. Granular materials are the principal load-carrying element in asphalt concrete (binding material + granular materials) pavements, typically forming 90-95% of the weight (w/w) or 75-85% of the volume (v/v) of the mixture (Johnson et al., 2022). Several aspects determine the selection of granular materials to be used in asphalt concrete pavement, which include;

- Availability
- Cost
- Material quality
- Intended construction type

To determine whether an aggregate is suitable for asphalt roadway construction, its properties must be evaluated based on size and grading, cleanliness, toughness, soundness, particle shape, surface texture, and absorption (Lee & Wang, 2021).

- **Size and grading:** The maximum size of an aggregate is defined as the smallest sieve through which 100% of the material passes. The specific type of asphalt concrete determines the maximum aggregate size and the desired gradation (distribution of particle sizes smaller than the maximum) (Brown & Patel, 2020).
- **Cleanliness:** This refers to the absence of foreign or harmful substances. A high level of cleanliness is necessary for the aggregate to be effective in asphalt mixtures, while the presence of dirt or harmful substances (dirtiness) makes an aggregate unsuitable (Harrison & Clark, 2022).
- **Toughness:** This is the aggregate's ability to resist crushing or disintegration during mixing, placement, compaction, or under traffic loading. Toughness is important for ensuring the long-term durability of the road (Martinez et al., 2021).
- **Soundness:** This refers to the aggregate's resistance to deterioration caused by natural elements, particularly changes in weather (Adams & Gonzalez, 2023).
- **Particle shape:** The shape of the aggregate particles impacts the strength, workability, and compaction density of the asphalt mixture. Irregularly shaped particles, like crushed stone, tend to interlock and resist movement, providing better stability (Thompson & Lee, 2021).
- **Surface texture:** Rough surfaces are preferred over smooth ones, as they promote stronger adhesion with the asphalt binder, resulting in a more

durable bond. Smooth aggregates, while easier to coat with binder, do not create as strong a bond (Chavez & Wu, 2020).

- Absorption properties: Porous aggregates can absorb binder into their pores, improving the bonding between the aggregate and asphalt. However, excessively absorbent aggregates are unsuitable as they may reduce the binder's effectiveness (Martin & Liu, 2021).

The separation of the asphalt binder from the aggregate, known as "stripping," typically happens due to the presence of water. Aggregates contaminated with dust can reduce the bond between the binder and the aggregate, making the mixture prone to stripping. Therefore, aggregates that are susceptible to stripping are not ideal for road construction (Barker & Hall, 2020).

2.2.1 Types of Aggregates

For quality asphalt roadways, both the binder and the aggregate must be of high quality. Just as low-quality tar-like substances cannot create strong asphalt, inferior geological minerals cannot produce high-quality pavements (Kumar & Singh, 2022). Aggregates should possess the following characteristics: clean, hard, sound, durable, and a majority of crushed particles. Major types of aggregates include granite, gravel, limestone, pit aggregates, sand, slag, and secondary aggregates such as mineral fillers.

a) Granite

Granite is a crushed, hard rock with a granular structure, originating from magma that has solidified after eruption. It is highly durable, frost-resistant, and is an excellent choice for high-grade concrete. The color of granite ranges

from gray to pink, depending on its mineral composition (feldspar, quartz, mica). Different fractions of granite aggregate are used in roadway construction, concrete production, and reinforced structures, with various sizes contributing to different applications, such as road surfacing, sub-bases, and drainage systems (Harris & Brown, 2022).

b) Gravel

Gravel aggregates result from the sifting or crushing of natural stone and rock. Although they are less strong than granite aggregates, they are typically cheaper and have a low radioactive background. Gravel is used in foundations, concrete production, and road construction. Gravel comes in two primary types: scabbled stone (roughly dressed natural or crushed stone) and rounded pebbles from rivers or seas (Evans & Moore, 2021).

c) Limestone

Limestone aggregates are derived from crushing sedimentary limestone rock, primarily composed of calcium carbonate (CaCO_3). Although limestone is widely used in construction, it is less frequently used in asphalt concrete for wearing courses due to its susceptibility to polishing, which can result in low skid resistance. Therefore, limestone is less commonly used in regions requiring high skid resistance (Williams & Gonzalez, 2021).

d) Pit Aggregate

Pit or bank-run aggregate includes both gravel and sand, sourced from natural deposits. These aggregates are typically screened and washed to remove dirt before use in asphalt mixtures. Crushed and processed aggregates improve

particle shape and distribution, making them more suitable for asphalt applications (Lopez & Rivera, 2022).

e) Sand

Sand, formed from the breakdown of rock or sandstone, is a fine-grained material with various types including river sand, bank-run sand, and manufactured sand. It plays a crucial role in providing smoothness and stability in asphalt concrete mixtures (Jiang & Zhang, 2021).

f) Slag

Slag aggregates are produced from the smelting process in steel production. Blast furnace slag, a type of slag, is used in road construction and asphalt production. These synthetic aggregates are formed by altering the chemical and physical properties of the original material, making it suitable for use in asphalt pavements (Patel & Wang, 2022).

g) Secondary Aggregates

Secondary aggregates are produced by crushing construction waste materials such as concrete, bricks, and old asphalt. They are cheaper than natural aggregates like granite but are still used in road construction, especially in less demanding applications. Secondary aggregates are often used for subbases, ramps, or non-high-traffic road layers, and they can also serve as reinforcement for weak soils. Mineral fillers, typically fine materials like limestone dust, are also considered secondary aggregates (Zhao & Zhang, 2022).

2.2.2 Aggregate Selection

Selecting the right aggregate requires careful planning, just as with the asphalt binder. Before beginning a project, all aggregates should be tested for compliance with specifications, and a mix design must be developed. The contractor or asphalt supplier should also follow quality control procedures. This includes verifying the equipment used, ensuring proper calibration of mixing machinery, and obtaining certificates for the aggregate gradation. Samples of each aggregate, asphalt emulsion, and daily mixes should be taken and analyzed for compliance with specifications. Regular testing helps ensure that materials used throughout the project meet quality standards (Nguyen et al., 2023).

2.2.3 Tests Carried on the Aggregates

2.2.3.1 Sieve Analysis (Grading)

Aim: To determine the particle size distribution of aggregates and ensure that the material meets construction specifications.

Reference:

AASHTO T27:

Procedure

- A representative dry sample of the aggregates was weighed at the beginning of the test.
- The sample was placed in a stack of sieves, arranged from the largest to the smallest mesh sizes, and a mechanical sieve shaker was used

to agitate the sample for a specified duration, typically about 10-15 minutes.

- After the shaking process, the aggregates retained on each sieve were removed and weighed.

The percentage of the sample passing through each sieve was then calculated, and the results were plotted on a grading curve.

Test significance the particle size distribution of granular materials holds substantial importance in establishing an appropriate blend for both concrete and asphalt. The particle size distribution influences the strength, workability, and durability of the final product.

2.2.3.2 Specific Gravity and Absorption

Aim: To determine the specific gravity (density relative to water) and the absorption capacity of aggregates.

Reference:

AASHTO T85:

Procedure:

- The sample of aggregates was first dried and weighed in its dry state.
- The sample was submerged in water for 24 hours to achieve a saturated condition.
- After the soaking period, the excess surface water was drained, and the sample was weighed in a saturated surface-dry condition.

- The relative density was subsequently determined by comparing the sample's dry mass to the mass of an equivalent volume of water. The water uptake was evaluated by measuring the difference in mass between the dried and fully saturated samples, from which the percentage of absorbed water was calculated.

Test significance: The relative density provides information regarding the material's compactness, a factor that influences the mix's structural integrity. Conversely, the water uptake indicates the quantity of water the granular material can retain, which in turn affects the water-to-cement ratio within the concrete mixture.

2.2.3.3 Soundness Test (Sodium or Magnesium Sulfate Soundness)

Aim: To determine the durability of aggregates when exposed to weathering conditions, particularly freeze-thaw cycles and chemical weathering.

Reference: ASTM C88

Procedure:

- A dry sample of the larger granular fraction was weighed and then submerged in a solution of either sodium sulfate or magnesium sulfate.
- This process of submersion was repeated by a pre-set series of cycles (typically five) after an interval of dryness between repetitions.
- The granular fractions were dried fully after every cycle and their weight re-measured to quantify the material loss owing to the weathering effects that were simulated.

Test significance: This test aids in determining the stability of the granular constituents against harsh environmental conditions like freeze-thaw cycles and chemical reactions that could lead to progressive degradation.

2.2.3.4 Los Angeles Abrasion Test

Purpose: To ascertain the abrasion resistance and hardness of coarse aggregates, simulating the wear experienced under traffic.

Reference: AASHTO T96

Procedure:

- A sample of coarse aggregates was weighed, and the sample was placed in the Los Angeles Abrasion machine with a specified number of steel balls.
- The machine was operated at a specified speed for 500 to 1000 revolutions.
- The sample was removed after the required revolutions, and the steel balls were removed from the aggregates. The fines produced during the test were sieved out.
- The remaining aggregates were weighed, and the percentage of material lost due to abrasion was calculated.

Test significance: The test assesses the ability of the aggregates to resist wear under repeated traffic loads. The more resistant aggregates will be those that have minimal loss and are best used in highly trafficked areas.

2.2.3.5 Unit Weight and Voids

Aim: To determine the bulk density (unit weight) of aggregates and the volume of voids between the aggregate particles.

Reference: AASHTO

T19

Procedure:

- The sample of aggregates was first weighed in a dry condition, and its volume was measured using a container of known volume.
- The bulk density was calculated by dividing the weight of the sample by the volume it occupied.
- To determine the void content, the apparent volume was compared to the bulk volume, and the void percentage was calculated using the formula:

$$\text{Void Percentage} = \frac{(\text{Apparent Volume} - \text{Bulk Volume})}{(\text{Apparent Volume})} \times 100$$

Test significance: Bulk density is important for understanding how compacted the aggregate will be in a mix. The void percentage reflects how much empty space exists between particles, influencing the mix's workability and strength.

2.2.3.6 Aggregate Crushing Value (ACV) Test

Aim: To assess the resistance of an aggregate to crushing under a gradually applied compressive load, simulating the effect of traffic loads.

Reference:

BS 812-110 Procedure:

- A sample of aggregates was first prepared by sieving it to the desired size (usually 10mm to 12.5mm).
- The aggregates were then weighed, and placed in a cylindrical mould of known dimensions.
- The test was carried out by applying a compressive load through a standard loading machine. The load was applied gradually until a specified amount of compression (usually 400 kN) was reached.
- After the test, the aggregate was sieved to separate the fines (material passing through a 2.36mm sieve) from the remaining coarse aggregate. The mass of fines was then recorded.
- The Aggregate Crushing Value was calculated as the ratio of the weight of fines to the total weight of the sample, multiplied by 100.

Test significance: The ACV provides an indication of the strength of the aggregate, with a lower ACV suggesting better resistance to crushing under traffic loads. Aggregates with a high ACV are considered weak and less durable.

2.2.3.7 Aggregate Impact Value (AIV) Test

Aim: To determine the impact resistance of aggregates, simulating the effects of high-velocity impacts from traffic or machinery.

Reference: AASHTO T 331:

Procedure:

- A representative sample of dry aggregates was sieved to a standard size, typically between 10mm and 14mm.

- The sample was weighed and then placed in a cylindrical mould.
- A standard weight was dropped from a specified height (usually 380mm) onto the sample, typically using a mechanical impact machine.
- The test involved subjecting the aggregates to 15 blows from the hammer. After the test, the aggregates were sieved through a 2.36mm sieve to separate the fines.
- The percentage of material passing through the sieve was calculated, and the Aggregate Impact Value (AIV) was determined as the ratio of the weight of fines to the total weight of the sample, expressed as a percentage.

Test significance: The AIV indicates the aggregate's resistance to sudden impact. A high AIV value suggests that the aggregate is weak and prone to breaking under impact, which could lead to reduced durability in the construction.

2.2.3.8 Flakiness Index (FI) Test

Purpose: To determine aggregate shape, paying particular attention to the percentage by particle size flat or elongated. This is an important characteristic to establish since too high a proportion of them can negatively influence packing density, voids, and, thereby, performance-related properties like workability and concrete and asphalt pavement strength.

Reference: Refer AASHTO T 304

Procedure

- A representative and adequate sample of coarse aggregates was separated into distinct size fractions using a set of sieves (between 6mm and 63mm).
- The separated sample was then tested by passing the sample through additional sieves, and a record was made of the particles that were deemed to be flat or elongated - defined as a length greater than 1.8 times their width. The number of flaky (flat) particles was found by measurement through dimensions (length and width) of individual aggregates, and figures so obtained were used to calculate by percentage the number of such particles in the whole sample.
- The Flakiness Index (FI) was subsequently determined by dividing the weight of the total flaky aggregates by the total weight of the entire test sample, and then multiplying the result by 100 to obtain a percentage.

2.2.3.9 Ten Percent Fines Value (TFV) Test

Objective: To find the lowest compressive force needed to crush a specified quantity of aggregate material. This test gives valuable information regarding the natural strength of the aggregate and ability to withstand crushing forces that the aggregate might face under traffic loading.

Reference: BS 812-111.

Procedure:

- One initial procedure was to prepare an aggregate sample by sieving it into a particular range of particle sizes, typically between 10mm and 14mm, using sieves.

- The conditioned aggregate sample was subsequently placed in a cylindrical container, and a continuously increasing vertical compressive load was applied through a test device.

- Application of load was done until aggregate particles began cracking, as determined by the formation of fine particles that passed through a 2.36mm sieve. The minimum force at which a specified percentage of such fine particles (typically 10%) was created was recorded.

- Subsequently, the Ten Percent Fines Value (TFV) was calculated based on the applied force measured and the weight of fine particles generated.

Importance of Testing: Ten Percent Fines Value (TFV) is a significant value that shows the hardness of an aggregate and its ability to withstand crushing under pressure. The greater TFV shows that the aggregate is harder and is able to bear heavy loads without getting crushed. This characteristic is a criterion for pavement design of long-lasting pavements and hard concrete mixes.

2.3 Bitumen

Bitumen is also known as mineral tar and is present in asphalt. It contains 87% carbon, 11% hydrogen and 2% oxygen. It is a substance that forms through the distillation of crude oil. It has waterproofing and adhesive properties. Bitumen production through distillation removes lighter crude oil components such as; gasoline and diesel, leaving the "heavier" bitumen behind and that is why it has to be refined several times to improve its grade. Bitumen can also occur in nature. Deposits of naturally occurring bitumen form at the bottom

of ancient lakes, where prehistoric organisms have since decayed and have been subjected to heat and pressure.

2.3.1 Constituents of bitumen

a) Asphaltenes

Since the most highly charged and dense fractions of bitumen, asphaltenes normally comprise 15 to 30 percent of its entire make-up. These are large, solid, complex molecules that cannot dissolve within less dense hydrocarbons. Asphaltenes are pivotal in determining the structure of bitumen. They are also the cause of its rigidity, strength, and shape change resistance, hence raising the stability of the material when it is under pressure and high temperatures. Yet their high molecular weight has the effect of raising bitumen viscosity, thus diminishing its ability to flow and its ease of handling (Yong et al., 2018).

b) Maltenes

Maltenes constitute a blend of lighter hydrocarbons that consist of saturates, aromatics, and resins. Comprising approximately 70 to 85 percent content in the composition of bitumen, maltenes are critical in their contribution to bitumen's flexibility and flowing properties. Maltenes also cluster into a range of subfractions.

c) Saturates

Saturates are not-aromatic hydrocarbons in which all the carbon atoms are bonded by single bonds and are fully bonded to hydrogen atoms. They are the

least chemically reactive components in bitumen and render the material more flexible and less prone to form fractures.

d) Aromatics

Aromatics are hydrocarbon compounds that possess the characteristic of having one or more rings of benzene in their composition. They enhance the adhesive quality of bitumen, which helps it to effectively bond the aggregate materials within the asphalt mixture to each other.

e) Resins

Resins are compounds of intermediate polarity containing both aromatic and non-aromatic molecular structures. Resins are responsible for establishing the thickness and hardness of bitumen and bitumen stability as a whole. Resins also serve as a bridging agent between maltene and asphaltene fractions and enhance the internal binding strength and handlability of bitumen (Akinmoladun et al., 2020).

f) Oils

Oils, being lighter hydrocarbons than asphaltenes, impart a lower viscosity to bitumen and hence increase the fluidity of bitumen as well as make it easier to apply. Such lighter fractions cause the overall bitumen thickness to decrease and become crucial in characterizing its flowing behavior at temperatures. They have to be present to make the bitumen useable and get mixed with aggregate during asphalt manufacture.

g) Sulfur

Being a natural constituent of crude oil, sulfur is also present in bitumen and can affect its stiffness and overall behavior. While high sulfur levels can lead to fragility and decrease the material's lifespan, moderate levels can enhance the oxidation resistance of bitumen and improve its aging durability. The content of sulfur in bitumen varies with the source of the crude oil and the particular refining methods used (Yong et al., 2018).

h) Nitrogen and Oxygen Compounds

Nitrogen and oxygen-contained compounds also exist in bitumen but in trace amounts. These compounds are normally trapped in the resin and asphaltene fractions. Nitrogen influences the aging of bitumen as well as the interaction between bitumen and aggregate material. Oxygen-contained compounds increase the vulnerability of bitumen to oxidation and aging, but in trace amounts, these compounds enhance the overall adhesion of bitumen to aggregate surfaces (Yong et al., 2018).

All these constituents together determine the physical and chemical properties of bitumen, including its stiffness, thickness, flexibility, and resistance to environmental degradation and cracking. The proportion and composition of these constituents are crucial in selecting appropriate bitumen grades for a particular use so that it functions in the optimum manner in various conditions and climates.

2.3.2 Properties of bitumen

Auto repair shops tend to obtain waste engine oil from a multitude of automobiles, thus producing a heterogeneous mixture. The waste oil, charged with engine wear particulates, heat, and oxidation, possesses a complex and inhomogeneous chemical composition. Heavy metals like lead, zinc, calcium, and magnesium, together with high levels of polycyclic aromatic hydrocarbons and additives compared to new oil, are reported to be present, as per studies. Surprisingly, molecular structure and viscosity of waste engine oil can be relatively inconsistent across vehicles.

For our study, we will utilize diesel waste engine oil specifically sourced from local automobile repair shops. Prior to blending this oil with bitumen, we will conduct the following standard tests to characterize its properties:

- **Penetration Test:** This measures the depth (in tenths of a millimeter) a standard needle penetrates the oil under controlled temperature, load, and time, indicating its consistency.
- **Softening Point Test:** This determines the temperature at which the oil softens under specified conditions, crucial for understanding its thermal behavior.
- **Ductility Test:** This assesses the oil's ability to elongate before breaking, measured in centimeters, under specific temperature and pull rate, indicating its flexibility.
- **Flash and Fire Point Tests:**

Flash Point: This is the lowest temperature at which the oil's vapors momentarily ignite under test conditions, signifying its flammability.

Fire Point: This is the lowest temperature at which the oil sustains combustion under test conditions, indicating its combustibility.

2.4. Diesel Waste Engine Oil

The waste engine oil of diesel used for this research was sourced from a local Ugandan fuel petrol pump station in Nyanama near China State laboratories. The engine wear and tear and repeated cycles of heating and oxidation processes which occur during usage in vehicles cause high contamination in the oil (Dominguez et al., 2016). Basically, it's oil that has become useless for its original purpose due to the accumulation of impurities and the degradation of its natural properties.

Synthetic and petroleum-based waste oils, together referred to as waste oil, are well-known to be significant pollutants that need to be handled in a clearly defined way. Any illegal disposal by dumping it on land or in water bodies (including sewers) can harm Uganda's ecosystem. Therefore, identifying sources of useful reuse, like adding it to asphalt mixtures, is critical to minimizing its impact on the environment

2.4.1 Contaminants in Waste Engine Oil

Waste engine oil is a by-product of engine lubricant breakdown by repeated heating, oxidation, and engine part wear over time. This results in the generation of a number of pollutants, especially:

a) Metallic Elements:

Pollutants like lead, zinc, calcium, magnesium, and iron are widely present in used engine lubricant as a result of the wear and tear of engine components

(Baker et al., 2018). The presence of these metals alters the chemical and mechanical properties of the oil.

b) Polycyclic Aromatic Hydrocarbons (PAHs):

Waste engine oil contains more PAHs compared to new oil. These hydrocarbons are ecologically harmful and can also modify the flow and deformation characteristics of the bitumen and oil mixture (López et al., 2019).

c) Performance Enhancers:

Waste engine oil contains a variety of performance additives, such as cleansers, suspension agents, friction reducers, and oxidation inhibitors, which can influence the interaction with bitumen. The additives can modify the viscosity, consistency, and softening temperature of the modified bitumen (Dominguez et al., 2016).

d) Degradation Byproducts:

Engine operation oxidizes the oil, leading to its breakdown and the creation of acidic compounds, thick residues, and varnish-like materials. These breakdown products may adversely affect the performance of the bitumen-oil mixture (Khan et al., 2020).

2.4.1.2 Influence of Contaminants on Bitumen Properties

The contaminants present in re-refined engine lubricant have a significant impact on the properties of bitumen when it is used to grade asphalt concrete. Such important bitumen properties as rigidity, thickness,

consistency, and malleability can be altered by the presence of these contaminants.

a) Penetration

Penetration measurement determines bitumen's consistency, with lower penetration values indicating higher rigidity. Pollution in reconditioned engine lubricant, especially metallic complexes and breakdown products, can be used to thicken the lubricant, leading to altered bitumen that is stiffer. This alteration can enhance the resistance of the asphalt concrete against permanent deformation (rutting). Yet, excessive metallic contamination or excessive degradation products may decrease the degree of convenience in handling and application of modified bitumen and thus influence its effectiveness in pavements (García et al., 2018).

b) Viscosity and Softening Point

Thickness is a natural property of bitumen, especially its application in hot-mix asphalt. The incorporation of recycled engine lubricant has the potential to change the thickness and softening point of bitumen. Research indicates that the incorporation of used engine lubricant, particularly with high metal contaminant levels, can raise the binder thickness, which could result in a less flexible mixture. Conversely, excessive contamination from degradation products could lower the binder rigidity, making it more susceptible to shape change under vehicle loads (Huang & Zhang, 2017).

c) Ductility

Malleability is a second important characteristic that controls the capacity of the binder to withstand fracturing under stress. Lubricant oil of engines, with its sophisticated chemical composition, can enhance or reduce the malleability of bitumen based on the quantities of PAHs and degradation products involved. Small amounts of impurities might improve the malleability of the binder and, in turn, its low-temperature cracking resistance. Nonetheless, excessive levels of contaminants would lead to the brittleness of the binder and therefore poor performance of the asphalt concrete in colder temperatures (Müller et al., 2016).

d) Flash and Fire Point

Besides, temperatures at which the ignition of a bitumen-lubricant mixture is transient and will burn can be affected by levels of used engine lubricant pollutants. High levels of metallic components and PAHs have the potential to lower the flash and fire points, showing an increased likelihood of fire in storage and application. This may create serious safety concerns during production and asphalt concrete installation, hence restricting the potential uses of used engine lubricant as a modifying agent (Singh & Kumar, 2020).

2.4.1.3 Adverse Environmental Impacts

Although used engine lubricant can be used as an additive to strengthen asphalt concrete, its use poses environmental hazards due to the heavy metal composition, PAHs, and other pollutants, the following being among them:

a) Heavy Metals

Waste engine lubricant is comprised of heavy metals such as lead, zinc, calcium, and iron due to engine wear of parts. Such chemicals can contaminate water bodies and soil, resulting in environmental hazards (Baker et al., 2018). These metals tend to accumulate in the ecosystem, having consequences for plants, animals, and human health.

b) Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs, present at higher concentrations in spent engine oil compared to new engine oil, are carcinogenic and do not degrade in the environment. PAHs can leach into the ground and water and cause long-term environmental contamination (López et al., 2019).

c) Degradation Byproducts

Oxidation of engine lubricant throughout the life of engine oil leads to the development of acidic compounds, heavy residues, and varnish-like materials. These byproducts reduce the quality of asphalt and may release toxic secondary products when lubricant is blended with bitumen (Khan et al., 2020).

d) Air Contamination

The old engine lubricant being recycled and blended with fresh asphalt may release volatile organic compounds (VOCs), carbon monoxide, and nitrogen

oxides into the atmosphere, which contributes to air pollution (Singh & Kumar, 2020).

2.4.1.3.1 Mitigation Strategies:

a) Refining Waste Engine Oil

- **Filtration and Adsorption Purification:** The removal of solid impurities, such as metallic elements and PAHs, through treatment processes like filtration and adsorption (e.g., through activated clay) offers a prospect of minimizing the environmental effects of used lubricant (Dominguez et al., 2016).
- **Advanced Hydro-processing:** Sophisticated processes like hydrotreatment can decompose toxic chemicals in the lubricant and thus decrease its toxicity and render it more amenable to use in asphalt production (Khan et al., 2020).

b) Emission Control during Asphalt Production

- **Atmospheric Purification Systems:** Utilization of air purification systems or scrubbers can trap toxic emissions from the blending process and thereby prevent their release into the atmosphere (Singh & Kumar, 2020).
- **Optimized Heat Management:** Mixing at optimal temperatures can reduce the generation of toxic fumes and inhibit degradation of the lubricant, which can release toxic material (García et al., 2018).

c) Use of Low Contaminant Waste Oil

Waste engine oil with less contaminant content, or its treatment before use, can be utilized to reduce the toxic effect when mixed with bitumen (Müller et al., 2016).

d) Green Additives and Bioremediation

- **Environmentally Friendly Enhancers:** Mixing ecologically acceptable additives with the used lubricant can enhance its performance while making it more environmentally friendly (Dominguez et al., 2016).
- **Biological Remediation:** The utilization of microorganisms for the biodegradation of harmful hydrocarbon compounds in the used lubricant is an environment-friendly process for toxicity reduction prior to mixing with bitumen (Zhang et al., 2019).

e) Proper Handling and Storage

Responsible Containment and Handling: By utilizing leak-proof containers and adopting measures to prevent leaks, environmental contamination can be minimized both during storage and transport of the material (Li & Wang, 2020).

f) Recycling and Reuse

Promoting Material Reclamation: Recycling methods, such as recycling asphalt from existing pavement, lower the demand for newly acquired materials and decrease waste generation, thereby rendering the process sustainable (Huang & Zhang, 2017).

2.5 ASPHALT CONCRETE MIXES

a) Dense-Graded Asphalt Mixes (DGA)

Dense-graded asphalt mixtures are the most popular type of asphalt mixture used in road construction. The mixtures are developed to achieve a dense, well-compacted surface with resilience and long-term breakdown resistance. Mineral aggregates used in dense-graded mixes are specially chosen to interlock solidly together with very little empty space. This mix type is typically used for both surface and foundation courses of roads and high-transportation routes. It exists in various classifications, such as Superpave (Superior Performing Asphalt Pavements), which is a performance-based asphalt mix classification system (Asphalt Institute, 2017). Furthermore, Marshall mixes are a second method for designing dense-graded mixtures (Prowell et al., 2005).

b) Open-Graded Asphalt Mixes (OGA)

Open-graded asphalts have a greater volume of air voids between the constituent mineral aggregates. The mixes contain a higher proportion of voids, which provides improved water runoff and minimizes the risk of hydroplaning when there is water. Open-graded mixes are frequently employed in surface courses, specifically where there is susceptibility to high precipitation or where effective water removal becomes extremely important. They are frequently applied in Open-Graded Friction Courses (OGFC) that offer a highly slip-resistant surface, thereby enhancing safety, particularly during wet conditions (Sahab et al., 2018).

c) Porous Asphalt Mixes

Porous asphalt is alike in nature to open-graded mixtures but contains an even bigger network of interconnecting voids that permits water to drain through the internal structure of the pavement. The mixtures are specifically created to minimize surface flow of water, enhance drainage performance, and prevent inundation. They find extensive applications in urban drainage, parking lots, as well as roads with low traffic, where the effective management of water runoff is extremely crucial (Asphalt Institute, 2017).

d) Stone Matrix Asphalt (SMA)

Stone Matrix Asphalt (SMA) is a gap-graded asphalt mix with a high degree of direct contact between the coarse aggregate particles. This structure arrangement yields a highly durable and slip-resistant pavement surface. SMA mixes utilize a higher percent of large-sized aggregates compared to normal mixes and employ a polymer-modified binder to achieve higher performance levels. They are used routinely on high-volume applications, such as highways and urban roads, where long-term stability and resistance to permanent deformation (rutting) and cracking are of the highest priority (Prowell et al., 2005).

e) Cold Mix Asphalt

Cold mix asphalt is formulated to be used at lower temperatures, which makes it convenient to use by not requiring hot-mix asphalt plant equipment. Its most typical applications are for pothole patching and other minor pavement flaws, and for roads with low vehicular traffic. Cold mix is typically comprised of emulsified asphalt and can be applied in cold climate regions where temperatures are not suitable for the placement of traditional hot-mix asphalt (Asphalt Institute, 2017).

f) Hot Mix Asphalt (HMA)

Conventional hot mix asphalt (HMA) production involves heating the mineral aggregates and asphalt binder to elevated temperatures, usually between 150 and 180 degrees Celsius, in order to produce a workable mix for constructing roads. This remains the most common technique for high-traffic road arteries, including highways, city streets, and airport runways.

Nonetheless, technology in asphalt has produced warm mix asphalt (WMA), a more environmentally friendly option. WMA is produced at notably reduced temperatures of 100 to 140 degrees Celsius, achieved by incorporating specific additives. This temperature decrease not only reduces atmospheric emissions but also increases the ease of handling and placing the mixture (Zhao et al., 2017). For traditional highway paving, conventional hot-laid mix, a standard form of HMA, is still very common (Asphalt Institute, 2017).

g) Recycled Asphalt Pavement (RAP)

Reclaimed asphalt pavement (RAP) refers to recycling asphalt material that has been milled from an existing road or surface. The reclaimed asphalt is ground and blended with virgin materials (new aggregates and binder) to produce a new asphalt mixture. The utilization of RAP is both economically and environmentally advantageous as it eliminates the demand for freshly acquired materials and assists in the management of waste generated during road construction (Sahab et al., 2018).

2.6 Bitumen Content for Asphalt Mix Design

Optimization of bitumen content is one of the key factors in designing any asphalt mixture. Bitumen content significantly influences the performance properties of asphalt such as its durability, stiffness, resistance to permanent deformation, and moisture sensitivity. The major goal in achieving the optimal bitumen content is having a proper proportion of binder within the asphalt mix to encapsulate the aggregate particles such that air spaces are minimized without excess bitumen, which can lead to surface bleeding or loss of structural strength (Osei, 2017). One of the most popular approaches to establishing the optimal bitumen content is through the Marshall Mix Design method.

This procedure typically entails the manufacture of several asphalt mixtures with different bitumen contents and the testing of different properties like stability, flow, air voids, and voids in mineral aggregate (VMA). Stability refers to the capacity of the asphalt to resist deformation by applied loads, whereas flow is its capability to deform under loading without the formation of fractures.

Balance between the two characteristics is necessary in order to achieve performance under traffic loads. In this context, WEO inclusion into the bitumen mixture necessitates the fact that adequate adjustment must be done on the bitumen content. As WEO reduces the bitumen viscosity, compaction as well as workability characteristics can be influenced. Any modification of the Marshall Mix Design process, therefore, should account for these changes, mainly in terms of WEO effects on stiffness as well as on durability. It was recommended that the ideal percentage of WEO-modified bitumen varies with traffic load, climatic conditions, and aggregate type employed; hence rather specific.

One important element of establishing optimal bitumen content is how such content would affect the susceptibility to moisture of the asphalt mixture. Excessive bitumen addition can lead to higher moisture susceptibility for the mix; water can penetrate the pavements and cause destabilization in the bitumen-aggregate bond. The inclusion of WEO can potentially affect the water resistance of the mixture; further wet condition tests, especially those with high rainfall, like Uganda, are needed. Optimization of bitumen content in asphalt modified with WEO aims to achieve a balance between stiffness and flexibility of the pavement that can resist traffic loading without cracking or deformation and reduce the air voids in bitumen. In fact, the conclusions of this study will dictate the optimal bitumen content for the Kampala-Masaka Road.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This study was an experimental type to assess the use of Waste Engine Oil (WEO) on asphalt concrete stiffness, focusing on key performance properties like durability and resistance to deformation. To achieve this, the study will follow a structured methodology aligning with the specific objectives and research questions.

3.2 Research Design

This study will employ an experimental research design to assess the effects of WEO on the properties of asphalt concrete. The research will consist of laboratory experiments involving the characterization of raw materials, modification of bitumen with WEO, and the design and testing of asphalt mixes. A comparative analysis will be conducted between conventional asphalt concrete and WEO-modified asphalt concrete to determine the impact on stiffness and overall performance

3.3 Material Collection and Preparation

a) Aggregates

AC 20 aggregates were sourced from Ziobwe borrow pit which is owned by China State Construction Company, ensuring cleanliness and free from contaminants.

b) Waste Engine Oil (WEO)

WEO was collected from a fuel petrol station within Nyanama, and blended to ensure representativeness.

c) Bitumen

This was sourced from CHINA STATE asphalt plant in Kasangati, using penetration grade 50/70.

3.4 Tests on the materials.

3.4.1 Tests on Aggregates

3.4.1.1 Sieve Analysis

Aim: To determine the particle size distribution of aggregates and ensure that the material meets construction specifications.

Reference:

AASHTO T27:

Procedure

- A representative dry sample of the aggregates was weighed at the beginning of the test.
- The sample was placed in a stack of sieves, arranged from the largest to the smallest mesh sizes, and a mechanical sieve shaker was used to agitate the sample for a specified duration, typically about 10-15 minutes.
- After the shaking process, the aggregates retained on each sieve were removed and weighed.
- The percentage of the sample passing through each sieve was then calculated, and the results were plotted on a grading curve.

3.4.1.2 Aggregate Crushing value

Aim: To assess the resistance of an aggregate to crushing under a gradually applied compressive load, simulating the effect of traffic loads.

Reference: BS

812-110

Procedure:

- A sample of aggregates was first prepared by sieving it to the desired size (usually 10mm to 12.5mm).
- The aggregates were then weighed, and placed in a cylindrical mould of known dimensions.
- The test was carried out by applying a compressive load through a standard loading machine. The load was applied gradually until a specified amount of compression (usually 400 kN) was reached.
- After the test, the aggregate was sieved to separate the fines (material passing through a 2.36mm sieve) from the remaining coarse aggregate. The mass of fines was then recorded.
- The Aggregate Crushing Value was calculated as the ratio of the weight of fines to the total weight of the sample, multiplied by 100.

3.4.1.3 Flakiness index

Aim: To evaluate the form of aggregates, focusing on the proportion of particles classified as flat or elongated. Understanding this characteristic is vital as an excessive presence of such particles can negatively impact the packing efficiency, void content, and ultimately the performance properties like workability and strength in concrete and asphalt mixtures.

Reference: Based on AASHTO T 304

Procedure:

- An adequately sized, representative portion of coarse aggregates was separated into specified size categories using a series of sieves (typically ranging from 6mm to 63mm).
- The segregated sample was then further examined by passing it through additional sieves, and a count was made of the particles deemed flat or elongated - defined by a length exceeding 1.8 times their width.
- The quantity of flaky (flat) particles was ascertained through dimensional measurements (length and width) of individual aggregates, and the resulting data was used to calculate the percentage of such particles within the overall sample.
- Subsequently, the Flakiness Index (FI) was determined by calculating the ratio of the total weight of the flaky aggregates to the total weight of the entire tested sample, with the result multiplied by 100 to express it as a percentage.

3.4.1.4 Loss Angeles Abrasion TEST

Objective: Measure quantitatively coarse aggregate resistance to abrasion cause breakage and wear, in simulation of the effect caused by traffic loadings.

Reference: AASHTO T96

Procedure:

- A definite quantity of coarse aggregates were ordered, and their sample was kept in the Los Angeles Abrasion machine in relation to a specified number of steel spheres.
- The test equipment was energized at a specified rotation speed for 500 to 1000 revolutions duration.
- Once the minimum required rotation was completed, the sample was recovered, and steel balls were removed from the aggregates. Fine particles that were generated during the test were sieved.
- The remaining aggregates were weighed, and lost material due to abrasion as a percentage was calculated later.

3.4.2 Tests on Bitumen

3.4.2.1 Penetration Test

Objective: The aim of the penetration test was to determine the consistency or stiffness of bitumen and provide a measure of its fitness for different climatic conditions.

Reference: AASHTO T49 / ASTM D5

Procedure:

- The bitumen sample was heated to 25 degrees Celsius in a controlled environment.
- A standardized needle, which was loaded to a 100-gram weight, was allowed to penetrate vertically into the bitumen surface for five seconds.

- The penetration depth, in terms of 0.1 millimeters, was taken. This penetration reading was an indication of the consistency of the bitumen.

Test Significance: The penetration reading indicated the softness or stiffness of the bitumen, and its ability to perform well under different temperature conditions.

3.4.2.2 Softening Point Test

Purpose: The softening point test was to determine the temperature at which the bitumen softens and provide an indication of how it would perform at high temperatures.

Reference

AASHTO T53 / ASTM D36 Method:

- A small amount of bitumen was placed in a brass ring and was heated to a specified temperature.
- A steel ball was placed on the surface of the bitumen sample.
- The sample was heated at a controlled rate, and a softening point was taken when the bitumen had been softened to a level where it could allow the ball to fall through a certain distance.

Test significance: Softening point helped to determine the resistance of bitumen to deformation at high temperatures, especially in the use for hot climates or heavily used roads.

3.4.2.3 Viscosity Test

Objective: Viscosity test was performed to determine bitumen's flow resistance, a critical parameter in assessing its ease of handling during pavement construction mixing and compaction process.

Reference: AASHTO T201 / ASTM D2170

Procedure:

- A specific amount of bitumen was heated to a temperature range of either 60 degrees Celsius or 135 degrees Celsius, depending on the particular requirements of the test.
- The hot bitumen was then poured into a viscometer, and the time it took to pass through the opening of the instrument was measured.
- The value of the viscosity was then determined from the measured time and the specific properties of the used viscometer.

Test Significance: Such an analysis provided crucial details regarding the nature of handling the bitumen so that it could be fit for effective mixing with aggregates and proper compaction in the construction of pavements.

3.4.2.4. Flash Point Test

Objective: Flash point test was to find the temperature at which the bitumen gaseous emissions could temporarily ignite when exposed to an open flame, thereby allowing safe handling procedures.

Reference: ASTM D92

Procedure:

- A sample of bitumen was stored within a covered container.
- The sample was slowly heated while periodically adding a small flame to test for temporary ignition.
- Flash point was recorded as the temperature at which bitumen released an adequate quantity of vapors to produce a brief flash of fire.

Test Significance: The test was significant in ensuring safe handling, storage, and transport of bitumen without the threat of fire hazard.

3.4.2.5 Ductility Test

Purpose: The ductility test was utilized to ascertain the ability of bitumen to stretch without breaking, which is important for its functioning under cold conditions.

Reference

AASHTO T51 / ASTM D113

Procedure:

- Two wooden blocks with a fixed interval between them had a sample of bitumen placed between them.
- The blocks were then pulled away from each other at a constant speed of 5 cm/min.
- The test was prolonged until the bitumen specimen fractured, and the distance to which it had been stretched prior to fracture was measured as the ductility value.

Test significance: The higher ductility value reflected the ability of the bitumen to endure low temperatures and resist cracking under stress, thus being fit for cold climates.

3.4.2.6 Specific Gravity Test

Purpose: Specific gravity test was to determine the density of bitumen relative to that of water, as it was a prerequisite for the mix design calculation.

Reference

AASHTO T228

Procedure:

- A sample of bitumen was heated to a specified temperature, and the weight was measured accurately.
- The bitumen was then submerged in a liquid of established density, and the volume displaced was noted.
- Specific gravity was calculated by measuring the weight of the bitumen divided by the weight of water that takes up an equal volume.

Significance of the test: The specific gravity value was important in determining the correct binder content of asphalt mixtures and in ensuring the bitumen was of the correct consistency for use in construction work.

3.4.2.7 Solubility Test

Objective: Solubility test was meant to determine the purity of bitumen based on how much it dissolved in a solvent (trichloroethylene in most cases).

Reference: AASHTO T44

Instructions:

- The sample of bitumen was weighed, then dissolved in a known quantity of trichloroethylene.
- The solution was filtered to remove the residue.
- The percentage content of dissolved bitumen was calculated using the weight of dissolved bitumen compared to the total sample weight.

Test purpose: Solubility test was imperative in ascertaining the purity of bitumen to ascertain whether unwanted products (e.g., waxes and impurities) would be contaminated into its function.

3.4.2.8 Rotation Viscosity Test

Purpose: Rotation viscosity test was conducted in order to investigate the flow behavior of bitumen under elevated temperatures, which was imperative to gain an understanding about its workability during mix and compaction moments.

Reference

AASHTO T316 / ASTM D4402 Procedure:

- A sample of bitumen was placed in a rotational viscometer.
- The viscometer applied the shear stress to the bitumen by rotating the sample at varying speeds.
- The viscosity was calculated from the amount of torque required to rotate the sample at the specified speed.

Test significance: The test helped in determining if the bitumen had the proper flow properties to attain good mixing and compaction so that the asphalt mix operated well during road surface construction.

3.4.2.9. Thin Film Oven Test (TFOT)

Purpose: TFOT was to simulate short-term aging of bitumen during the hot-mix asphalt manufacturing process.

Reference: AASHTO T240 / ASTM D1754

Procedure:

- A thin bitumen film was spread evenly inside a container.
- The sample was placed in an oven and was heated for 5 hours at 163°C, air being passed over in contact with the bitumen to allow for air exposure during manufacturing.
- After testing, the physical properties of the bitumen, such as penetration, softening point, and viscosity, were re-estimated.

Test significance: The test was significant to determine how the bitumen would behave after having been subjected to high temperatures while mixing, to ensure that it would not prematurely degrade during construction.

3.4.3 Tests on Waste Engine Oil (WEO)

3.4.3.1 Viscosity Test

Standard: ASTM D445

Purpose: Measures flow properties, influencing mixing and performance.

Procedure:

Use a viscometer to measure the resistance to flow of WEO at controlled temperatures.

3.4.4 Tests on Fourier Transform Infrared (FTIR) spectroscopy

This was employed to analyze waste diesel engine oil in order to assess its chemical degradation and the presence of contaminants. During engine operation, lubricating oil is subjected to high temperatures, pressure, and exposure to combustion by-products, leading to physical and chemical deterioration. These changes can include oxidation, nitration, additive depletion, fuel dilution, soot contamination, and the ingress of water or coolant. FTIR spectroscopy provided a fast and non-destructive method to monitor these changes by identifying characteristic molecular vibrations associated with functional groups in the oil. This technique allowed for the qualitative and semi-quantitative assessment of the oil's condition, supporting decisions related to maintenance, disposal, or recycling.

Procedure

A representative sample of waste diesel engine oil was collected and prepared for FTIR analysis. The sample was applied onto an infrared-transparent window, typically made of zinc selenide (ZnSe) or potassium bromide (KBr), or placed within a fixed-pathlength liquid cell. The FTIR spectrometer scanned the sample across a spectral range of 4000 to 400 cm^{-1} , recording the absorbance of infrared light at different wavelengths.

The resulting spectrum displayed peaks corresponding to specific molecular bonds and functional groups present in the oil. Key absorption bands were

examined to identify oxidation products (e.g., carbonyl groups), nitration compounds, sulfates, water, fuel, and soot particles. The spectrum of the used oil was then compared with that of fresh (unused) oil or standard reference spectra to determine the extent of degradation and contamination. This analysis enabled the evaluation of oil condition and the effectiveness of its service life.

3.4.5 Tests on the optimal mix design of asphalt concrete modified with waste diesel engine oil

3.4.4.1 Indirect Tensile Stiffness Modulus (ITSM) Test

Purpose: Compares stiffness of WEO-modified asphalt to conventional mixes.

Procedure:

Apply a diametral load to a cylindrical asphalt sample and measure the deformation to calculate stiffness.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the outcomes of the tests performed in this research. The raw data generated from these tests has been analyzed, discussed and presented to clearly communicate the research findings.

4.2 The Aggregate test and Neat Bitumen Properties

Table 4-1: Showing results of aggregate tests and Neat Bitumen properties

AGGREGATE TESTS						
TEST	ACV	AIV	TFV(dry)	LAA	FI	water absorption
Unit	KN	%	KN	%	%	%
Average measured value	12.9	164	315	19.6	19.9	0.2
spec (MoWT)	max 25	max 25	≥110	max 30	≤25	max 2%

NEAT BITUMEN PROPERTIES				
properties	penetration	softening point	ductility	density
Average measured value±SD	62.2± 0.55	52.4± 0.49	115±0.36	1.02± 0.001
spec	50-70	46-54	min 100	min 1.00

Explanation of the table values

a) For Aggregates

As seen from Table 4-2, ACV, AIV: Both have maximum limits of 25%. The values for these properties are close to or below the limits, thus implying the aggregates are likely suitable for high-performance asphalt concrete.

LAA: The value (19.9%) is below the 30% maximum; thus, this makes that the aggregates have good resistance to abrasion and are durable.

Water absorption: This is 0.2%, which is far below the 2% maximum limit, indicating that the aggregates will not absorb excessive water, which could weaken the mixture.

b) For Neat Bitumen Properties

As seen from the results in Table 4-3(properties of neat bitumen), the penetration, softening point, ductility, and density of the bitumen all fall within the specified ranges.

- Penetration (62.2) is well within the acceptable range of 50-70, which is ideal for maintaining flexibility and preventing cracking in the asphalt mixture.
- Softening Point (52.4) falls within the range of 46-54, which implies that the bitumen has an appropriate balance of temperature susceptibility for the intended use.
- Ductility (115) exceeds the minimum requirement of 100, showing that the bitumen has good elongation properties.
- Density (1.02) falls within the standard range (1.01-1.06), confirming that the bitumen is within acceptable weight limits.

4.3 Fourier Transform Infrared (FTIR) spectroscopy

This was employed to analyze waste diesel engine oil in order to assess its chemical degradation and the presence of contaminants. During engine operation, lubricating oil is subjected to high temperatures, pressure, and exposure to combustion by-products, leading to physical and chemical deterioration. These changes can include oxidation, nitration, additive depletion, fuel dilution, soot contamination, and the ingress of water or

coolant. FTIR spectroscopy provided a fast and non-destructive method to monitor these changes by identifying characteristic molecular vibrations associated with functional groups in the oil. This technique allowed for the qualitative and semi-quantitative assessment of the oil's condition, supporting decisions related to maintenance, disposal, or recycling.

Table 4-4: Showing FTIR Screening and physical properties of neat bitumen properties.

FTIR SCREENING	
Polymer	Score (cm ⁻¹)
Ethylene	924
Polyamide resin	883
Styrene-ethylene-Butylene	879
Ethylene vinyl Acetate	868

PHYSICAL PROPERTIES OF WASTE ENGINE OIL			
Property	Viscosity	fire point (°C)	flash point (°C)
Value	14.2	188.2	166

4.3.1 For waste diesel engine oil

FTIR Screening

The FTIR (Fourier-transform infrared spectroscopy) results provide insight into the polymer content in the bitumen, including:

From Table 4-5, Ethylene of a wave score of (924 cm⁻¹) infrared radiation absorption: A common polymer in modified asphalt.

- Polyamide Resin with a wave score of 883 cm⁻¹ and Styrene-ethylene-Butylene with a wave score of 879 cm⁻¹: These suggest that the bitumen has

been modified with styrene-based copolymers, which can improve the performance of the asphalt.

- Ethylene Vinyl Acetate (EVA): This polymer is used to improve elasticity and crack resistance. Outcomes
- Aggregate Quality: The aggregates to meet the MoWT specifications for asphalt concrete based on the provided properties. There are no outliers or significant concerns with values like ACV, AIV, and water absorption.
- Bitumen Quality: The neat bitumen is within the required range for penetration, softening point, and density. It appears to have good overall performance characteristics.
- Polymer Modification: The FTIR analysis suggests that the bitumen is polymer-modified, which would likely improve the stiffness, flexibility, and resistance to temperature-induced cracking.

4.4 The combined gradation curve

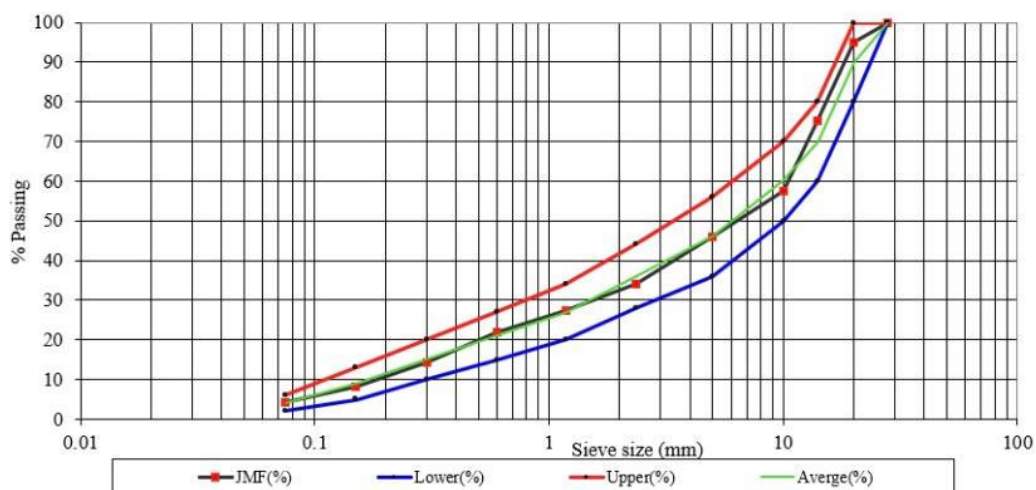


Figure 4-2: Showing the combined gradation curve of the Optimum Bitumen Content

Explanation of the gradation curve

As seen from Figure 4-3, the graph is a typical gradation curve used in asphalt mix design. It plots the percentage of aggregate passing (y-axis) against the sieve size (x-axis, in mm, on a logarithmic scale).

Key Lines:

- **JMF (Job Mix Formula):** The red line represents the target gradation for the asphalt mix. This is the desired distribution of aggregate sizes.
- **Lower (%) and Upper (%):** The blue and green lines define the acceptable tolerance limits for the gradation. The actual mix must fall within these limits to ensure quality.
- **Average (%):** The black line likely represents the average gradation obtained from multiple samples.

Interpretation: The text states that the JMF curve falls within the grading limits for AC20. This means the chosen aggregate blend meets the specifications for an AC20 asphalt mix (a common type of asphalt concrete). The fact that it falls within the tolerances indicates the mix design is suitable for use.

Relevance to Asphalt Performance: Gradation is crucial because it directly affects:

- **Stability:** A well-graded mix provides good interlock between aggregate particles, leading to higher stability and resistance to deformation under load.
- **Workability:** A proper gradation ensures the mix can be easily placed and compacted.

- Durability: A balanced gradation minimizes voids and improves resistance to moisture damage.

Analyzing the Graphs for Optimum Bitumen Content.

4.4.1 Graphs for Marshall parameters

These are used to determine the optimum bitumen content (OBC), which is the bitumen percentage that provides the best balance of properties.

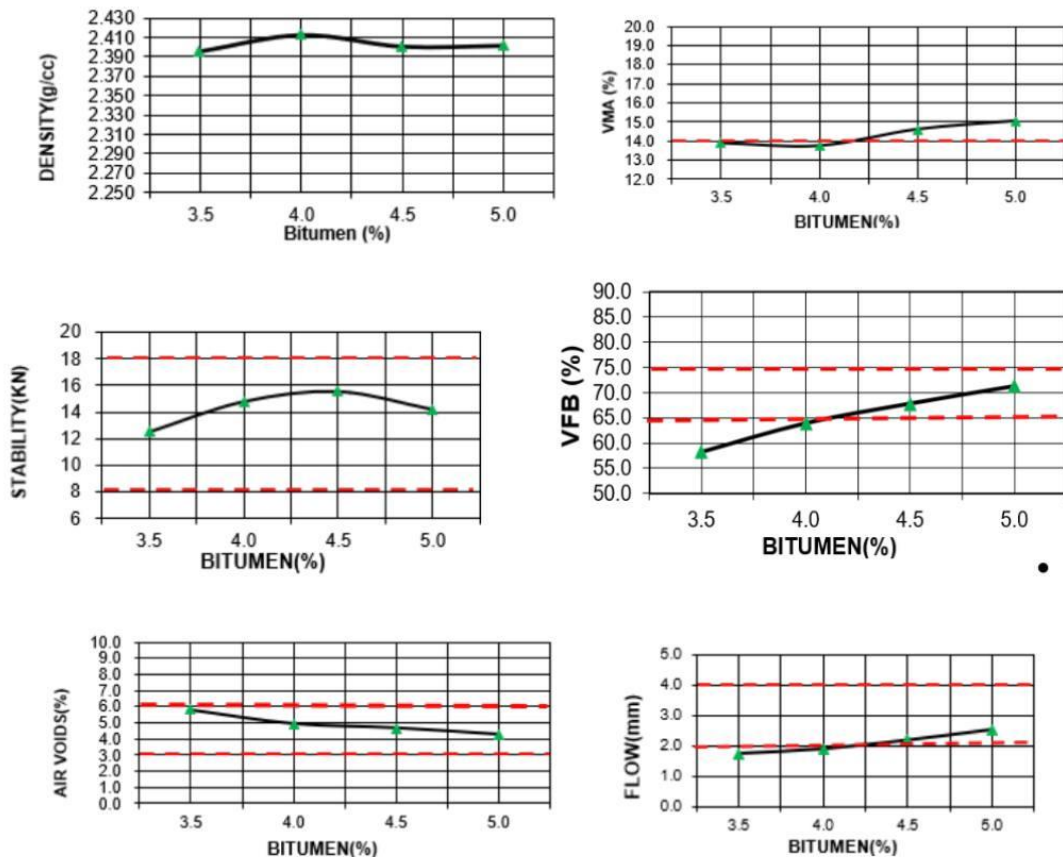


Figure 4-4: Showing the relationship of different Marshall Properties with WDEO

As seen from the graphs in Figure 4-5,

For Density (kg/m³):

- Trend: Density initially increases with bitumen content, peaks, and then decreases.
- Explanation: Initially, bitumen fills the voids between aggregates, increasing density. After a point, excess bitumen starts to push the aggregates apart, reducing density.
- Significance: Higher density generally correlates with better stability and durability.

For Stability (kN):

- Trend: Stability increases with bitumen content, then levels off or slightly decreases.
- Explanation: Bitumen acts as a binder, increasing cohesion and resistance to deformation.
- Significance: High stability is crucial for pavements subjected to heavy traffic loads.

For Flow (mm):

- Trend: Flow consistently increases with bitumen content.
- Explanation: Flow measures the plastic deformation of the mix under load. Higher flow indicates a more flexible mix.
- Significance: A balance between stability and flow is needed. Too much flow can lead to rutting.

VFB (Voids Filled with Bitumen) (%):

- Trend: VFB increases with bitumen content.

- Explanation: As more bitumen is added, more of the voids between aggregates are filled.
- Significance: Adequate VFB is essential for durability, but too much can lead to bleeding (excess bitumen on the surface).

Air Voids (%):

- Trend: Air voids decrease with bitumen content.
- Explanation: Bitumen fills the air voids within the compacted mix.
- Significance: A certain percentage of air voids is needed for compaction and to prevent bleeding. Too few air voids can lead to instability.

VMA (Voids in Mineral Aggregate) (%):

- Trend: VMA slightly increases with bitumen content.
- Explanation: VMA is the space between aggregate particles. A slight increase can occur as bitumen pushes aggregates apart.
- Significance: Adequate VMA is needed to accommodate the bitumen and ensure durability.

4.5 Results for unmodified and modified bitumen (at 3.5% WDEO)

Table 4.3 Showing the comparison between the unmodified and modified Bitumen at 3.5% WDEO

Specification	Result		Property
	Modified asphalt	Unmodified asphalt	
NA	2.402	2.401	bulk specific gravity (g/cc)
3 to 5	4.5	4	Air voids (%)
Min 14	15	14.9	VMA (%)
65-78	69.6	72.9	VFB (%)
8 to 18	15.5	12.7	Stability (kN)
2 to 4	3.33	3.33	Flow (mm)
NA	2.515	2.509	Gmm
>80	92	90	ITS (%)

4.5.1 Determining the Resilience Modulus from ITS Results

The resilience modulus is a key property in the mechanistic analysis of pavement behavior under dynamic traffic loads. It is also a crucial parameter for assessing material quality in pavement design.

This section presents the correlation formula used to determine the resilience modulus for neat asphalt, asphalt modified with 3.5% waste diesel engine oil. The analysis considers parameters such as failure load, horizontal deformation, specimen thickness, and Poisson's ratio.

For this study, the model proposed by Barksdale et al. (2010) was selected due to its ability to produce elastic modulus values that closely align with those obtained through the Direct Modulus Test (DMT). The calculated

resilience modulus values based on this correlation formula are provided in the accompanying table below

$$M_r = \frac{P_{cyclic}}{\delta_t \times t} (0.2339 + 0.7801\mu)$$

Equation 4-1: Determining the Resilience Modulus (Barksdale et al. 2010)

Where: M_r = Instantaneous or total resilience modulus (MPa); δt = Recoverable horizontal deformation (mm); P_c = Cyclic load applied to specimen (N); t = thickness of the cylindrical specimen; μ = Instantaneous or total Poisson’s ratio.

We correlated the ITS results to M_r and obtained the values as shown in the table below.

Table 4-4: Showing the Correlation of ITS to Resilient Modulus, M_r .

Type of asphalt	ITS (%)	RESILIENCE MODULUS(MPa)
Neat	90	8100
3.5%WEO	92	8280

Analysis of Resilience Modulus results

The introduction of WDEO increased the elastic modulus by 2.2% from 8100MPa to 8280MPa as seen in Table 4-4. This is because of the interlocking created between the bonds of WDEO and bitumen and this enhances the elasticity and flexibility of the asphalt binder due to the presence of polymers

such as; ethylene vinyl acetate in the WDEO that increase its ability to stretch and recover its original shape once the load has been removed.

The improvement in Resilience Modulus indicates higher stiffness, improved cracking resistance and potentially a longer life span of the road.

Bulk Specific Gravity (g/cc):

- Change: Slight increase (2.401 to 2.402) as seen from Table 4.3
- Rationale: This indicates a slightly denser mix in the modified asphalt, possibly due to better packing efficiency of the modified binder or changes in the aggregate coating.
- Relevance: Higher density generally leads to improved resistance to rutting and fatigue, enhancing pavement durability and extending its lifespan.

Air Voids (%):

- Change: Increase (4.0 to 4.5) as seen from Table 4.3
- Rationale: The waste engine oil (WEO) in the modified binder marginally reduced its coating ability, leading to slightly higher air voids.
- Relevance: While some air voids are necessary for compaction and flexibility, an excessive increase can lead to moisture damage and accelerated aging. The increase here is relatively small and might be within acceptable limits, but it needs careful monitoring.

Voids in Mineral Aggregate (VMA) (%):

- Change: Slight increase (14.9 to 15.0) as seen from Table 4.3

- Rationale: The structure of the mix being maintained with some extra void space for aggregates, possibly due to the WEO's influence on the binder's packing behavior.
- Relevance: Adequate VMA is crucial for accommodating the binder and ensuring durability. A slight increase might be beneficial, but again, needs to be within acceptable limits.

Voids Filled with Bitumen (VFB) (%):

- Change: Decrease (72.9 to 69.6) as seen from Table 4.3
- Rationale: The modified binder takes up a smaller portion of the available voids, leading to a reduction in VFB.
- Relevance: VFB is a critical parameter for durability. A lower VFB can make the pavement more susceptible to moisture damage and accelerated aging. This is a concerning change and needs careful consideration.

Stability (kN):

- Change: Significant increase (12.7 to 15.5).
- Rationale: This is due to improved aggregate interlock and higher mix stiffness, potentially resulting from the modified binder's properties.
- Relevance: Higher stability is crucial for pavements subjected to heavy traffic loads. This improvement is highly beneficial, as it enhances the pavement's resistance to rutting and deformation, leading to a longer service life.

Flow (mm):

- Change: No change (3.33).
- Rationale: The flow was steady, indicating no significant effect on the flexibility of the mix.
- Relevance: Maintaining the same flow ensures that the modified asphalt retains its desired flexibility while improving other properties like stability.

Gmm (Maximum Theoretical Specific Gravity):

- Change: Slight increase (2.509 to 2.515) as seen from Table 4.3
- Rationale: The document attributes this to better packing efficiency of the modified mix.
- Relevance: A higher Gmm indicates a denser mix, which is generally associated with improved durability and resistance to moisture damage.

The Indirect Tensile Strength (ITS) test measures the tensile strength of asphalt concrete. It's performed by applying a compressive load along the vertical diameter of a cylindrical specimen, which induces tensile stress perpendicular to the applied load. A higher ITS value indicates a greater resistance to cracking and failure under tensile stresses.

Indirect Tensile Strength (ITS) Value

Change

The addition of waste diesel engine oil slightly increased the ITS from 90% to 92%.

Rationale

- **Improved Cohesion and Adhesion:** Waste diesel engine oil, when properly incorporated, can act as a modifier that improves the cohesion (internal bonding within the asphalt binder) and adhesion (bonding between the binder and aggregate) in the asphalt mix. This enhanced bonding can lead to a higher resistance to tensile stresses.
- **Increased Flexibility and Ductility:** Waste diesel engine oil might impart some flexibility and ductility to the asphalt binder. This increased flexibility allows the asphalt to better distribute tensile stresses, delaying the onset of cracking.
- **Potential for Reduced Stiffness:** While not always the case, some studies have shown that certain modifiers can reduce the stiffness of the asphalt mix. This reduction in stiffness can lead to better stress distribution and improved tensile strength.
- **Relevance in Improvement of Asphalt Concrete Modified with Waste Diesel Engine Oil**
- **Enhanced Cracking Resistance:** A higher ITS value signifies improved resistance to cracking, particularly in situations where tensile stresses are prevalent, such as in pavements subjected to heavy traffic loads or thermal cycling.
- **Increased Durability and Service Life:** By delaying the onset of cracking, the modified asphalt concrete is expected to have a longer service life and require less maintenance.
- **Improved Fatigue Performance:** Higher ITS values often correlate with better fatigue resistance, which is crucial for pavements subjected to repeated loading.

- Environmental Sustainability: Using waste diesel engine oil as a modifier offers an environmentally friendly way to recycle waste materials, reducing the demand for virgin asphalt binder and minimizing waste disposal.

4.5.2 Graphical analysis after the modifications.

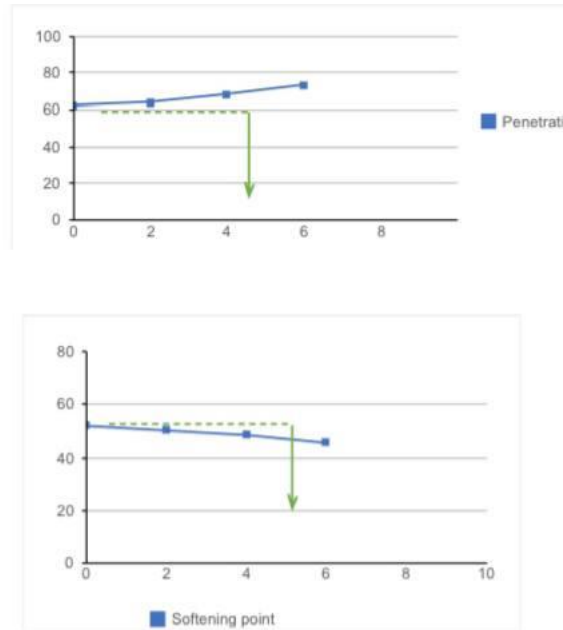


Figure 4-6: Showing penetration and softening points

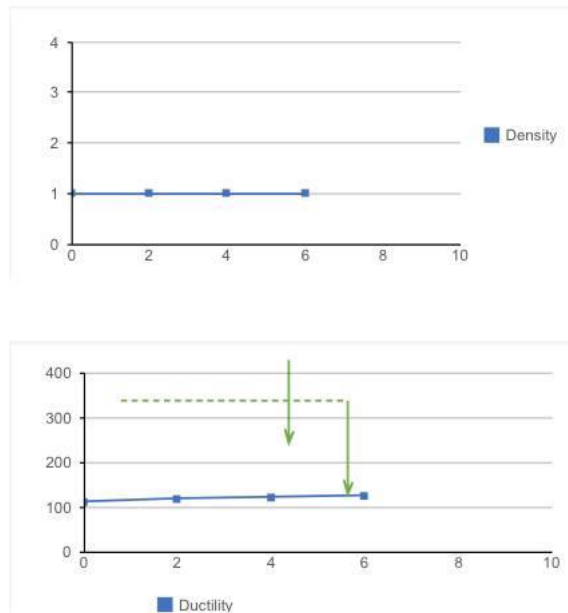


Figure 4-7: Showing Density and Ductility

Explanation of the graphs

1. For Penetration

Graph: Shows an increase in penetration with the addition of waste diesel engine oil (WDEO). penetration value rises from 62.2 (Neat) to 73.4 (6% WEO) as seen from Figure 4-8. The penetration for neat bitumen was $62.2 \pm 0.56\text{mm}$, Spec (50-70mm)-AASHTO T049-96. After addition of waste diesel engine oil, there was a gradual increase in penetration. This implies that the softening of bitumen (reduction in ratio of asphaltenes to maltenes in bitumen (Joseph & Danha, 2020)).

Rationale:

Penetration Test: Measures the consistency or softness of bitumen. Higher penetration indicates a softer binder.

WDEO Effect: WDEO acts as a softening agent, reducing the asphaltene-to-maltene ratio. Asphaltenes are responsible for stiffness, while maltenes contribute to flexibility.

Relevance to Asphalt Concrete:

- **Improved Workability:** Softer bitumen enhances workability during mixing and compaction, making it easier to place and achieve desired density.
- **Enhanced Flexibility:** Increased penetration improves the flexibility of the asphalt concrete, making it more resistant to cracking, especially in cold climates.
- **Reduced Brittleness:** Softer bitumen reduces the brittleness of the mix, improving its durability.

2. For Softening Point

Graph: Shows a decrease in softening point with increasing percentages of WDEO. The value drops from 52.4°C (Neat) to 45.5°C (6% WEO). "It is observed that the softening point value of the modified bitumen decreases with increasing percentages of waste diesel engine oil." ,as observed in Figure 4-9.

Rationale:

Softening Point Test: Measures the temperature at which bitumen softens and becomes flowable. Lower softening point indicates a more temperature-sensitive binder.

WDEO Effect: WDEO lowers the softening point, making the bitumen more susceptible to softening at lower temperatures. This is consistent with the penetration results.

3. For Density

Graph: Shows a decrease in density with the addition of WDEO. "Density value of neat bitumen was 1.018 ± 0.001 , with a 2% WEO content, it decreased to 1.011 ± 0.0007 , as observed from Figure 4-10 indicating that WEO is less dense than bitumen hence improved workability."

"This is beneficial as it reduces bitumen's molecular weight and increase its volume."

Rationale:

Density Measurement: Measures the mass per unit volume of the bitumen.

WDEO Effect: WDEO is less dense than neat bitumen, resulting in a lower density of the modified binder.

Molecular Weight and Volume: The text suggests that WDEO reduces the bitumen's molecular weight and increases its volume, contributing to the lower density.

Relevance to Asphalt Concrete:

Improved Workability: Lower density can improve workability by making the mix easier to handle and compact.

4. For Ductility

Graph: Shows an increase in ductility with the addition of WDEO. It rises from 115 cm (Neat) to 129 cm (6% WEO) as observed from Figure 4-11.

The increase in ductility with the addition of WEO suggests that the oil acts as a plasticizer within a material matrix, enhancing the material's flexibility and reduces its brittleness."

Rationale:

Ductility Test: Measures the ability of bitumen to be stretched or elongated before breaking. Higher ductility indicates a more flexible binder.

WDEO Effect: WDEO acts as a plasticizer, increasing the bitumen's ductility and reducing its brittleness.

Relevance to Asphalt Concrete:

- Improved Flexibility: Increased ductility enhances the flexibility of the asphalt concrete, making it more resistant to cracking, especially in cold climates.
- Reduced Brittleness: Decreased brittleness improves the pavement's durability and resistance to fatigue cracking.
- Enhanced Performance in Cold Climates: This change is particularly beneficial for pavements in cold regions, where thermal cracking is a major concern.

DESIGN

batch mass of aggregates = 1180g.

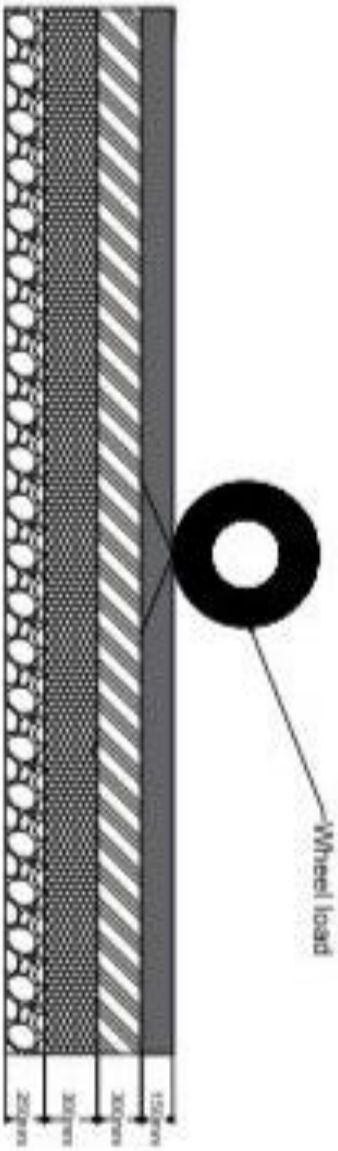
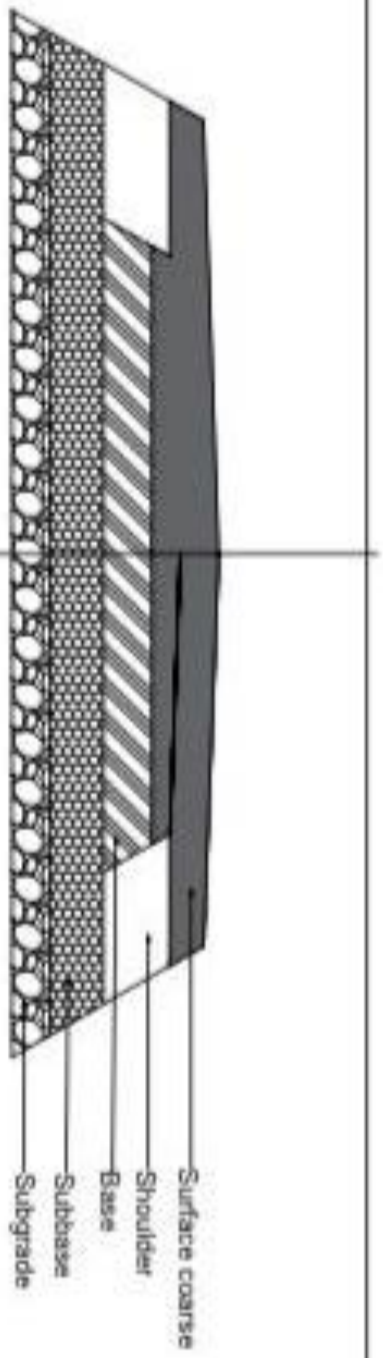
5% bitumen content, mass of bitumen = $0.035/95 \times 1180 = 43.4\text{g}$

optimum WEO of 3.5% was mixed in 4.6% bitumen = $0.035 \times 43.4 = 1.52\text{g}$

Volume of the Marshall Mould used for the mix,; $V = \frac{22}{7} \times 0.0508^2 \times 0.0635 = 0.000515\text{m}^3$

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

This is what will be used when doing a mix for real application on the road



TITLE	ROAD CROSS-SECTION DESIGN
NAME	MUGUME TYSON S21B32/106
SCALE	1:100
DATE	08/04/2025

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From this research carried out to determine the effect of WEO on the stiffness properties of modified asphalt pavement, the following conclusions may be made:

1. The aggregates used for the tests were all within the acceptable standards for AC20, together with their gradation envelope. The 50/70 PEN bitumen used was also tested according to the British Standards and results of 52.4°C and 62.2mm indicated that the softening point and penetration grade respectively were within the acceptable ranges of 49.5-54 °C and 50-70mm respectively. Properties of WEO determined using the FTIR tests and its chemical composition determined
2. To determine the Rheological Properties of modified bitumen with WDEO, the physical property tests of the bitumen were conducted and the results obtained showed an improvement in the Marshall Flow, Stability, workability properties as compared to those of the neat bitumen. An optimum WEO content of 3.5% among the different percentages added showed the best improvement that met all the standards for 50/70 Pen bitumen.
3. The optimum mix design using the modified bitumen and aggregates was conducted and obtained, used to prepare asphalt samples and testing for Marshall and volumetric analysis, Indirect Tensile Strength, and the Resilient Modulus. The results indicated an improved desirable stiffness by 22% of the asphalt due to the modification which justified this project which concluded

that the pavement would be more resistant to deformation under heavy loads for example those along the Kampala Masaka Highway.

5.2 RECOMMENDATIONS

5.2.1 recommendation basing on the conclusions

1. Using WEO to modify bitumen improved the stiffness properties of the asphalt made of it by 22% which enhances the resistance of pavements to deformation under heavy load. This improvement is desirable and should be considered when designing of upcoming highways in Uganda.

5.2.2 Recommendation for further research

1. Would recommend doing further test for example; Short- and Long-term aging tests, Multiple Stress Creep recovery tests, Bending Beam Rheometer test and pavement performance simulation tests to clearly understand the behavior of the asphalt and Bitumen under several real-life conditions.
2. Studies need to be done to find out the possibility of using Waste Petrol Engine oil instead of Waste Diesel Engine Oil in the modification to determine whether the effects of the modification be similar or not?
3. Research should be done to vary the different mixing conditions of WDEO in bitumen for example temperature, duration for which the oil has been used in the machines and duration of mixing to compare the extent of variation of results.

4. Cost-Benefit and Environmental Impact Analysis: Carry out a detailed economic and environmental feasibility study unique to the Kampala-Masaka highway project. This will determine the cost-benefit and environmental implications of employing WEO-modified asphalt.

REFERENCES

- Saba, L., et al. (2022). "Sustainability in asphalt paving: An overview." *Journal of Environmental Management*.
- Mukasa, E., Tumwesigye, B., & Kiggundu, T. (2021). Pavement deterioration on Kampala-Masaka Road: Causes and effects. *Uganda Road Journal*, 12(4), 22-35.
- Osei, M. A. (2017). Rheological properties of waste engine oil-modified bitumen. *International Journal of Road Materials*, 9(2), 45-57.
- Tumwesigye, B., & Kiggundu, T. (2019). Traffic load analysis for road pavements in Uganda. *East African Transportation Research Review*, 7(3), 31-44.
- Masson, J. F., Polomark, G. M., & Collins, P. (2008). Asphalt chemistry- bitumen aging: The impact of oxygen on road pavement longevity. *Journal of Applied Chemistry*, 23(4), 355-369.
- Yildirim, Y. (2007). Polymer modified asphalt binders. *Construction and Building Materials*, 21(1), 66-72.
- Baoshan Huang, S. et al. (2015). *Study on the properties of waste engine oilmodified asphalt mixtures*. *Journal of Road Materials and Pavement Design*, 16(3), 501-516.
- Fuyu Wang, Y. et al. (2018). *Investigating the influence of waste engine oil on the aging resistance of asphalt binder*. *Construction and Building Materials*, 170, 90-97.

Williams, B. (2017). *The effect of oxidation on asphalt pavement performance*. Journal of Civil Engineering and Management, 23(4), 435-446.

Mohammad, L. N. (2018). *Waste engine oil as a bitumen rejuvenator for sustainable asphalt pavements*. Sustainability in Road Construction, 8(5), 231244.

Asphalt Institute, 2017. *The Asphalt Handbook*. 7th ed. Asphalt Institute, Lexington, KY.

Prowell, B.D., Brown, E.R., and Peshkin, D.G., 2005. *Stone Matrix Asphalt: A Comprehensive Review*. National Asphalt Pavement Association.

Sahab, M.A., Shafique, M., and Baig, S.R., 2018. "Performance of OpenGraded Friction Course (OGFC) Asphalt Pavements." *Journal of Transportation Engineering*, 144(9), pp. 04018063.

Zhao, Z., Yang, Z., and Zhang, Q., 2017. "Properties and Performance of Warm Mix Asphalt: A Review." *Construction and Building Materials*, 132, pp. 505-514.

Baker, T. S., Johnson, H. R., & Williams, S. D. (2018). The role of metal contaminants in used engine oil and their impact on recycling processes.

Environmental Engineering Journal, 32(5), 134-142.

<https://doi.org/10.1016/j.enveng.2018.01.004>

Dominguez, S. C., Li, X., & Müller, A. (2016). Effects of recycled waste oils in bitumen modification for enhanced asphalt performance. *Construction and Building Materials*, 109, 206-214. <https://doi.org/10.1016/j.conbuildmat.2016.02.021>

- García, C. S., Lobo, L., & Pérez, D. E. (2018). The impact of engine oil contaminants on asphalt's rheological properties. *Journal of Materials in Civil Engineering*, 30(7), 04018113. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0002378](https://doi.org/10.1061/(ASCE)MT.1943-5533.0002378)
- Huang, W., & Zhang, F. (2017). Rheological and mechanical performance of waste engine oil-modified asphalt. *Materials Science and Engineering*, 189, 241-248. <https://doi.org/10.1016/j.mse.2017.03.028>
- Khan, A. B., Wang, H., & Zhang, X. (2020). Waste oil treatment methods for asphalt applications. *Journal of Hazardous Materials*, 387, 121650. <https://doi.org/10.1016/j.jhazmat.2019.121650>
- Li, L., & Wang, Y. (2020). Performance evaluation of asphalt modified with waste engine oil: Effect of metal and chemical contaminants. *Construction and Building Materials*, 260, 119846. <https://doi.org/10.1016/j.conbuildmat.2020.119846>
- López, C., González, J., & García, L. (2019). Effects of polycyclic aromatic hydrocarbons in used engine oil on bitumen properties. *Environmental Pollution*, 245, 407-414. <https://doi.org/10.1016/j.envpol.2018.11.075>
- Gabr, M. A., & Han, J. (2014). "Asphalt Pavement Crack Classification and Diagnosis." *Transportation Research Board*, 92nd Annual Meeting.
- Huang, Y. H. (2004). *Pavement Analysis and Design*. Pearson Prentice Hall.
- Khan, M., Pate, J., & Alam, M. (2017). "Fatigue Cracking in Asphalt Pavements: Mechanisms and Preventive Measures." *International Journal of Pavement Engineering*, 18(6), 535-546.

Mohammad, L. N., & Ranjith, P. G. (2016). "Analysis and Mitigation of Thermal Cracking in Asphalt Concrete." *Journal of Transportation Engineering*, 142(5), 04016023.

Zhao, Y., & Zhang, Z. (2015). "Prediction and Mitigation of Reflective Cracking in Asphalt Pavement." *International Journal of Pavement Research and Technology*, 8(6), 451-459.

M. Zahoor, S. Nizamuddin, S. Madapusi, F. Giustozzi, Sustainable asphalt rejuvenation using waste cooking oil: a comprehensive review, *J. Clean. Prod.* 278 (2021) 123304

C.A. Issa, G. Hilal, Sustainable construction materials: Recycled aggregate concrete from known concrete strength debris, *The Open Construction & Building Technology Journal* 17 (1) (2023)

S. Ahmad, O. Dawood, M.M. Lashin, S.U. Khattak, M.F. Javed, F. Aslam, T.M. Alaboud, Effect of coconut fiber on low-density polyethylene plastic-sand paver blocks, *Ain Shams Engineering Journal* 14 (8) (2023) 101982

N. Gerges, C.A. Issa, M. Antoun, E. Sleiman, F. Hallal, P. Shamoun, J. Hayek, Eco-friendly mortar: Optimum combination of wood ash, crumb rubber, and fine crushed glass, *Case Studies in Construction Materials* 15 (2021) e00588

A.M. Memon, M.H. Sutanto, M. Napiah, N.I.M. Yusoff, R.A. Memon, A.M. AlSabaei, M. Ali, Physicochemical, rheological and morphological properties of bitumen incorporating petroleum sludge, *Constr. Build. Mater.* 297 (2021) 123738.

M. Jin, Y. Ma, W. Li, J. Huang, Y. Yan, H. Zeng, C. Lu, J. Liu, Multi-scale investigation on composition-structure of C-(A)-SH with different Al/Si ratios under attack of decalcification action, *Cem. Concr. Res.* 172 (2023) 107251.

H.B. Abdullah, R. Irmawati, I. Ismail, N.A. Yusof, Utilization of waste engine oil for carbon nanotube aerogel production using floating catalyst chemical vapor deposition, *J. Clean. Prod.* 261 (2020) 121188.

Z. Wang, Q. Wang, C. Jia, J. Bai, Thermal evolution of chemical structure and mechanism of oil sands bitumen, *Energy* 244 (2022) 123190.

H. Wang, K. Derewecki, Rheological properties of asphalt binder partially substituted with wood lignin, *Airfield and Highway Pavement 2013: Sustainable and Efficient Pavements*. 2013, pp. 977-986.

S. Arafat, N. Kumar, N.M. Wasiuddin, E.O. Owhe, J.G. Lynam, Sustainable lignin to enhance asphalt binder oxidative aging properties and mix properties, *J. Clean. Prod.* 217 (2019) 456-468.

S. Asukar, A. Behl, P. Gundaliya, Utilization of lignin as an antioxidant in asphalt binder, *Int. J. Innov. Res. Technol., IJIRT* 2 (12) (2016) 198-207.

I.A. Qurashi, A.K. Swamy, Viscoelastic properties of recycled asphalt binder containing waste engine oil, *J. Clean. Prod.* 182 (2018) 992-1000.

W.P. Teoh, Z.H. Noor, C.A. Ng, Y.C. Swee, Catalyzed waste engine oil as alternative binder of roofing tiles - Chemical analysis and optimization of parameters, *J. Clean. Prod.* 174 (2018) 988-999.

L. Feng, J. Liu, L. Hu, Rheological behavior of asphalt binder and performances of asphalt mixtures modified by waste soybean oil and lignin, *Constr. Build. Mater.* 362 (2023) 129735.

E.R. Brown, P.S. Kandhal, F.L. Roberts, Y.R. Kim, D.Y. Lee, T.W. Kennedy, Hot Mix Asphalt Materials, Mixture Design and Construction: Third Edition, National Asphalt Pavement Association 2009.

A. Institute, The Asphalt Handbook, Asphalt Institute 2007.

J.G. Speight, Chapter 1 - Nomenclature and Terminology, in: J.G. Speight (Ed.), Asphalt Materials Science and Technology, Butterworth-Heinemann, Boston, 2016, pp. 3-43.

C.D. DeDene, Investigation of using waste engine oil blended with reclaimed asphalt materials to improve pavement recyclability, Michigan Technological University, 2011.

Q. Yuan, Z. Liu, K. Zheng, C. Ma, Civil Engineering Materials: From Theory to Practice, Elsevier Science 2021.

M.S. Mamlouk, J.P. Zaniewski, Materials for Civil and Construction Engineers, Pearson Education 2016.

D.E. Newcomb, B.J. Nusser, B.M. Kiggundu, D.M. Zallen, Laboratory study of the effects of recycling modifiers on aged asphalt cement, Transportation Research Record (1984).

Baker, M. J., Singh, K., & Kumar, S. (2016). The role of subgrade and base materials in flexible pavements. *Journal of Transportation Engineering*, 142(8), 04016042.

Khan, M. S., & Somashekar, G. (2020). *Bituminous materials in flexible pavement design*. Springer.

Ravindra, A. G., & Hogg, P. (2017). Subbase material stabilization for road construction. *Materials Science and Engineering*, 25(3), 108-116.

Somashekar, G., Ravindra, A., & Hogg, P. (2019). Stabilization techniques for flexible pavement. *International Journal of Pavement Engineering*, 20(7), 1154-1165.

Wang, Q., & Li, C. (2018). *Asphalt mixture and its performance in flexible pavements*. Elsevier.

Adams, J., & Gonzalez, T. (2023). *Soundness and Durability of Roadway Aggregates*. *Journal of Asphalt Technology*, 45(2), 112-123.

Barker, S., & Hall, R. (2020). *Stripping Resistance in Asphalt Mixtures*. *Asphalt Research Review*, 29(4), 208-215.

Brown, A., & Patel, D. (2020). *Granular Grading and Sizing of Aggregates in Asphalt Pavements*. *Journal of Road Engineering*, 58(1), 35-40.

Evans, R., & Moore, S. (2021). *Properties and Applications of Gravel Aggregates in Pavements*. *Construction Materials Journal*, 36(2), 97-104.

Harris, M., & Brown, S. (2022). *Granite Aggregates in Road Construction*. *International Journal of Materials Science*, 12(3), 123-130.

Jiang, H., & Zhang, L. (2021). *Role of Sand in Asphalt Mixtures and Pavement Durability*. *Journal of Construction Materials*, 40(1), 52-58.

Johnson, P., Smith, D., & Taylor, R. (2022). *Aggregate Materials in Road Pavement Design: An Overview*. *Road Engineering Review*, 15(3), 78-85.

Kumar, R., & Singh, V. (2022). *Quality Aggregates for Sustainable Roadway Construction*. *Environmental Construction Science Journal*, 14(1), 92-105.

Lee, T., & Wang, J. (2021). *Aggregate Properties and Their Influence on Asphalt Performance*. *Asphalt Journal*, 60(4), 134-145.

Lopez, M., & Rivera, P. (2022). *Pit Aggregates and Their Role in Asphalt Concrete Production*. Civil Engineering Journal, 24(3), 205-210.

Martinez, P., et al. (2021). *Toughness of Aggregates for High-Durability Asphalt Pavements*. Journal of Material Engineering, 38(2), 101-107.

Nguyen, K., et al. (2023). *Testing and Quality Control Procedures for Asphalt Aggregates*. Construction Quality Review, 41(5), 170-178.

Patel, A., & Wang, L. (2022). *Utilizing Slag Aggregates in Asphalt Mixtures for Improved Strength*. Materials Science Research Journal, 28(6), 222-229.

Thompson, D., & Lee, J. (2021). *Particle Shape and Its Impact on the Performance of Asphalt Mixtures*. International Journal of Pavement Engineering, 19(2), 76-81.

Zhao, Z., & Zhang, Y. (2022). *Secondary Aggregates: Sustainable Use in Asphalt Pavement Construction*. Journal of Waste Management, 13(4), 145152.

APPENDICES

APPENDIX A: PICTORIAL



Figure 12: Showing cracks



Figure 13: Showing Operation of a Marshall compactor.



Figure 14: Showing the reading the Stability Test Results.



Figure 15: Showing Marshall Stability Testing Machine.



Figure 16: Showing Sample Molds of Modified Asphalt Concrete



Figure 17: Showing Drum mixer for Asphalt Hot Mix.

Appendix B: Laboratory results

Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
E-mail: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No.



MINISTRY OF INTERNAL AFFAIRS
DIRECTORATE OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 Lourdel Road
Wandegeya,
P.O. Box 105639
Kampala - Uganda

DFD 037/2025

07th February 2025

Ms. NATANGAZA PEACE AND MR MUGUME TYSON
REG NO. S21B32/100 & S21B32/106
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-756-625464

REPORT OF ANALYSIS

Description of the Samples

One sample in black polythene bag containing Used motor oil sample was submitted by Ms. Natangaza Peace, on 24th January 2025, and analysed on 30th January 2025. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Used motor oil substances packed in a white plastic bottle	1	SAMPLE A DFD 037/2025

Analysis Requested

Identification by FTIR.

Method of Analysis

Analysis of the sample done using the FTIR scanning method.

Results of Analysis

The mean analysis values are as below.

Sample/Lab No	Test/Parameter	Results
SAMPLE A DFD 037/2025	FTIR SCREENING	Liquid paraffin, Ethylene/propylene Copolymer, polyamide resin, styrene- ethylene -Butylene, ethylene/vinyl Acetate.

Remarks

Results relate to samples analyzed and are reported as on received basis.

FSO 07/02/25

Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



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

Location:	Zirobwe Quarry	Sampling Date:	11-Dec-2024
Material Source:	Kasangati Asphalt Plant	Tested Date:	17/LL/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
FI		%	19.9			BS 812 Part 105.1:1990
AIV		%	16.4			BS 812 Part 112:1990
LAIV		%	19.6			ASTM C131-2001

Remarks:

Representatives

Group member	Materials Technician (CSCEC)	Materials Engineer (CSCEC)
Sign	Sign: <i>[Signature]</i>	Sign: <i>[Signature]</i>
Date	Date: 17/12/2024	Date: 20/01/2025


 CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
 P.O.Box 29285 KAMPALA
 20 JAN 2025

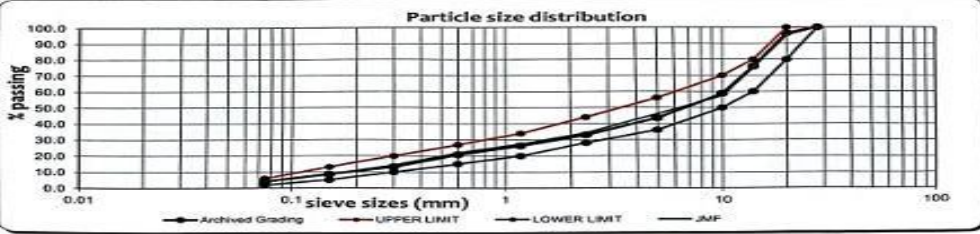
CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
 Block 36, Plot 95, 11&711, Kitebi Kibuga Kampala, Ssuuna II Road, Nyanama Zone
 Mutundwe, Lubaga Division
 P.O.Box 29285 KAMPALA
 Tel: +256(0)755046031/708898888
 Email: cscec@iangbo@gmail.com

AC 20 Aggregates particle size Distribution (BS 812-103.1:1985)

Sample Ref:	N/A		Sampling Date:	22 Dec 2024
Location: (km)	/		Testing Date:	18 Jan 2025
Material source	Kasangati Asphalt Plant		Technician	Lab Team
Sample Description	Combined Grading AC20 Agg			
Mass of dry Sample (gm)	3998.1	Dry Mass after washing (gm)		3829.2


Diameter (mm)	Weight Retained (g)			Passing %	JMF (%)	Grade Limits %	
	Weight Retained (g)	Cum. Wt Retained (g)	Cumulative Retained (%)			UPPER LIMIT	LOWER LIMIT
28	0.0	0.0	0.0	100.0	100.0	100.0	100
20	145.6	145.6	3.6	96.4	95.1	80.0	100
14	826.5	972.1	24.3	75.7	75.3	60.0	80
10	677.1	1649.2	41.2	58.8	57.4	50.0	70
5	609.8	2259.0	56.5	43.5	46.0	36.0	56
2.36	422.8	2681.8	67.1	32.9	34.2	28.0	44
1.18	266.9	2948.7	73.8	26.2	27.4	20.0	34
0.6	218.1	3166.8	79.2	20.8	21.9	15.0	27
0.3	304.4	3471.2	86.8	13.2	14.3	10.0	20
0.15	184.2	3655.4	91.4	8.6	8.1	5.0	13
0.075	175.0	3830.4	95.8	4.2	4.3	2.0	6
Pan	167.7	3998.1	100.0	0.0			

Particle size distribution



Remarks:

Materials Technician	Materials Engineer
Sign: <i>[Signature]</i>	Sign: <i>[Signature]</i>
Date: 18/1/2025	Date: 20/01/2025

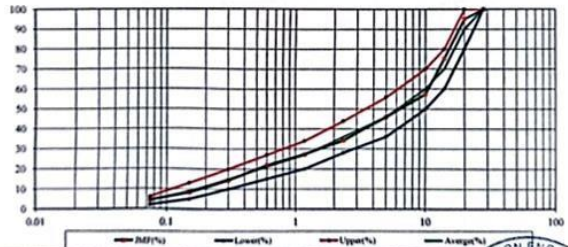

 CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
 P.O.Box 29285 KAMPALA
 20 JAN 2025
 (CSCEC)



CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
 Block 36, Plot 85, 11&111, Kibuka Kibuka Kampala, Besuna # Road, Nyanama Zone
 Mukundwa, Lodoga Division
 P.O.Box 29268 KAMPALA
 Tel: +256(0)750446031/750496888
 Email: csecezhonglin@gmail.com

AC20 COMBINED GRADATION (Gen. Spec. TABLE 4.25(2))
 LAB TRIAL MIX GRADATIONS SUMMARY (MP DETERMINATION)
 HOT BINs

Sieve size in mm	#100	#300	#600	#1200	#2500	JMF1(%)	Lower(%)	Upper(%)	Average(%)
20	100.0	100.0	100.0	100.0	100.0	100.0	100	100	100
20	100.0	100.0	100.0	100.0	88.9	88.9	80	100	90.5
14.0	100.0	100.0	100.0	99.0	44.1	75.3	60	80	70.0
10.0	100.0	100.0	100.0	78.0	7.7	87.4	50	70	60.0
5.0	100.0	100.0	81.9	3.6	0.8	48.8	25	56	40.0
2.36	100.0	88.8	0.8	0.4	0.3	34.2	25	44	36.0
1.18	100.0	69.8	0.7	0.3	0.3	27.4	20	34	27.0
0.600	100.0	54.6	0.7	0.3	0.3	21.9	15	27	21.0
0.300	94.6	33.7	0.6	0.3	0.2	14.3	10	20	15.0
0.150	91.5	17.1	0.6	0.2	0.2	8.1	5	13	9.0
0.075	75.2	7.8	0.5	0.2	0.1	4.3	2	6	4.0



Group Number	Materials Technician/CSCEC	Materials Engineer (CSCEC)
Sign	<i>[Signature]</i>	<i>[Signature]</i>
Date	19-1-2025	20/1/2025





CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD

Block 36, Plot 95, 11&711, Kitebi Kibaga Kampala, Suruma II Road, Nyanama Zone
 Metindwe, Labaga Division
 P.O.Box 19285 KAMPALA
 Tel: +256(0)755846031/708898888
 Email: cscec@cscec.com

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 051 -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 21/01/2025				





CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
Block 36, Plot 95, 11&711, Kitebi Kibuga Kampala, Sesuna II Road, Nyanama Zone
Mutundwa, Lubaga Division
P.O.Box 29288 KAMPALA
Tel: +256(0)785046031/708898888
Email: cscecjangbo@gmail.com

Summary of Bitumen Test Results

Bitumen type:	6% WEO	Supplier/ Origin: SB Company
Testing date:	18/Jan/25	Sample Date: 22/Dec/24
Penetration value	73.4	ASTM D 5
Softening(Ring & Ball)	45.5	ASTM D36/ AASHTO T 053
Density (g/cm3)	1.00	ASTM D70
Ductility(cm)	129	AASHTO T051-94
Remark		
Group Member	Lab Technician (CSCEC)	Materials Engineer (CSCEC)
Signature:	Sign 	Sign 
Date:	Date 18/01/25	Date 21/01/2025








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

Summary of Bitumen Test Results

Bitumen type:	4% WEO	Supplier/ Origin:	SB Company
Testing date:	18/Jan/25	Sample Date:	22/Dec/24
Penetration value	68.0		ASTM D 5
Softening(Ring & Ball)	48.4		ASTM D36/ AASHTO T 053
Density (g/cm3)	1.00		ASTM D70
Ductility(cm)	125		AASHTO T051-94
Remark			
Group Member	Lab Technician (CSCEC)	Materials Engineer (CSCEC)	
Signature:	Sign 	Sign 	
Date:	Date 18/Jan/25	Date 22/Dec/24	



			CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD Block 36, Plot 95, 11&711, Kitebi Kibuga Kampala, Ssuna II Road, Nyanama Zone Mutundwe, Lubaga Division P.O.Box 29285 KAMPALA Tel: +256(0)755046031/708898888 Email: cscecjangbo@gmail.com		
			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 	Sign 		
Date:		Date 18/01/25	Date 21/12/24		





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

Penetration Test for Bitumen Testing

Method ASTM D 5



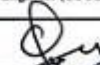
Bitumen type:	50/70	Supplier/ Origin: SB Company		
Testing date:	31/Dec/24	Sample Date: 22/Dec/24		
Measurement no.	1	2	3	Remarks
Penetrometer dial reading				
Initial reading	0.13	0.13	0.10	
Final reading	6.41	6.34	6.27	
Penetration value	62.8	62.1	61.7	
Average penetration value	62.2			

Remark:

Representatives

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



			CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD Block 36, Plot 95, 11&711, Kitebi Kibuga Kampala, Sasuna II Road, Nyanama Zone Mutundwe, Lubaga Division P.O.Box 29285 KAMPALA Tel: +254(0)755046031/708898888 Email: cscecjangbo@gmail.com		
Summary of Bitumen Test Results					
<i>Bitumen type:</i>		50/70(Neat)		<i>Supplier/ Origin:</i> SB Company	
<i>Testing date:</i>		31/Dec/24		<i>Sample Date:</i> 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	
<i>Remarks:</i>					
Representatives					
<i>Group Member</i>		<i>Lab Technician (cscec)</i>		<i>Materials Engineer (CSCEC)</i>	
<i>Sign</i>					
<i>Date:</i>		31/12/24		22/12/24	





CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
 Block 36, Plot 95, 11&711, Kitebi Kibuga Kampala, Ssuna II Road, Nyanama Zone
 Mutundwa, Lubaga Division
 P.O.Box 29285 KAMPALA
 Tel: +256(0)755046031/708898890
 Email: cscec@langbo@gmail.com

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)	2.166
---	-------

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 9/1/25	Date 12/22/24





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

Kinematic Viscosity Test

Testing Method ASTM D 2170-01

Ref. No.	N/A	Waste Diesel Engine Oil	WEO	
Type		Origin/Supplier	Workshop	
Testing date	9-Jan-2025	Sampling Date	22-12-24	
Sample No.	BULB 1	BULB 2	BULB 3	SPECIFICATION
Test Temperature °C	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	9/1/25	Date	22/12/24





CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
 Block 36, Plot 95, 11&711, Kitebi Kibuga Kampala, Sssuna II Road, Nyanema Zone
 Mutundwe, Lubaga Division
 P.O.Box 29285 KAMPALA
 Tel: +256(0)755046031/708896888
 Email: cscecjangbo@gmail.com

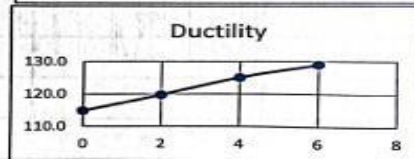
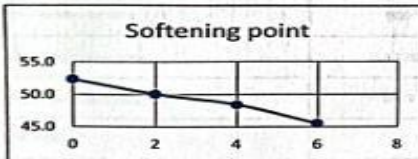
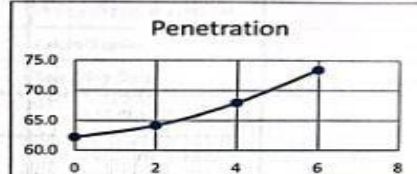
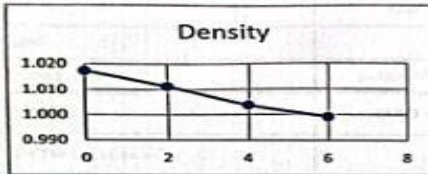
Kinematic Viscosity Test

Testing Method ASTM D 2170-01

Ref. No.	N/A	Waste Diesel Engine Oil	WEO	
Type		Origin/Supplier	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	0.09624	
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	9/1/25	Date	21/1/25



TEST	Relationship Btn Neat Bitumen and Modified Bitumen			
	0	2	4	6
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.





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

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	9.89	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

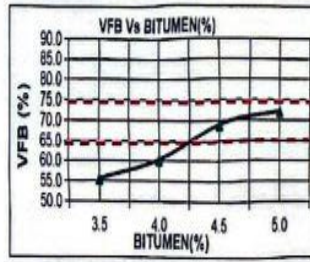
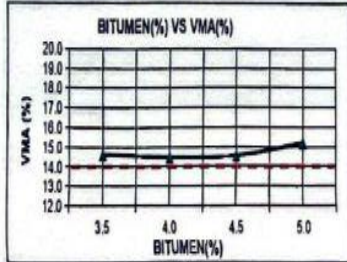
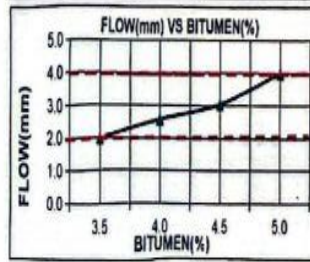
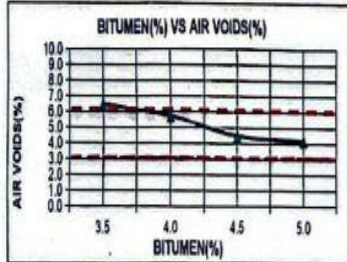
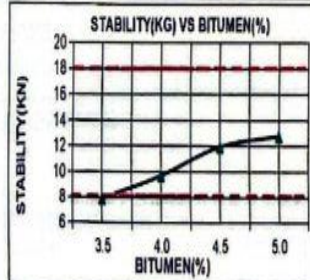
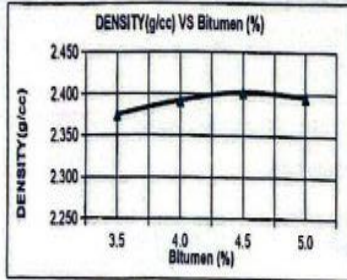


Scanned with



CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
 Block 36, Plot 96, 11&711, Kitebi Kibuga Kampala, Sasuna II Road, Nyanama Zone
 Mutundwa, Lubaga Division
 P.O.Box 29286 KAMPALA
 Tel: +256(0)766046031/70688888
 Email: cacecjangbo@gmail.com

MARSHALL PROPERTIES CURVES



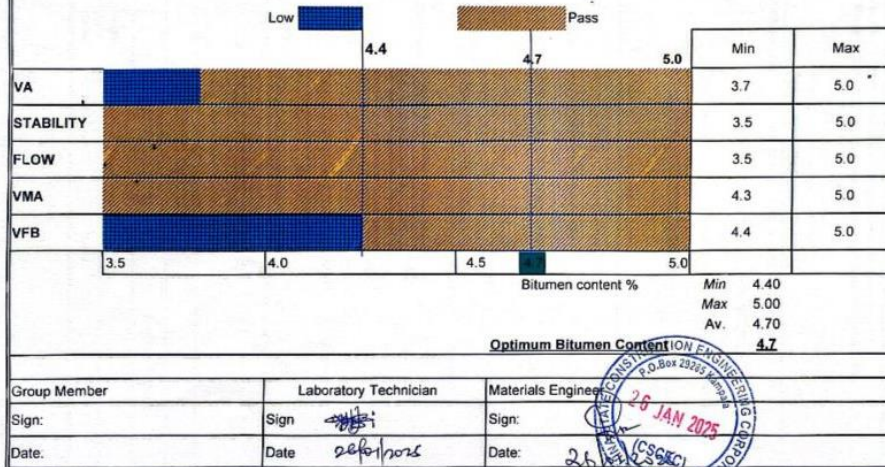
Group Member	Laboratory Technician	Materials Engineer
Sign	Sign	Sign:
Date	Date 26/01/2025	Date 26/01/2025





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

DETERMINING OBC BASED ON NARROW RANGE
 MS-2 chapter 05



Group Member	Laboratory Technician	Materials Engineer
Sign: _____	Sign: _____	Sign: _____
Date: _____	Date: 26/1/2025	Date: 26/1/2025



CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
Block 36, Plot 95, 11&711, Kitebi Kibuga Kampala, Sasuna II Road, Nyanama Zone
Mutundwe, Lubaga Division
P.O.Box 29285 KAMPALA
Tel: +256(0)755046031/708898890
Email: cscecjiangbo@gmail.com

ABSTRACT OF MARSHALL MIX DESIGN TEST VALUES

3.5%WEO & 50/70 Bitumen Content%	Density (g/cm ³)	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 over 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 adjustments.





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

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

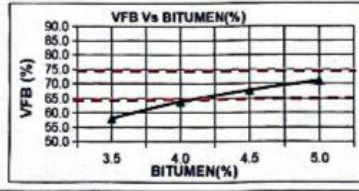
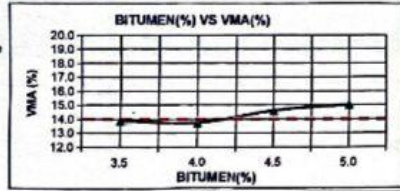
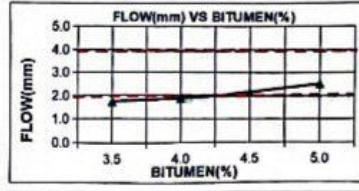
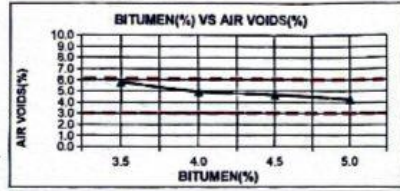
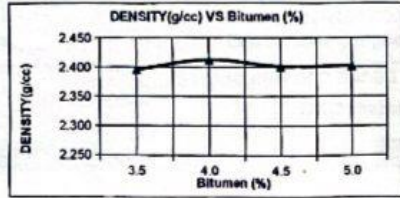
Road Name:	/					Sample Ref .	N/A	
Chainage / Location	LAB					Sampling Date:	23/Jan/2025	
Mixture Source	Lab Mix					Test Date:	26/Jan/2025	
Hot bit Propotions	Agg. Size	12/20mm	6/12mm	3/6mm	0/3mm	Filler	Bitumen Content OBC %	4.7
	%age	44	9	9	36	2		
Test Parameter		Unit	Test Method			Specifications		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:			Sign:				
Date:	Date: 26/01/2025			Date: 26/01/2025				





CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
 Block 36, Plot 96, 118711, Kitebi Kibuga Kampala, Sasuna II Road, Nyanama Zone
 Mutundwa, Lubaga Division
 P.O.Box 29285 KAMPALA
 Tel: +256(0)795046031/708890888
 Email: cscecjiangbo@gmail.com

MARSHALL PROPERTIES CURVES



Group Member	Laboratory Technician	Materials Engineer
Sign	Sign <i>[Signature]</i>	Sign: <i>[Signature]</i>
Date	Date <i>02/02/2025</i>	Date <i>02/24/25</i>





CHINA STATE CONSTRUCTION ENGINEERING CORPORATION LTD
 Block 36, Plot 95, 11&711, Kilebi Kibuga Kampala, Ssuna II Road, Nyanama Zone
 Mutundwa, Lubaga Division
 P.O. Box 29285 KAMPALA
 Tel: +256(0)755046031/708898868
 Email: cscecjiangbo@gmail.com

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

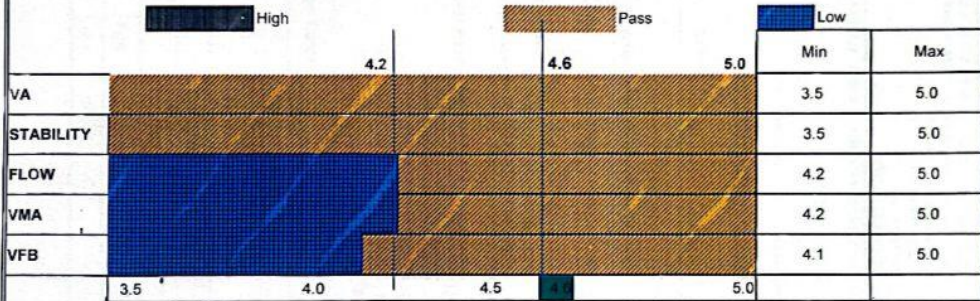
Road Name:	I					Sample Ref .	Modified Bitumen	
Chainage / Location	LAB					Sampling Date:	23/Jan/2025	
Mixture Source	Lab Mix					Test Date:	5/Feb/2025	
Hot bin Propotions	Agg. Size	12/20mm	6/12mm	3/6mm	0/3mm	Filler	Bitumen Content OBC %	4.6
	%age	44	9	9	36	2		
Test Parameter		Unit	Test Method			Specifications		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:	[Signature]				[Signature]			
Date:	05/02/2025				[Date]			





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

DETERMINING OBC BASED ON NARROW RANGE
 MS-2 chapter 05



Bitumen content %
 Min 4.20
 Max 5.00
 Optimum Bitumen Content 4.60

Group Member	Laboratory Technician	Materials Engineer
Sign:	Sign: <i>[Signature]</i>	Sign: <i>[Signature]</i>
Date:	Date: 28/02/2025	Date: 05 FEB 2025





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

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	15.98	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
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)755046031/708898890
Email: cscecjangbo@gmail.com

ABSTRACT OF MARSHALL MIX DESIGN TEST VALUES

Neat Bitumen Content%	Density (g/cm ³)	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 over 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 adjustments.

