ASSESSING THE USE OF CRUMB RUBBER AND KAOLINITE TO THE RESISTANCE OF ASPHALT TO DEFORMATION

ANTHONY MUSTAFA PITIA

S21B32/033

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

Flexible pavement performance is often reduced by rutting, fatigue and lack of durability especially under heavy traffic.

This study aimed to improve bitumen by modifying it with Crumb rubber (CR) and kaolinite clay to enhance resistance to fatigue cracking. Waste tires were used due to their high elasticity. CR was added to 60-70 pen grade bitumen in proportions of 5%, 10%, 15% and 20%. Tests showed that 5% CR gave the best balance of thermal, fatigue and moisture resistance. To improve storage stability, kaolinite was added in amounts of 1%, 1.5%, 2% and 2.5% with 2% showing the best results.

DECLARATION

I, **PITIA ANTHONY MUSTAFA**, hereby declare to the best of my knowledge and skills that this report is a result of my effort and has never been submitted to any higher institution of learning for the award of Bachelor of Science in Civil and Environmental Engineering.

Signature………………………….Date……………………………….

PITIA ANTHONY MUSTAFA

APPROVAL

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

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

Ms. AGUTI JOSEPHINE

Academic Supervisor

Department of Engineering and Environment

Uganda Christian University

DEDICATION

This report is fully dedicated to my parents, lecturers and mentors, whose guidance, patience and encouragement have shaped me into the person I am today. Your unwavering support has been instrumental in my academic journey and I am deeply grateful for your belief in my potential. This achievement is as much yours as it is mine.

Thank you for everything.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to **Ms. AGUTI JOSEPINE** my supervisor, for her invaluable guidance, encouragement and support throughout the completion of this report. Their expertise, feedback and patience have been instrumental in shaping the direction and quality of my work.

I would also like to extend my thanks to my lecturers, classmates and parents for their unwavering support, encouragement and understanding during this academic journey. Their belief in me has been a constant source of motivation.

Additionally, I am grateful to the different laboratories for providing resources and facilities that facilitated the completion of this report.

Finally, I acknowledge the contributions of all the authors and researchers whose work in this report been put to reference.

Thank you to everyone who has played a part in making this Project a reality.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AC-Asphalt Concrete

ACV–Aggregate Crushing Value

AIV- Aggregate Impact Value

CR- CRUMB RUBBER

CRMB-Crumb Rubber modified bitumen

ESALS-Equivalent Single Axle Load

GDOT-Georgia Department of Transport

HMA- Hot Mix Asphalt

Mm-Millimeters

MoWT-Ministry of Works and Transport

Pen-Penetration

PMB-Polymer Modified Bitumen

TFV-Ten Percent Fines

TS-Indirect Tensile Strength

CHAPTER 1: INTRODUCTION

1.1 Background of the research

In Uganda, asphalt pavements are more commonly used due to their smooth and comfortable surface road (Mahajan, 2020). However, they often fail due to traffic loads and environmental factors leading to cracks, potholes and other surface defects. Damage can be begin during or soon after construction as seen at Km 51+900 to 52+100, Nabusanke on the Kampala Masaka Highway (Mugume, 2020).

Crumb rubber from waste tires can improve bitumen's flexibility and performance (Appiah et al., 2017). But challenges like phase separation occur due to incompatibility and temperature changes (Zhu, 2016).

Studies in South Africa by Marais (2017) show that additives and proper mixing at high temperatures can improve storage stability and performance. Kaolinite clay, a hydrophobic minerals help slow separation and improves compatibility of modified asphalt (Biro et al., 2021).

1.2 Problem Statement

Fatigue cracking is a common type of distress seen along the Kampala–Masaka Highway at Km 51+950 to 52+100 in Nabusanke (TRL, 2019). This is mainly caused by repeated loading from heavy trucks which creates tension at the bottom of the asphalt layer. A reported by Rolt et al. (2019) submitted to UNRA showed that an axle load survey at Buwama recorded tire pressures of 900kPa which is much higher than the design range of 550 to 700kPa and a MESA of 49 exceeding the design value of 44.

These high tire pressures and axle loads cause serious pavement distress. Overtime, cracks form and spread and environmental factors like temperature changes and moisture make the situation worse.

As the cracks grow, rain water enters the pavement, weakening the bond between bitumen and aggregates. This leads to potholes, poor road performance, traffic jams and even accidents (Costa,2022).

A study by Gou J. (2081) investigated the improvement of storage stability of modified asphalt with nano clay. It was found that incorporation of nano clay enhances storage stability by preventing phase separation.Another study by Costa (2022) investigated the impact of heavy traffic and environmental factors on asphalt fatigue. The study recommended the use of modified bitumen and improved pavement design to withstand higher loads and temperature changes. The purpose of this study is to modify bitumen with Crumb Rubber and Kaolinite clay to improve asphalt's resistance to deformation.

1.3 Objectives of the study

1.3.1 Main objective

To assess the use of Crumb rubber and Kaolinite clay to the deformation resistance of asphalt pavements.

1.3.2 Specific objectives

1. To determine the properties of bitumen, aggregates, crumb rubber and neat asphalt.

2. To determine the properties of Crumb Rubber modified bitumen and obtain the optimum rubber content.
3. To determine the storage stability of the CR-Kaolinite modified bitumen and obtain the optimum Kaolinite content.
4. To compare the indirect tensile strength of the modified and unmodified asphalt.

1.4 Research questions

1. What are the properties of bitumen, aggregates, crumb rubber and neat asphalt?
2. What are the properties of CR modified bitumen?
3. What is the storage stability of CR-Kaolinite modified bitumen?
4. What is the indirect tensile strength of the modified and unmodified asphalt?

1.5 Scope of research

1.5.1 Content scope

This study focuses on evaluating the effectiveness of crumb rubber and kaolinite clay in enhancing asphalt's resistance to deformation. The research explores how the combination of these modifiers can improve the mechanical properties and performance of bitumen under load and environmental stress.

1.5.2 Geographical scope

The research will be conducted along a section of the Kampala–Masaka Highway, a major roadway in Central Uganda connecting Kampala, the capital city, to Masaka in the southwestern region. The highway stretches approximately 127 kilometers, starting in Kibuye (Makindye Division) and passing through key towns including Kyengera, Nsangi, Mpigi, Buwama, Kayabwe, and Lukaya, before reaching Masaka. The specific area of investigation will be at Km 51+900 to 52+100, Nabusanke.

1.5.3 Time scope

This project will be carried out over a duration of eight months, beginning in September 2024 and concluding in April 2025.

1.6 Justification

Blending crumb rubber with hot bitumen significantly enhances binder properties, especially in terms of viscosity and softening point. This is largely due to the swelling effect of rubber particles, which absorb maltenes from bitumen, increasing their volume by up to three to five times. The resulting binder contains a higher concentration of asphaltenes, leading to increased viscosity. In addition to improving high-temperature performance, crumb rubber also reduces creep stiffness, thereby enhancing low-temperature crack resistance and decreasing the aging index. This makes the pavement more flexible and better able to withstand repeated heavy loading (Zhang, 2019).

Kaolinite clay, with its large surface area, serves to mitigate phase separation by reducing oxygen intrusion and improving the compatibility between the polymer and bitumen, leading to a more homogeneous blend (Favakeh, 2022).

1.7 Significance of the study

The integration of crumb rubber and kaolinite clay into hot mix asphalt (HMA) presents numerous benefits in terms of both performance and sustainability. Crumb rubber improves HMA durability by increasing resistance to moisture damage, rutting, and fatigue cracking, which leads to extended pavement life and lower maintenance costs (Li et al., 2015). Meanwhile, kaolinite clay, a naturally occurring mineral, enhances HMA performance by increasing fatigue resistance and overall strength (Silva et al., 2018). The synergistic use of these two modifiers results in a stiffer, stronger, and more crack-resistant asphalt mix with improved workability (Yin et al., 2019).

CHAPTER 2: LITERATURE REVIEW

2.1 Pavement

A highway pavement is an engineered structure composed of multiple layers of selected materials laid over the natural subgrade. Its primary function is to transfer traffic-induced loads down to the underlying soil in a safe and efficient manner.

2.1.1 Types of pavements

Highway pavements are generally classified into two main categories: flexible pavements and rigid pavements.

a) Rigid Pavements

Rigid pavements are constructed using cement concrete or reinforced concrete slabs. Compared to flexible pavement, rigid pavements are placed either directly on the prepared subgrade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and subbase, this layer can be called as base or subbase course (Tom and Rao,2021). The concrete slab ranges in thickness from 6 to 14 inches (152.4 -355.6mm).

The core design principle of rigid pavements is to create a high-strength concrete slab that can bear and distribute vehicular loads with minimal deformation. Due to their high stiffness and elastic modulus, rigid pavements spread applied loads over a wider area of the subgrade enhancing overall performance and extending service life (Zzigwa,2024).

b) **Asphalt pavement**

Asphalt pavements get their name because they are designed to deflect or flex under traffic loads rather than remain rigid. These pavements typically consist of multiple layers, with each one distributing the load it receives to the layer below it. This layered system helps spread out stress from vehicle efficiently (Mathakiga,2016).

A standard asphalt pavement is made up of the surface course, base course,subbase and subgrade as illustrated in figure 1 (Hoffman,2008). The surface layer usually a hot mix asphalt is the stiffest and contributes most of the pavement's strength. As you go deeper into the pavement, the layers tend to be less rigid but equally important especially for drainage, frost resistance and overall structural support. The general rule in asphalt pavement design is that the quality of materials gradually reduces with depth.

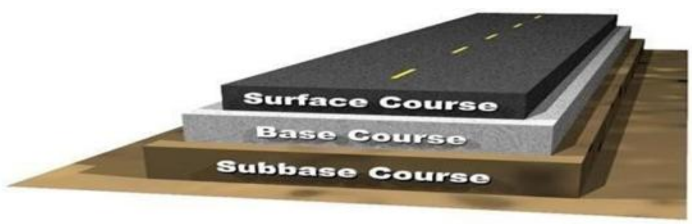


Figure 2:1 Pavement structure *(Hoffman,2008)*

2.1.2 Elements of asphalt pavement

a) Surface course

This is the top layer that directly interacts with vehicle traffic. It's made of high quality materials and is designed to provide friction, smoothness and noise reduction. It also prevents surface water from penetrating into the lower layers. According to Hoffman (2008), Surface course is divided into:

- Wearing Course: The very top layer that endures most of the traffic wear.
- Binder Course: It is located just below the wearing course, its main job is to distribute load across the pavement structure.

b) Base course

This layer lies directly under the surface course and supports it by spreading loads further and assisting in drainage. It should have a CBR (unsoaked) ≥ 80%, Resilient Modulus 500-800Mpa, compacted at 90% MDD and with a plasticity index ≤ 6.

c) Subbase Course

Found below the base course, this layer typically uses lower quality material than the base but still offers better performance than the natural soil. The performance requirements of the subbase layer are; CBR (unsoaked) ≥ 30-40%, Resilient Modulus 150-300Mpa, compacted ≥ 95% MDD and with a plasticity index ≤ 10.

d) Subgrade

The subgrade is the natural grounds or soil that supports the entire pavement structure. Its strength is crucial to the long term performance of the pavement. It has a minimum CBR ≥ 8%, PI < 12, M_R 50-100Mpa and compacted ≥ 95% MDD.

2.1.3 Design and functional requirements of asphalt pavements

i) Functional requirements of asphalt pavements

Asphalt concrete in surface layers must be durable, waterproof and resistant to deformation, fatigue and aging (Handbook of Highway Engineering, 2024). Key properties required in asphalt mixes for surfacing include:

- Resistance to plastic deformation and cracking to handle traffic loading.

- Workability to ensure the mix can be laid and compacted properly without segregation.
- Air voids should be sufficient to prevent bleeding and deformation after compaction.
- Adequate binder content to with the right type and grading of aggregates to form a durable, near impermeable surface.

ii) **Asphalt pavement design process**

The design process generally follows five key steps:

a) Estimating how much traffic the road will carry over its lifetime

To design a road properly, engineers must first figure out how much traffic it will handle each day—specifically, the number of Equivalent Standard Axles (ESAs) using one lane when the road first opens. This number is then projected over the road's intended lifespan to estimate total traffic loading. To get this data, traffic counts are done to identify vehicle types and how often they pass, along with weighing vehicles at weighbridges to determine axle loads.

This step helps prevent underestimating loads, which can cause the road to fail early, or overestimating them, which can make the road more expensive than necessary.

b) Assessing the strength of the soil beneath the road (subgrade)

After traffic loading, the next crucial factor is how strong the soil is where the road will be built. This strength affects how the pavement layers will be structured. Engineers use tests like the California Bearing Ratio (CBR) to classify soil strength (from S1 to S6), especially in wet conditions. If the subgrade is weak, a thicker base or subbase is needed, or the soil may need to be stabilized.

Strong soil reduces construction costs, making it an advantage in the design.

c) Understanding the local climate

Here, the goal is to study the area's rainfall, temperature changes, and groundwater levels. This helps engineers predict how bitumen will behave under these conditions. For example, moisture can weaken the subgrade, so wet climates need better drainage. In hot areas, harder bitumen is used to prevent rutting.

Knowing the climate ensures the road materials will perform well over time.

d) Considering practical factors that may affect design choices

Things like whether local materials are available, how difficult the terrain is, and whether construction equipment and labor are accessible all impact the final design. These real-world conditions help decide what materials and methods are most practical and cost-effective for that specific road project.

2.1.4 Asphalt pavement failures

a) Rutting

Ruts are depressions in the wheel paths caused by permanent deformation under traffic loading.

Cause: Poor compaction, inadequate pavement thickness and improperly designed

Figure 2:2 Rutting on an asphalt pavement (Handbook of Highway Engineering, 2024)

Solutions: Reduce vertical pressure on the surface and improve on the drainage. Also use a proper mix design to obtain a marshall flow of 2 to 4mm and stability of 8-18KN.

b) **Potholes**

These are holes formed in the pavement due to poorly graded aggregates or insufficient binder during mix design. Bitumen may strip from the aggregates especially in thin pavement layer.

Figure 2:3 Potholes on as asphalt pavement (Handbook of Highway Engineering, 2024)

c) **Alligator Cracks**

These cracks form a pattern similar to an alligator’s skin and a clear sign of structural failure.

Cause: weak subgarde or subbase, poor compaction.

Mitigation: Use appropriate subgrade/subbase materialswith a required CBR values. Also ensure layers are compacted to maximum dry density. This can be confirmed by using sand cone replacement to confirm proper compaction.

2.2 Materials used to make asphalt

2.2.1 Bitumen

Bitumen is one of the oldest and most widely used engineering materials primarily serving as a binder for mineral aggregates in pavement construction (Coplantz,1993). Although it constitutes only 5% by weight in asphalt concrete, its characteristics significantly influence both the construction process and the long term performance of flexible pavements.

Chemically,bitumen can be sourced from natural deposits or from distillation of crude oil. At room temperature, bitumen appears almost solid but becomes soluble in solvents like toluene (Lesueur, D, 2009). Commercial production typically involves destructive distillation, starting with the atmospheric distillation of crude oil to separate lighter components. The remaining residue is then refined under vacuum conditions at elevated temperatures (Speight, J, 1999; Topal, 2010). The internal structure of bitumen is heavily influenced by the dispersion of asphaltenes within the oily matrix. Surrounding each asphaltene particle is a layer of hydrocarbons, stabilized by resins through polar interactions, which helps maintain the material's stability and consistency.

i. Chemical composition of bitumen

Bitumen is primarily made up of hydrocarbons including aliphatic, aromatic and naphthenic compounds along with their derivatives (Porto, 2019). The major elements in bitumen are carbon about 90% and hydrogen around 10% (Anderson, 1994). In addition, it contains small amounts of other elements such as sulfur, oxygen and nitrogen as well as trace levels of transition metals like vanadium, nickel and manganese (Lesueur, D, 2009).

A key component in bitumen is asphaltenes. When mixed with a solvent, these molecules tend to cluster together forming negatively charged micelles. These micelles are responsible for improving the adhesion of bitumen to mineral aggregates. Asphaltenes also pay a major role in determining the surface activity of the bitumen (Speight, 2020).

The internal structure and many physical properties of bitumen are influenced by how asphaltenes are dispersed within the oily matrix. Each asphaltene particle is surrounded by a layer of hydrocarbons. Resins, through polar interactions, help to stabilize these particles and keep them evenly distributed in the mixture.

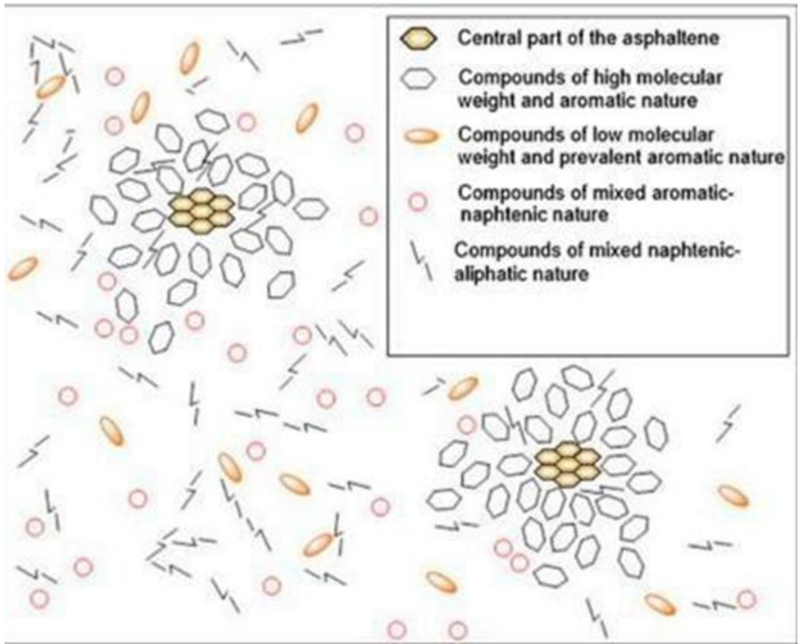


Figure 2:4 Visual representation of the colloidal structure of asphalt

(Speight, 2020)

ii. Grades of Bitumen

A paving grade refers to a type of bitumen that has the appropriate viscosity characteristics for the specific HMA application as well as the climate and traffic loads where it will be used A paving grade is a grade of bitumen with viscosity characteristics appropriate for the type of HMA (Transport Research Laboratory & Development, 2002). Bitumen is typically classified into two main grading systems:

a) **Viscosity grades**

Viscosity measures how fluid or resistant to flow a bitumen material is. This type of grading is based on scientific viscosity test conducted at 60 ^{o}C, which closely reflects the highest pavement temperatures during summer. The results are measured in poise, a unit of dynamic viscosity. There are 2 approaches to viscosity grading: AC grading which is done on the original bitumen as it is supplied and AR grading which is carried out on aged binder residue to simulate performance over time (Raha,2014).

b) **Penetration grades**

The penetration test is used to assess the hardness of bitumen. The basic idea is that softer bitumen allows a standard needle to penetrate deeper while harder bitumen resists penetration. During the test, the depth the needle penetrates measured in 10^{th} of mm under specific conditions of temperature, load and time reflects the bitumen's consistency.

One of the most widely used penetration grades is bitumen 60/70, commonly applied in various regions. This penetration value is closely linked to how the asphalt binder performs in different climates. Softer binders(higher penetration values) are ideal for colder climates while harder binders(lower pen values) perform better in warmer climates(Raha,2014).

In this study, bitumen 60/70 was selected due to its thermoplastic behavior. It softens when heated and hardens when cooled. This makes it suitable for hot climates and areas with heavy traffic where durability is essential.

To reduce distress in asphalt pavement, it's important to enhance the performance properties of the bituminous layers. One effective approach is to improve existing asphalt by modifying the bitumen with various additives. This not only boosts the binder's performance but also extends pavement life and reduces vehicle operating costs (Shaikh et,al.,2017).

Table 2:1 specifications for bitumen property (MoWT,2010)

Bitumen property	Specification
Penetration at 25 C (mm)	60/70
Softening point (^{o}C)	49/56
Ductility at 25 C (mm)	Min 100
Specific Gravity (g/cm^3)	1.01/1.06
Viscosity (mm^2/sec)	Min 295

2.2.2 Aggregates

Varying types and sizes of aggregates can be used in an asphalt mixture. That is coarse aggregates and fine aggregate (Transport Research Laboratory & Development, 2002). The aim of using varying aggregate size is to increase the interlocking mechanism of interlocking is the asphalt mixture. Aggregate usually contributes to 90% or more by bitumen mixtures' weight. They have three aims when used in bituminous surfaces;

- They distribute the load from the surface to bottom of the base course. This is achieved by the mechanical interlocking of the aggregate particles.
- They resist the abrasive action of the traffic. Laying a wavering surface binder alone can wear out due the effects of abrasion from tires.
- They provide a non-skid surface. A portion of the aggregate extends slightly above the normal surface of the wearing mat, thereby providing a roughened surface for the tires to grip. (Asphalt Institute, 2014).

a) Tests done on aggregates to determine their mechanical properties

They include; Aggregate Crushing Value (ACV), Aggregate ImpactValue (AIV), Ten Percent Fines Value (TFV), Sieve Analysis, Flakiness Index with the required standards and specifications according to the (MoWT 2010).

Table 2:2 Specification for properties of aggregates (MoWT,2010)

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

2.2.3 Filler Materials in asphalt mixtures

Fillers are finely ground mineral powders added to asphalt mixes to improve certain properties including workability, durability and stability. The selection of a filler often depends on project requirements and the availability of local materials. A well chosen filler enhances the performance of the mix and contributes to the overall quality of the pavement.

In bituminous mixtures, fillers serve two main purposes:

- Filling voids between larger aggregates to increase strength and impermeability.
- Enhancing the mechanical and physical performance of the asphalt mix.

a) **Effects of fillers in Bituminous mixes**

- Improved Rutting Resistance

Fillers like limestone or hydrated lime can enhance the asphalt's resistance to rutting, one of the most common pavement failures.

- Moisture Susceptibility Reduction

Certain fillers can decrease the moisture susceptibility of asphalt mixes, improving their durability in wet conditions.

- Mix Workability

Fillers can enhance mix workability, making it easier for construction crews to achieve proper compaction during placement.

b) **COMMON FILLERS**

- Limestone Filler

Limestone filler is a widely used material in asphalt mix design. It is known for its ability to enhance rutting resistance and moisture susceptibility.

- Portland cement

Portland cement is sometimes employed as filler to improve asphalt mix properties.

- Hydrated Lime

Hydrated lime is utilized as a filler to enhance asphalt mix durability and workability.

2.3 Crumb rubber

The increasing number of vehicles globally has led to the generation of large quantities of waste tires. With limited disposal space and growing environmental concerns, recycling waste tires has become a necessary alternative. One of the effective recycling methods is converting waste tires into crumb rubber which can then be used as a modifier in bitumen for asphalt pavement applications.

2.3.1 Properties of Crumb Rubber

During Crumb rubber is produced by shredding scrap tires, resulting in rubber particle that are free from fibers and steel. These particles come in various sizes and shapes and their gradation is typically based on the mesh size of the screen or sieve they pass through during processing.

There are two main processes for producing crumb rubber:

i) Ambient grinding

This method operates at room temperature and can be further divided into:

- Granulation; Tires are cut into smaller pieces using granulators.
- Cracker mills; Rubber is crushed and reduced in size by rolling between heavy rotating rollers.

ii) Cryogenic grinding

This technique involves freezing the rubber using liquid nitrogen then shattering it into finer particles.

2.3.2 Rubber composition in tires

Passenger car tires are primarily composed of styrene butadiene rubber, a synthetic rubber derived from styrene and butadiene while truck tires generally contain a higher proportion of natural rubber which is derived from the hevea brasiliensis tree and consists mainly of polyisoprene (Han, L,2016).

The type of rubber used can either be natural or synthetic. This can significantly influence the interaction between the rubber and bitumen. For instance:

Natural rubber has excellent elasticity, durability and fatigue resistance making it suitable for heavy duty applications while SBR offers a good process ability and temperature performance which is more common in lighter traffic pavements.

TABLE 4: Chemical composition of various types of tires (adopted from [10]).

Chemical composition	Passenger/light truck tread rubber (%)	Heavy truck tread rubber (%)	Whole tire rubber (%)	Range (%)
Acetone extract	17.2	11.4	15.1	5.8
Ash	4.8	5.1	5.0	0.29
Carbon black	32.7	33.2	32.0	1.2
Rubber hydrocarbon	42.9	50.2	47.9	7.3

Figure 2:5 Chemical composition of various types of tires

(Han, L,2016)

2.3.3 Performance of Crumb Rubber in Bitumen

The performance of CR in bituminous mixtures depends on several factors such as the type and amount of bitumen, mixing duration and temperature, the size and amount of rubber used, and the mixing method—whether wet or dry (Huang et al., 2007; Airey et al., 2003; Jeong et al., 2010). Liu et al. (2009) ranked rubber content as the most significant factor, followed by the type and particle size of the rubber.

2.4 Bitumen Modification

Bitumen in its pure form is not suitable for modern pavement demands due to its susceptibility to various types of failure during service. These limitations have driven significant interest in the field of bitumen modification to enhance its performance characteristics under different traffic and climatic conditions (Walter H. F., 1993).

2.4.1 Types of Bitumen Modification

Two major types of bitumen modification have been explored:

i) **Chemical Modification**

This involves the use of chemicals such as acids and metallic oxides to alter the chemical structure of bitumen. However, due to the complex molecular structure of bitumen, chemical modification has not yet been commercialized extensively.

ii) **Physical Modification**

This is more commonly practiced and involves blending polymeric materials with bitumen. The most promising modifiers include: Thermoplastics, thermoplastic elastomers and rubbers.

Among these, rubber-based modifiers are particularly attractive due to their lower cost and proven performance enhancements. Common rubber types used include: Polybutadiene Rubber (PBR), Styrene-Butadiene Rubber (SBR) and Ground Tire Rubber (GTR).

Although thermoplastic elastomers like styrene-butadiene-styrene (SBS) and plastomers such as ethylene-vinyl acetate (EVA) are effective, rubbers are often preferred in practice due to economic considerations (Youseft A., 2001).

2.4.2 Need for Modified Bitumen in Pavements

With the increasing axle loads, tire pressures, and traffic volumes, conventional bitumen mixtures often fail to deliver the required durability. As a result, polymer-modified bitumen has become increasingly popular.

According to Islam (2014), several classes of modified binders have been adopted to address pavement distress problems. Vasudevan et al. (2012) further emphasized that bitumen modification aims to:

- Increase stiffness at high temperatures to reduce rutting
- Improve fatigue resistance under repeated traffic loading
- Enhance adhesion between binder and aggregates, reducing moisture damage

2.5 Interaction Between Bitumen and Crumb Rubber

When crumb rubber (CR) is mixed with bitumen, a physical interaction takes place. The CR absorbs some of the lighter aromatic components in the bitumen, causing the rubber particles to swell. This swelling leads to changes in the structure of the rubberised binder. The modified binder performs better than the original (unmodified) bitumen due to these changes. Researchers like Airey et al. (2003) and Bahia & Davies (1995) observed that this process results in increased viscosity and enhanced physical and rheological behavior, which contributes to the pavement's resistance to rutting (Huang et al., 2007). The swelling restricts the movement of rubber particles within the bitumen matrix, minimizing the free space between them, which is key to improved performance (Abdelrahman & Carpenter, 1999).

2.5.1 Factors that influence performance of Crumb rubber in bitumen

a) Rubber Particle Size (Gradation)

Crumb rubber is usually categorized based on particle size: coarse (6.3–9.5 mm), medium (2 mm–600 µm), fine (425–180 µm), and very fine (100–500 mesh) (Sunthonpagasit, 2004). Very fine particles, when subjected to high shear mixing, tend to remain suspended and do not settle, allowing for shorter mixing times and lower temperatures, which helps resist ageing (Billiter, 1997). Finer rubber particles swell more quickly due to their larger surface area, increasing viscosity but also speeding up depolymerisation during heating. The extent of swelling is also influenced by the type of bitumen and the characteristics of the rubber (Airey et al., 2003).

b) Rubber Grinding Method

The production method also affects performance. Crumb rubber made using the cryogenic process appears smooth and angular, while the ambient method produces rubber with a rougher, more porous surface (Shen, 2005). The ambient process results in a higher surface area, which promotes better interaction with the binder and improved performance overall (Cong, 2013). Binders modified with ambient rubber typically have higher viscosity and elasticity, offering better rutting resistance (Thodesen).

c) Mixing Methods

There are two main approaches for adding rubber to bitumen. The first method dissolves the rubber into the binder, while the second substitutes part of the fine aggregate with ground rubber, which doesn't fully blend with the binder (Huang et al., 2007). According to Kim, the wet process outperforms the dry method in both strength and deformation resistance, especially at high temperatures.

d) Blending Conditions

Blending conditions, especially temperature and time, play a crucial role in determining the consistency of the modified binder. Xiao et al. (2006) found that blending the materials for 45, 60, or 90 minutes did not significantly alter binder properties, although changes tended to stabilize between 60 and 90 minutes.

e) Rubber Content

Research by Lee et al. (2008) indicated that increasing crumb rubber content raises the binder's viscosity at 135°C and improves rutting resistance. However, it also reduces binder resilience. Becker et al. (2001) noted that more rubber results in higher viscosity and softening points, while penetration decreases—meaning the binder becomes stiffer.

f) Neat Bitumen Characteristics

The original bitumen properties also influence the performance of CRMB. Softer bitumen, with a higher proportion of light fractions, leads to greater rubber swelling, enhancing the binder's behavior in both high and low temperatures compared to harder bitumen (Han et al., 2016).

2.6 Physical and Rheological Properties of CRMB

2.6.1 Penetration

Penetration measures how soft or hard the bitumen is. When crumb rubber is added, this value decreases, showing that the binder becomes stiffer and more viscous. Mahrez (1999) observed lower penetration values in rubberised binders both before and after aging, especially with increased rubber content.

2.6.2 Elastic Recovery

Elastic recovery shows how well a binder stretches and returns to its original shape. It reflects resistance to permanent deformation. According to Jensen and Abdelrahman (2006), this property is vital for assessing rutting and fatigue resistance. Rubber-modified binders have significantly better elastic recovery than unmodified ones (Oliver, 1981; Mashaan et al., 2011).

2.6.3 Ductility

Ductility describes how far a binder can stretch before breaking. Finer rubber particles enhance ductility, allowing for more elongation. Mashaan et al. (2011) found that ductility and toughness increase with rubber content. Jensen and Abdelrahman (2006) also noted that both blending time and temperature affect these properties, with the best results observed at 240°C after two hours.

2.6.4 Viscosity and Softening Point

Viscosity refers to how resistant the binder is to flow, while the softening point is the temperature at which the binder begins to soften. Adding crumb rubber increases both. Higher viscosity can make mixing and compaction harder but improves overall performance (Mahrez, 1999; Mashaan et al., 2011).

2.7 Challenges in Polymer Modification

While CRMB enhances performance, it has a couple of drawbacks. First, the high viscosity of rubberised binders requires higher mixing and compaction temperatures, which drives up energy use (Wang, 2018). Second, CRMB suffers from storage instability at high temperatures (140–180°C), a problem that's even worse than in other polymer-modified binders (Polacco, 2015). The issue arises due to differences in density, structure, and chemical composition between the bitumen and rubber (Zhu, 2015).

Poor storage stability affects binder quality, complicates handling, and limits pipeline transport, which can impact pavement durability. Therefore, it's essential to understand how factors like rubber content and additives influence stability. Two main solutions are used: adding chemical agents to improve bonding or treating the surface of the rubber itself (Sienkiewicz, 2017).

2.7.1 Measuring Storage Stability of CRMB

To evaluate how stable CRMB is, several methods are used. Microscopy—especially fluorescence microscopy—can visualize the phase separation of rubber and bitumen by highlighting their response to UV light (Abdelrahman et al., 2014). However, this method isn't ideal for CRMB due to the large particle size.

Fourier Transform Infrared Spectroscopy (FTIR) helps detect changes in the polymer content by analyzing specific chemical bonds, but it often produces inconsistent results (Liu et al., 2013; Kuang et al., 2019).

The most common practical test is the cigar tube method. This simulates field conditions without stirring, allowing researchers to test samples from different parts of the tube to evaluate how well the rubber stays mixed with the bitumen.

2.7.2 Addressing Storage Instability with Nanoclay (Kaolinite)

The tendency of modified asphalt to separate into different phases during storage can be explained using Stoke's Law, which governs the settling velocity of particles:

$$v_t = \frac{2a^2 \Delta \rho g}{9\eta}$$

Where:

Vt is the velocity at which particles settle,

α is the radius of the dispersed particles,

Δρ is the difference in density between the particle and the medium,

g is the acceleration due to gravity, and

η is the dynamic viscosity of the liquid.

In the case of modified asphalt, crumb rubber (CRM) tends to sink due to its higher density compared to the base asphalt, whereas lighter polymers like SBR (Styrene-Butadiene Rubber) and SBS (Styrene-Butadiene-Styrene) tend to rise to the top. This phase separation during storage leads to uneven distribution of components, resulting in significant differences in both composition and performance between the top and bottom layers of the stored binder.

Earlier attempts to mitigate this issue have included adjusting the asphalt density using bio-modifiers (Fini, 2019) or chemically activating the crumb rubber (Cheng, 2011). However, these strategies have only provided limited success.

A more promising approach explored in this study involves adding nanoclay to the polymer-modified asphalt. Nanoclay helps reduce phase separation by slowing down the movement of insoluble polymer additives within the binder (Yu, 2015). By lowering the migration rate, the additives remain more uniformly distributed during storage.

Nanoclay, a naturally occurring mineral, includes forms such as kaolinite (KC), vermiculite (VMT), and montmorillonite (MMT). These clays have a 2:1 layered structure—two silica tetrahedral layers encasing an alumina octahedral sheet. Previous research shows that nanoclays significantly enhance the rheological (flow) properties of asphalt binders.

For instance, Vargas et al. (2017) observed that organo-nanocomposite asphalt forms an intercalated structure, as confirmed by X-ray diffraction (XRD) and transmission electron microscopy (TEM). This means that the polymer chains in the binder can insert themselves into the clay layers, improving the overall performance. Leng et al. (2019) found that asphalt modified with SBS and clay exhibited good storage stability and showed better resistance to aging by reducing both bitumen oxidation and SBS degradation.

Galooyak et al. (2010) also confirmed that nanoclays enhance the storage stability of SBS-modified asphalt, based on their analysis of binder morphology. Because of these benefits, nanoclay has gained attention in the asphalt industry as a reliable additive to improve storage stability in polymer-modified asphalts (PMAs).

It’s important to note that complete dissolution of polymers in the bitumen is not ideal. When this happens, the asphalt can break down the polymer’s structure, preventing the binder from fully benefiting from the polymer’s mechanical properties.

CHAPTER 3: METHODOLOGY

3.1 Research design

This was a practical study type along the Kampala-Masaka highway aimed at accessing cracks and thus finding a sustainable and workable solution to the existing problem by modifying bitumen using Crumb Rubber and Kaolinite clay. There were three data collection methods used in this research design. They include;primary, secondary and data collection methods.

3.2 Primary data collection method

3.2.1 Material collection and preparation

14/20 mm basalt aggregates and 60/70 PEN grade bitumen were sourced from Stirling Engineering Ltd in Mbalala because they are the same materials used during the construction of the Kampala-Masaka highway project. 60/70 pen grade bitumen was used because Uganda is in the tropical climate region.

Crumb rubber was purchased from City Tyres shredding unit, 6th street Industrial Area. Several operations such as milling, shredding and magnetic iron separation were done to obtain the crumbs. Kaolinite clay was purchased from Kabal Chemical Suppliers LTD in Banda.

3.2.2 Testing for properties of Bitumen

I. Penetration Test at 25 ^{o}C for 5 seconds, AASHTO T49

This aimed at measuring the hardness or softness of a bitumenmaterial through measuring in tenths of a millimeter, which a standard needle can penetrate vertically into a sample under a given set of conditions of temperature 25 ^{o}C, load 100g and time 5 sec. For instance, if the needle penetrates 60mm within 5 sec, then it is 60 and is designated as 60 penetration. The penetration value is the length of penetration the needle can reach in 1/10 mm increments.

Higher penetration values indicate softer or more fluid bitumen, while lower penetration values indicate harder or more viscous bitumen. The Standard Test method for Penetration is the ASTM D 5-86 Test. For 60/70 pen, the penetration value at 25^{o}C should lie between 60 and70 mm.

II. Softening Point Test AASHTO T53 using a Ring and Ball test

This is the temperature at which bitumen binders begin to flow. The softening point test is done to measure the viscosity of the bitumen thus will enable predict the temperature necessary to obtain the fluidity required in the mixture. It indicates the tendency of the material to flow at high temperatures that are experienced during operation. The temperature at which the ball touches the bottom of the container is recorded as the softening point. The softening point of bitumen helps determine the temperature range over which the material remains in a sufficiently soft and flexible state to resist deformation under traffic loads. ASTM D 36-70 is the Standard of Softening Point Test. The softening point for 60-70 PEN bitumen should lie between 49 and 56 degrees Celsius.

III. Specific Gravity Test

To determine the mass per unit volume of the bituminous material, the specific gravity test is conducted. This was done by weighing a sample of a bitumen in a calibrated pycnometer after initially measuring for its mass and volume. Temperature, type of bitumen, compaction and moisture content are some of the factors that can affect density of the bitumen. After being tempered to 25 °C and filled with distilled water, the pycnometer was weighed. The relative density and material density were computed using this data. ASTM D70-97 is the Standard of Bituminous Binder Density. The specific gravity at 25 degrees should lie between 1.01 and 1.06 kg/m^3

IV. Ductility test

The ductility is a distinct strength of bitumen, allowing it to undergo notable deformation or elongation. The ductility is defined as the distance in centimetre, to which a standard sample or briquette of the material will be elongated without breaking. The bitumen-rubber modification resulted in a better rutting resistance and higher ductility.

The bitumen-rubber modification resulted in a better rutting resistance and higher ductility.

The ductility values for this modification are very key to this study because they will confirm the action of the crumb rubber to increasing the elastic properties of base bitumen to enable it to resist cracking after heavy loads are applied on the asphalt surface. The ductility value is proportional to the flow value in the Marshall Flow and Stability Test.

The ductility test is conducted according to ASTM D-113.for 60/70 Pen bitumen, the ductility at 25 ^{o}C should be above 100 min.

V. Viscosity Test

The viscosity refers to the fluid property of the bitumen, and it is a gauge of flow-resistance. At the application temperature, viscosity greatly influences the potential of the resulting paving mixes. Mahrez and Rehan (2003) claimed that there is a consistent relationship between viscosity and softening point at different aging phases of rubberised bitumen binder. Also, it is reported that the higher crumb rubber content leads to higher viscosity and softening point. The viscosity is a continuously increasing non linear function of rubber content and the relative increase is a factor related to the application of temperature (Bahia and Davies, 1995). According to a study conducted by Lee et al. (2008), the higher crumb rubber content produced increased viscosity at 135°C and improved the rutting properties. It was also observed that the increased crumb rubber amount (fine crumb rubber) produced rubberised bitumen with higher viscosity and lower resilience. Lee et al. (2008)

3.2.3 Testing for aggregate properties

The mechanical property tests on aggregates such as gradation, AIV, ACV, TFV, LAAV, water absorption and combined specific gravity were conducted on the aggregates.

a) Density and Water Absorption of Aggregates

The capacity of an aggregate to absorb water is known as water absorption. It is often stated as a percentage of the dry weight of the aggregate. Porosity, particle shape, surface roughness, and the existence of pores or spaces inside the aggregate are some of the variables that might affect water absorption.

This was selected to characterize to aggregates used in the mix design by how much water they take in. High water absorption can lead to several issues in concrete, including reduced workability, increased water demand, decreased strength, and durability problems such as cracking, breaking away of pieces of concrete from the surface of a road or bridge deck, and freeze-thaw damage. Both density and water absorption are typically determined through standardized testing procedures prescribed by ASTM. BS 812: Part 2: 1975 is the Standard for Density and Water Absorption of Aggregates.

b) Aggregate crushing value ACV

The Aggregate Crushing Value (ACV) was selected as it gives the relative measurement of an aggregate's ability to withstand crushing under a weight that is delivered gradually.

The aggregate specimen is put in a cylindrical container and given a predetermined load during the ACV test. Until the aggregate fractures or fails under pressure, the load is supplied progressively over time. The weight of the fines, or material that passes through particular sieve sizes, is divided by the specimen's total weight to determine the ACV. The material that passes through a certain sieve after being crushed with a 400 KN force is measured to find the aggregate crushing value, or ACV. The ASSHTO specification indicates that the ACV of aggregates to use for an asphalt should be below 30.

c) Ten Percent Fines Value TFV

The Ten Percent Fines Value (TFV) was selected because it gives relative measure of the resistance of an aggregate to crushing under a gradually applied load hence qualifies for strength of the aggregates. The TFV is calculated as the percentage of fines produced relative to the total weight of the aggregate sample. This number indicates how resilient the aggregate is to shocks or abrupt impacts, which is crucial information for determining whether or not the aggregate is suitable for use in concrete mixtures that are subjected to dynamic loading conditions, including pavements and roads.

In pavement design, there exist precise criteria for the TFV (Toughness and Abrasion Resistance of Fine Aggregate) of materials, evaluated in both dry and soaked conditions. BS 812: Part 111: 1990 is the Standard for Ten Percent Fines value. The specification states that the TFV should lie between the range of 7.5 – 12.5

d) Aggregate Impact Value (AIV)

The Aggregate Impact Value (AIV) was selected because it gives relative measure of the resistance of an aggregate to sudden shock or impact. It assesses the toughness of aggregates by subjecting them to a standard amount of impact in a rotating drum containing steel balls or hammers. When building a road, aggregates should be sturdy enough to withstand crushing by tire loads from vehicles. Impact or crushing tests can be used to gauge the aggregates' strength. BS 812: Part 112: 1990 is the Standard for Aggregate Impact Value (AIV). The standard of aggregates to use for asphalt should lie below 30.

Aggregates with higher AIV values are considered less tough and more susceptible to fragmentation under impact loading. On the other hand, aggregates with lower AIV values are deemed tougher and better suited for use in applications subjected to dynamic loading conditions, such as road pavements.

3.2.4 Tests on the crumb rubber

Rubber particles that passed sieve size 300mm was used in this study. This is because the fine particles have a greater surface area to volume ratio compared to the coarser sizes thus having a better advantage in improving the properties of modified bitumen. The macromolecules of the rubber was determined using the FTIR test where it was carried at 4000 cm^{-1} to 400 cm^{-1} wave numbers to examine the spectrum of each sample.

3.2.5 Modification of bitumen with rubber

Procedure

The crumb rubber was placed in an oven for 24 hours so as to be completely dried to remove any moisture present in the rubber. Then after, it was passed through sieve size 300micrometer to obtain the fine particles.

Using the wet mixing procedure, different percentages of the rubber say 5%, 10%, 15% and 20% were added to the bitumen by weight.

To modify the bitumen, about 500g of neat bitumen were used for each percentage of crumb rubber content as shown on the table below

Table 3:1 Different weights of rubber in the different modified bitumen samples

Percentage of Crumb Rubber	Mass of Bitumen(g)	Mass of crumb rubber added (g)	Total weight(g)
5%	475	25	500
10%	450	50	500
15%	425	75	500
20%	400	100	500

The rubber was placed on a pan on top of heat from a gas heater to maintain its temperature and was mixed by stirring manually for 25 minutes at 155 ^{o}C. The stirring time was increased by 5 minutes per increase in the rubber content. This was to ensure that they fully melt into the bitumen and the bubbles on the surface were removed. With increased crumb rubber dosage, the modified bitumen became thicker hence more mixing time was needed to completely be uniform. After mixing, the various pans were placed in an oven at 150 ^{o}C for 16 hours to further improve the homogeneity of the mix.

In order to carry out the bitumen consistency tests (penetration grade test, softening point, ductility, viscosity and specific gravity tests) on the different rubber percantages, the samples were conditioned for 2 hours in a cool water at 25 ^{o}C. The results are presented in the proceeding chapter.

An optimum crumb content of 5% was obtained as the optimum after conducting the bitumen consistency tests. With 5% rubber modified bitumen as the optimum, a

Marshall mix design was conducted and 4 asphalt briquettes, using the same procedure as that for the neat asphalt were made. The properties of the modified asphalt (marshall flow and stability test, GMM, bulk density, Volume of air voids and VFA) were determined as shown in the appendix. These results form a basis of comparison of the modified asphalt to the neat asphalt, whose analysis is presented in the proceeding chapters.

As mentioned earlier, the challenges with rubber modification of bitumen is storage instability. To confirm the storage instability of the mix, a storage stability test is carried out

3.2.6 Storage stability tube test ASTM D7173

According to ASTM 7173, to simulate the high temperature storing process in the laboratory, about 70 g of hot asphalt was poured into an aluminum tube with a diameter of 25 mm. Before cutting the tube into three equal parts horizontally, it was being stored at 163 °C for 48 h followed by cooling down at −5 °C. for at least 4 hours (Vargas, 2012)

The storage stability of the modified binder will then be quantified by measuring the difference softening point of binder samples collected from the top third and the bottom third of the tube. When the difference is less than 2.5°C, the material is considered to have sufficient storage stability (Fu *et al*. 2017).

To establish the optimum SBR-Kaolinite content to achieve an effective mix, different percentages of the kaolinite in 1%, 1.5%, 2% and 2.5% will be added in the mix design. The storage stability of each kaolinite percentage will then be obtained. The best performing kaolinite content in terms of Storage stability will be considered as its optimum content.

3.2.7 Modified Asphalt Concrete Performance Tests

To evaluate polymer modified asphalt mixtures, it is important to determine performance properties. Indirect tensile test for prediction of tensile strength was carried out. Two testing temperatures (25,45C°) are used to predict changes of the modified asphalt concrete with temperature. A Retained Marshall Stability test for evaluating the durability of asphalt polymer modified will also carried out.

i) Indirect Tensile Strength

To evaluate the engineering properties of asphalt mixtures, the indirect tensile test has been used. The test is conducted by loading specimen with a parallel load to the vertical diameter, this causes specimen failure along the vertical diameter. The test gives information on tensile strength and fatigue characteristics. The test is done according to manual of testing procedures, 1966 (Texas high way department).

3.3 Secondary data collection method.

This was obtained using Literature review and applied where relevant in the research.

3.4 Data analysis method

The data was analyzed using statistical methods in excel using graphically representations to identify significant differences and trends in the above parameters based on the varying crumb rubber content to establish the optimal value.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter shows the results from the tests carried out in this study. The raw data was analyzed, discussed and represented as per the results from tests.

4.2 Properties of bitumen

From table 4:1, the consistency obtained from the Penetration test is **69.0 mm** and this categorizes it as the Bitumen Grade of 60/70 hence making it suitable for Asphalt Concrete production (Department of Transportation and Transport Road Manual for design plus General Specification). This enhances the durability of the Asphalt concrete.

Table 4:1 Bitumen properties, values and specifications

Bitumen property	Standard	Value	Specification
Penetration at 25 C (mm)	ASTM-D5	69	60/70
Softening point (^{o}C)	ASTM-D36	50	49/56
Ductility at 25 ^{o}C (cm)	ASTM-D113	116.7	Min 100
Specific Gravity (g/cm^3)	ASTM-D70	1.014	1.01/1.06
Viscosity (mm^2/sec)		320	Min 295

The softening point of bitumen is the temperature at which the substance attains a particular degree of softening. Temperature susceptibility of Bitumen is **50ºC** was obtained which lies in the allowable range of 49ºC to 56ºC as per the Department of

Transportation and Transport road Manual for design plus General Specification. This makes it suitable for making Asphalt Concrete for road construction in the Tropical climates.

The Specific Gravity of Bitumen is **1.014 g/cm^3** which lies in the appropriate range of 1.01 – 1.06 g/cm^3 which is suitable for production of Asphalt Concrete in Tropical locations. This ensures adequate cohesion and adhesion of the aggregates, which is achieved after Compaction leads to the durability of the pavement.

Ductility value means that the bitumen can be stretched to this value without breaking indicating that it has a strong cohesive force. This also means that the binder can elongate and fill the voids making the mixture easily compacted. This implies that it suitable for road use.

4.2 Properties of Aggregate test

From the table below, the value of AIV was **14.9%** which is within the required value of **30%**. This implies that the aggregates are strong enough to resist a sudden impact from moving vehicles. All properties were within the specified specifications.

Table 4:2 Aggregate properties, values and specifications

Property	Result	Specification
AIV (%)	14.9	Max 30
ACV (%)	15.9	Max 30
10% fines value Ratio (%)	8.4	7.5 – 12.5
LAAV (%)	40	Max 50

The Aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually compressive load. ACV is 15.9% and it lies within the acceptance range of Max 30% for production of Asphalt Concrete. This makes the aggregates strong enough to withstand traffic loading. Therefore, this makes the aggregates be able to coat with the bitumen. This enhances the durability of the Asphalt Concrete.

TFV value of 8.4% lies within the required range of (7.5 – 12.5) %. Since the TFV dry value is 304.2KN, which is greater than 110KN as required and the TFV wet value of 104% is greater than the required 75% for Asphalt concrete aggregates in the Department of Transportation and road Manual for design plus General Specification. The aggregates are suitable to produce Asphalt concrete for road construction in Uganda.

LAAV measures the degradation of aggregates when subjected to abrasion and impact, the abrasion value should be Max 50% to resist abrasion. Since tested material had an abrasion value of 40% the aggregates are tougher and more resistant to abrasion.

4.3 Properties of Crumb Rubber

The chemical composition of the rubber as tested by the FTIR test done by at the Government Analytical Laboratory indicated the following composition

Table 4:3 Crumb rubber properties

Component	Score
Tencel	991
Methylycellulose	984
SBR	998
polyisopropene	867
Latex	869
hydrocarbons	840
Carbon black	911

4.4 Effect of Crumb Rubber on bitumen consistency

4.4.1 Penetration

The penetration test is commonly used to control the penetration grade. The variations in penetration values with different percentages of Crumb rubber, as depicted in the figure below, clearly demonstrate a reduction in consistency as crumb rubber is incorporated. Compared to neat bitumen, the reductions are 6.5%, 16.4%, 19.3% and 23.4% with the addition of 5%, 10%, 15%, and 20% of crumb rubber respectively. These results indicate that as the crumb rubber content increases in the mix, the penetration values for modified bitumen decrease.

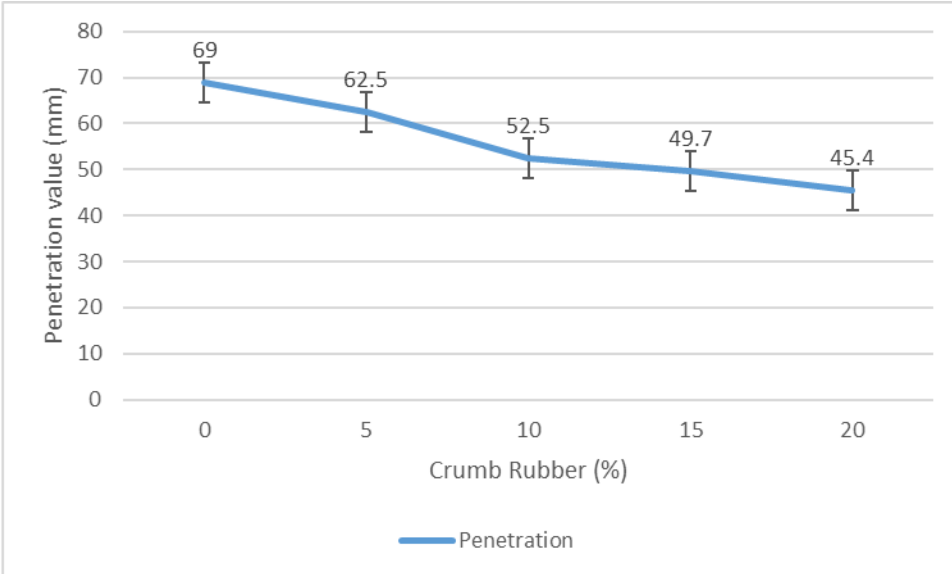


Figure 4:1 Penetration value against Crumb rubber percentage

The penetration decreased as the amount of rubber increases up to 20%. It shows that CRM content has a significant effect on penetration value. The crumb rubber content has a strong effect on reducing the penetration value by increasing the stiffness of crumb rubber bitumen binder, thus, would make the binder less temperature susceptible and lead to high resistance to permanent deformation like rutting as mentioned by (Liu et al., 2009).

In addition, the linear dramatic decrease in penetration behavior is justified because the rubber addition turns the bitumen more viscous. This increase in rubber content lead to enhanced the particle size of the rubber. This was due to the increase in rubber mass through the interaction and swelling of the rubber into the bitumen during the blending process, which led to the decrease in the penetration of rubberized bitumen. Thus, indicate that the rubberized bitumen binder will be less susceptible to high temperature change and more resistance to rutting.

Since we are using 60/70 PEN bitumen, to maintain the grade of the bitumen within the range of 60 and 70, the percentage of crumb rubber modification that resulted to a mix within that range qualifies to be effective while that is below will have failed. For this modification, only the Crumb rubber with 5% dose of the weight of bitumen was within the acceptable range. 10%, 15% and 20% had penetration ranges as **52.5%, 49.7% and 45.4%** which were below 60% thus failing.

4.4.2 Softening point

Increasing Crumb rubber content in the mix leads to a rise in the softening point. The results demonstrate that CR enhances the softening point value.

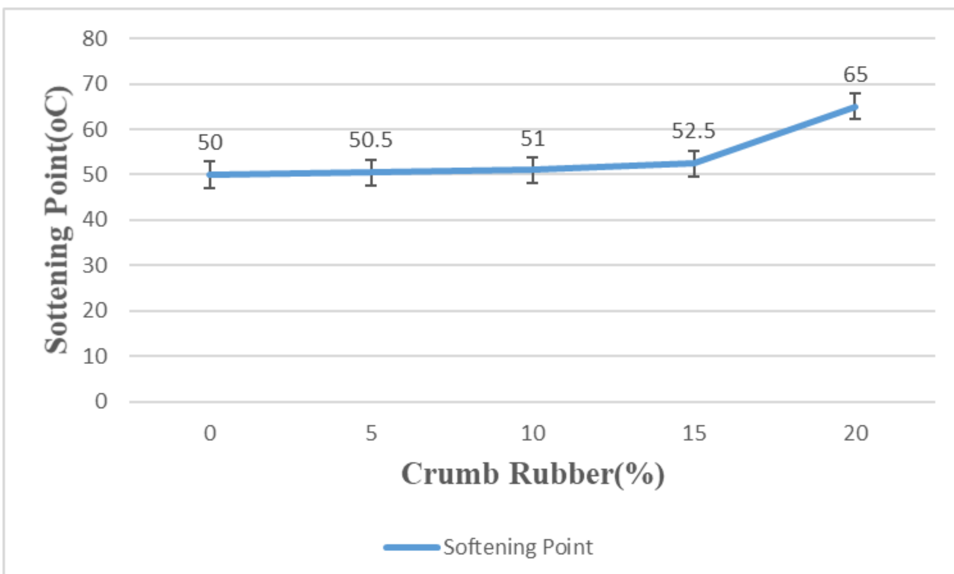


Figure 4:2 Softening point against Crumb rubber percentage

The softening point across the different percentages increased with increase in the concentration of CR. This is because crumb rubber is made of cross-linking polymers for example styrene butadiene rubber and carbon black that increase the thermal stability of the binder. With rubber modification of bitumen, there is increased elasticity and cohesiveness to form a reinforced structure that requires higher temperatures to break down, resulting into a higher softening point.

From the acceptable range, according to standards, is **49 to 54°C**. From the results obtained above, it is clear that all the CR modification were within the range except the 20% CR. This therefore implies that 20% is out of the sample space to get an optimum CR percentage.

4.4.3 Specific gravity

Increasing Crumb rubber content in the mix leads to a rise in the specific gravity. The results demonstrate that CR enhances the specific gravity value.

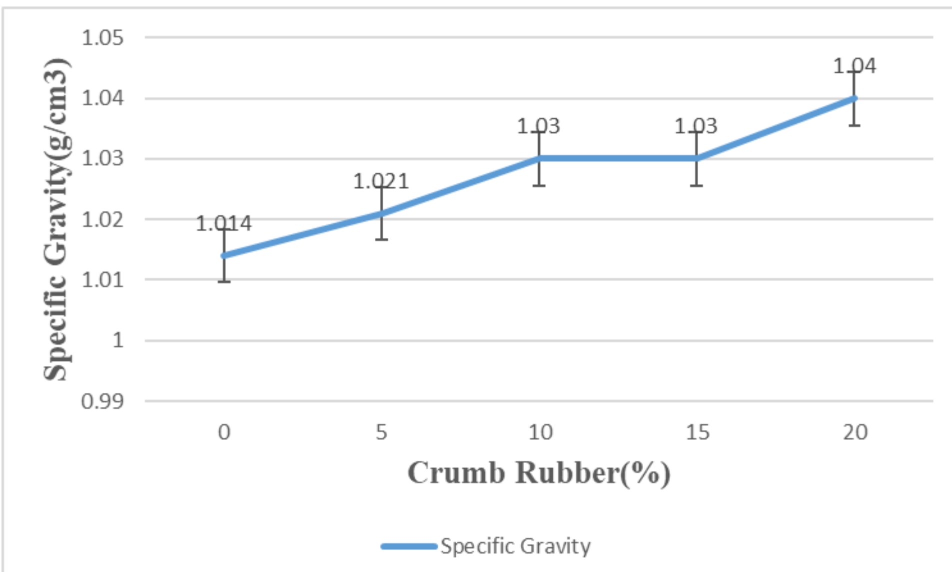


Figure 4:3 Specific gravity against Crumb rubber percentage

The specific gravity increased with increase in the CR content. This is because when rubber is added to bitumen, the rubber particles swell and absorb aromatic oils and light fractions. This absorption increases the overall density of the modified bitumen.

The rubber particles also reduce the voids in the bitumen structure reducing the free volume in the bitumen and eventually leading to a denser structure.

All the CR modifications had a specific gravity within the acceptable range of **1.02 to 1.06g/cm^3**

4.4.4 Ductility

Increasing Crumb rubber content in the mix leads to a decrease in the ductility. The results demonstrate that CR enhances the specific gravity value.

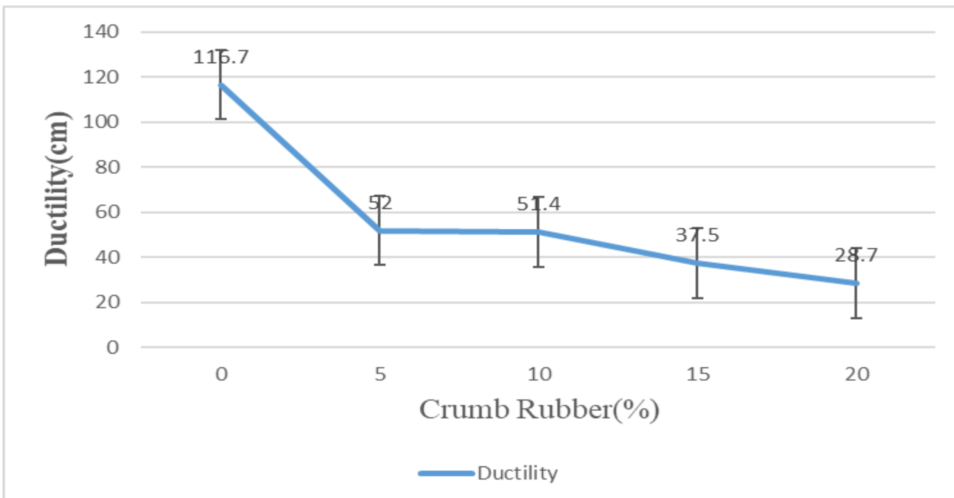


Figure 4:4 Ductility against Crumb rubber percentage

The reduction in ductility is attributed to the physical interactions during the blending process of the rubberized bitumen. Additionally, an increase in binder mass could make the binder more elastic, stiff and highly resistant to cracking. Meanwhile, the decrease in ductility value could be due to the oily part of the bitumen absorbed into the rubber powder and increase in mass of the rubber particles. In effect, the modified binder became thicker compared with the unmodified bitumen sample.

According to the findings, the ductility values for **5%** and **10%** fall within the permitted limits which mandates a minimum ductility value of 50 cm.

4.4.5 Viscosity

Increasing Crumb rubber content in the mix leads to an increase in the viscosity. The results demonstrate that CR enhances the viscosityvalue.

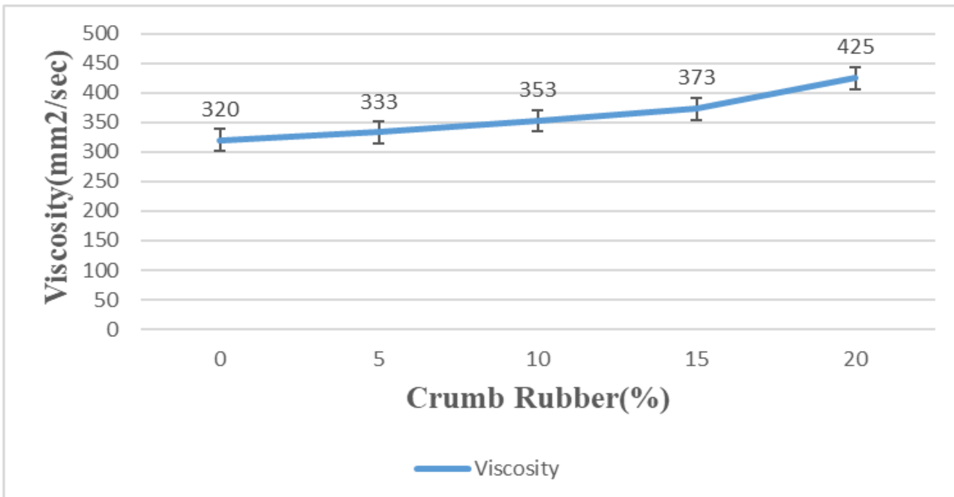


Figure 4:5 Viscosity against Crumb rubber percentage

The increase in the viscosity with increase in Crumb rubber doses is due to the interaction between the rubber particles and the bitumen matrix. Crumb rubber obtained from waste tires consists of elastomers such as natural rubber, styrene butadiene rubber and polybutadiene that absorb the lighter fractions of bitumen and swell. This swelling effect increases the binder's viscosity by forming a more interconnected and elastic network within the bitumen matrix (Wypych,2022).

4.5 AC14 Combined Gradation curve

The curve below shows the particle size distribution of the combined grading of the asphalt mix. Figure shows the AC14 combined gradation and it also shows that the grading lay in the specified grading envelopes. The green line is the finer side, the red line is the coarser side and the maroon line is the grading curve obtained.

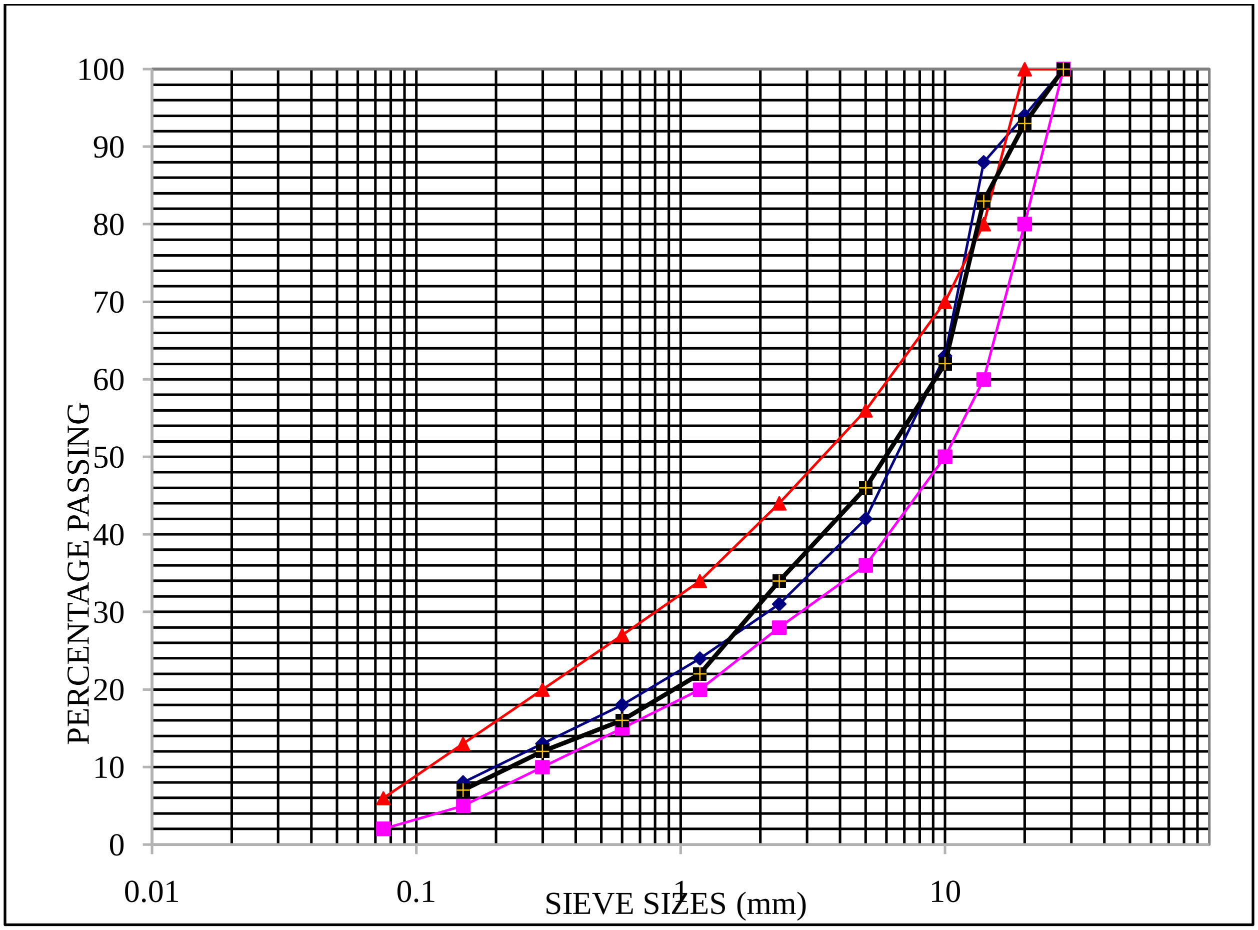


Figure 4:6 Combined aggregates grading

The curve starts at the finer side and then moves on to the coarser side and then to the fine side and coarse side again, with the bigger percentage towards the coarser side. This means there's more coarse aggregates than the fine aggregates in the mix and this implies that the particle distribution of the aggregates achieved a proper mechanical interlock of aggregates which positively proves the moisture resistance and lowers water penetration into the asphalt mix.

4.6 Determination of optimum bitumen content

a) Job mix

A combined aggregate gradation of 14/20mm, 10/14mm, 6/10mm, 0/6mm and a filler were proportion as 10%, 5%, 15%, 65% and 5% as seen below

Table 4:4 Aggregate blending for AC14

Aggregate Size (mm)	Blending Proportions
14/20	10.0
14/10	5.0
6/10	15
0/6	65
Filler	5.0

b) Optimum Bitumen content determination

A varied Bitumen content was added as a percentage of the total mass as Six (6) batches were blended in table 4.5,

Table 4:5 Optimum Bitumen Content determination

Optimum Bitumen Content					
BITUMEN (%)	3.5	4	4.5	5	5.5
DENSITY	2.33	2.336	2.365	2.386	2.372
STABILITY	7.1	13	15.5	15.4	13.8
FLOW	2.63	2.45	2.6	2.8	3.2
VOIDS	6.8	5.7	4.7	4.3	2.3

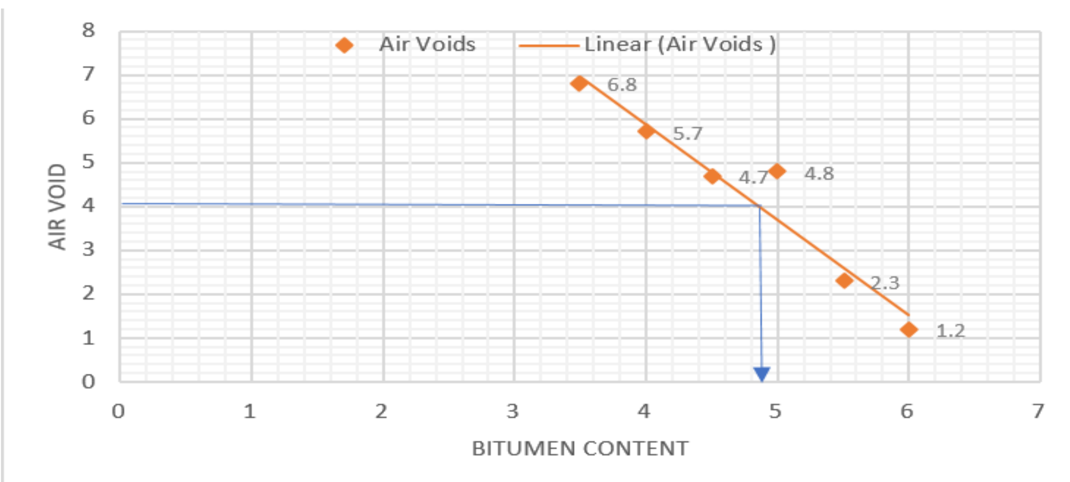


Figure 4:7 Air voids against Bitumen content

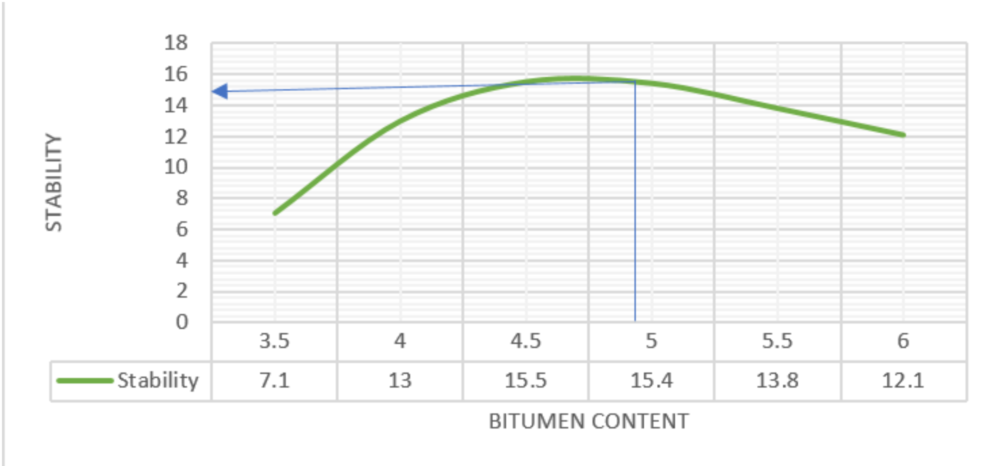


Figure 4:8 Stability against Bitumen content

At 4.9% BC, the stability is 15 which is in the range of 8-18kn. This implies improved rutting resistance and deformation since there is increased structural integrity.

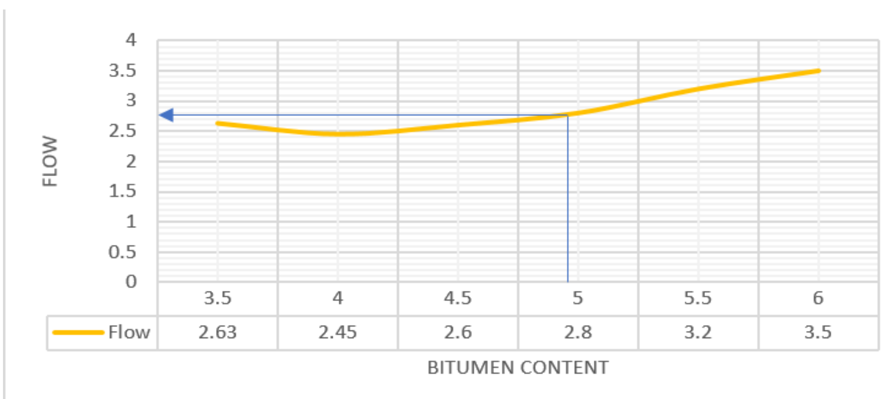


Figure 4:9 Flow against Bitumen content

The Flow is 2.6 at 4.9% Bitumen Content lies within the expected range of 2 – 4 by Uganda Standards which means there is proper Compaction and Density leading to better workability.

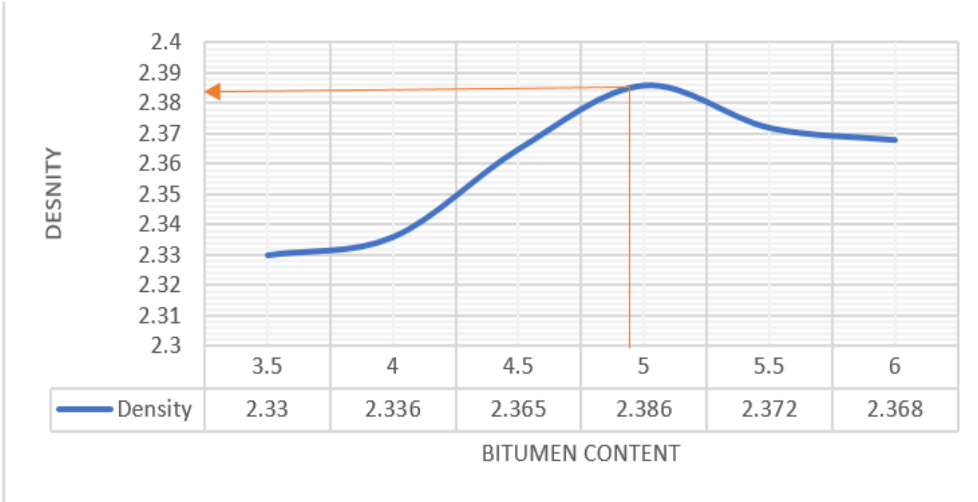


Figure 4:10 Density against Bitumen content

Density at Asphalt mix at 4.9% Bitumen Content 2.38g/cm3 which lies within the expected of 2.3 – 2.5 g/cm3.

Optimum Bitumen Content for the mix was **4.9%** which yields the required Air Voids of 4% Stability 15 and Flow 2.6 which conforms to the Department of Transportation and Transport road Manual for design plus General Specification.

4.7 Asphalt mix design

The following is the control mix design of the research

Table 4:6 Control asphalt mix design

Material composition	Blending proportions of aggregates (By mass)	Percentage Composition of Asphalt Concrete (%)	Mass in the Mix (g)
Bitumen	-	4.9	490
14/20	10.0	9.5	950
14/10	5.0	4.8	480
6/10	15	14.5	1410
0/6	65	61.9	6190
Filler	5.0	4.8	480
Total	100	100%	10000

4.8 Test result on asphalt concrete for unmodified and modified bitumen.

The control hot mix asphalt (HMA) (0% CR) was designed according to the Marshall mix design method. The optimum bitumen content was 4.9%. This bitumen content was used to produce the modified mixes by Crumb rubber. As aforementioned, CR was added to the asphalt mixture as a partial replacement of bitumen by weight in the mentioned percentages. From the modification of the bitumen using different CR percentages, 5% CR was selected as the optimum rubber content for the biumen because it improved the rheological properties of the neat bitumen, maintaining the standards within which 60/70 Pen bitumen must lie. The comparative study was based on the change in the HMA performance. 4 control and 4 CR modified mix asphalt briquettes were tested for:

Table 4:7 Summary of Marshall and Volumetric property results of neat asphalt

Specimen	GMB	Unitwt	%A.V	%VMA	%VFB	Stability	Flow	Stab/flow	GMM
Neat (0)	**2.342**	**2.330**	**4.9**	**15.1**	**67.7**	**12.8**	**3.0**	**4.4**	**2.250**
A	2.366	2.355	4.5	14.7	73.7	23.56	3.45	6.829	2.450
B	2.337	2.325	3.7	15.8	67.9	19.08	3.90	4.892	
C	2.370	2.359	4.9	14.6	74.6	23.03	3.38	6.814	2.449
D	2.337	2.326	4.7	15.8	68.0	21.72	3.31	6.562	

Table 4:8 Lower and upper limits of asphalt

Parameter	Limits		standard
	Lower	Upper	
VMA	Na	Na	Na
Stability	9	18	9-18
flow	2	4	2-4
Air voids	3	5	3-5
VFB	67	75	67-75

i) **Voids in mineral aggregates (VMA)**

This is the total volume of void spaces between aggregate particles in a compacted asphalt mix.

4.8.1 Effect of crumb rubber on VMA

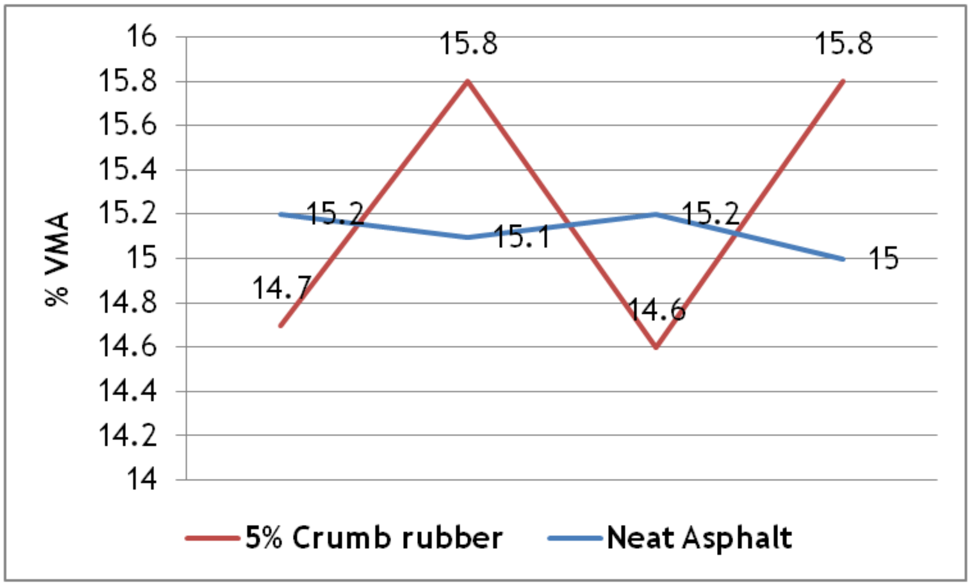


Figure 4:11 Comparison of %VMA of the neat asphalt and 5% CRMA

The addition of CR led to a reduction in VMA dropping from 15.1% in the neat bitumen to 14.1% in the modified mix. This change is mainly due to a decrease in air voids from 4.9% to 4.0% which reduced the space between aggregate particles and in return, lowered the overall VMA.

Crumb rubber tends to absorb some of the bitumen increasing the effective binder volume in the mix. With more binder present, there's less room for voids, contributing to the reduction in VMA.

Based on BS EN 13108-1 for AC14 mixes, the minimum required VMA is 14%. The modified mix achieved 14.1% which meets the standard. This suggests that the modification strikes a good balance between durability and structural integrity.

ii) Marshall stability

This refers to the highest load a compacted asphalt sample can handle before it breaks or deforms under pressure.

4.8.2 Effect of crumb rubber on asphalt's stability

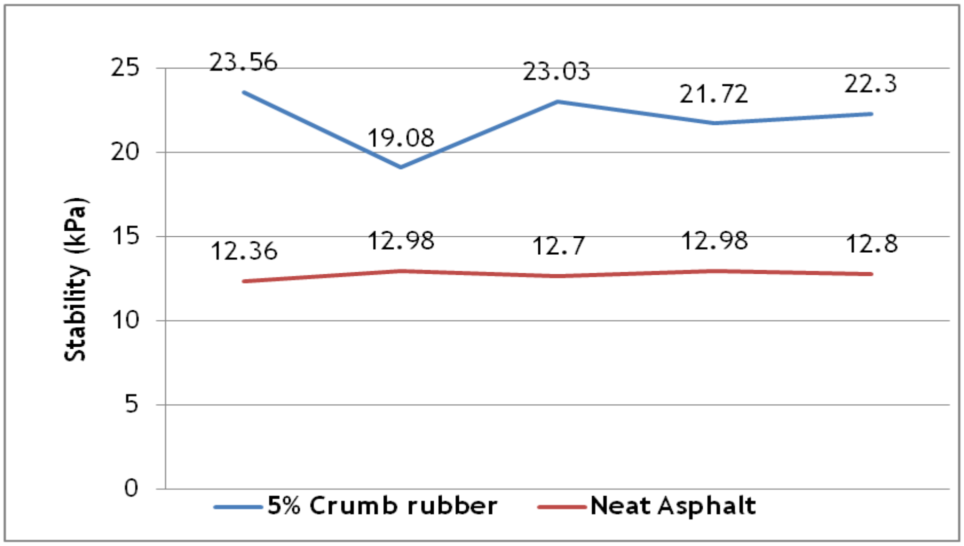


Figure 4:12 Comparison of Stability of the neat asphalt and 5% CRMA

The addition of 5% CR significantly improved the stability of asphalt, doubling the average value from 12.8KN in the neat bitumen to 25KN. This increase is largely due to the enhanced elasticity and strength of the modified binder which makes the sample more resistant to cracking under heavy loads. Crumb rubber also improves the adhesion between aggregates and bitumen reducing the likelihood of aggregate displacement when subjected to stress.

Among the 4 tested asphalt briquettes, 3 had notably higher marshall stability values that is 23.56KN, 23.03KN and 21.72KN compared to the fourth, which measured 19.08KN. The difference of 4.5KN is quite significant in pavement design. Based on a general rule of thumb, every 1KN increase in stability can support approximately 100000 to 150000 ESALS. Therefore, a 4.5KN difference could support up to 450,000 additional axel loads before pavement failure, making it a considerable variance. This drop in stability may have been caused by the briquette with the lower value being formed from the top layer of the CRMB where the mixture may have been less homogeneous. Overall, the increase in marshall stability demonstrates that crumb rubber modification can significantly enhance the performance of asphalt especially under heavy traffic conditions.

As per BS EN 12697-34, the minimum required marshall stability value for highway pavements is 12KN. The 5% CR modification clearly surpasses this threshold, greatly improving the load bearing capacity of the pavement.

iii) Marshall flow

This refers to the amount of deformation measured in millimeters that an asphalt sample experiences just before it fails under loading during the marshall stability test.

4.8.3 Effect of crumb rubber on marshall flow of asphalt

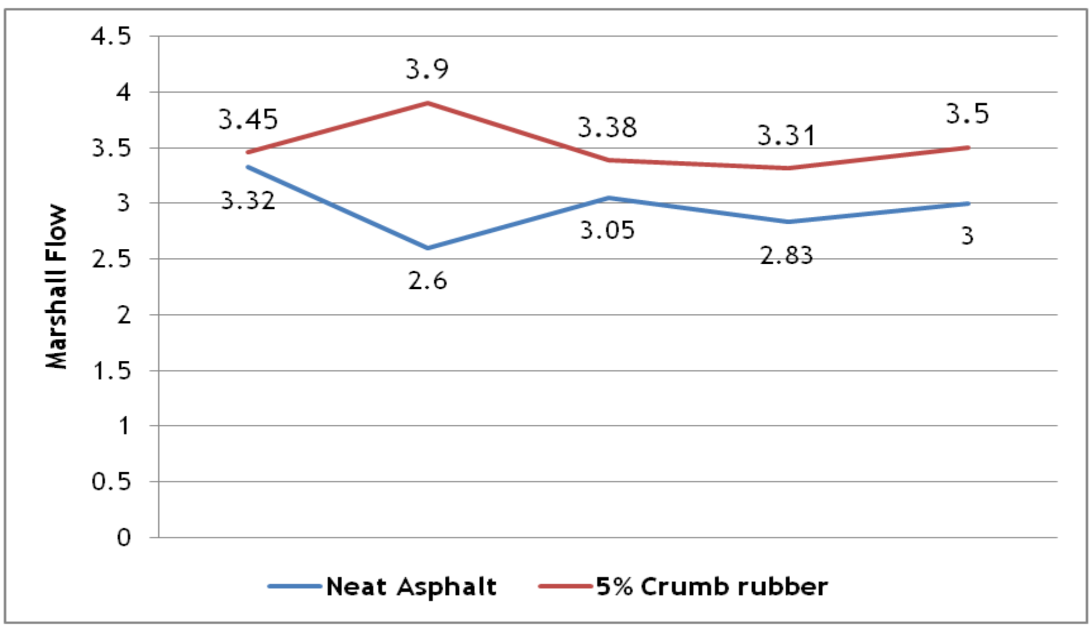


Figure 4:13 Comparison of Marshall Flow of the neat asphalt and 5% CRMA

The marshall flow of asphalt increased from 3.0mm in the neat asphalt to 3.9mm after incorporating 5% CR. This improvement is mainly due to the presence of long chain polymers in CR such as SB which stretch under load and return to their original shape once the load is removed. This elastic behavior allows the asphalt mix to deform more before failing, thereby increasing its flow value. This is shown below

Crumb rubber also boosts the viscosity and ductility of the binder by absorbing the lighter fractions of bitumen and swelling. This reduces the risk of brittle failure and enhances the mix's ability to flow under stress.

A higher flow indicates greater flexibility, enabling the pavement to better absorb heavy traffic loads without developing fatigue cracks.

Similar to the pattern seen in the marshall stability and air voids, there was a noticeable variation in flow values among the 4 samples. Three briquettes had similar values that is 3.45mm, 3.38mm and 3.31mm while the 4th showed a sharp increase to 3.90mm. This difference could be due to inconsistency in the CR bitumen blend especially if the lower performing briquette was produced using material from a more rubber rich portion of the mix.

The average flow value of 3.9mm falls within the recommended range of 2.5mm to 5.0mm for highway pavements as per BS EN 12697-34. This suggests that the modified mix achieves a good balance between flexibility and stability, making it suitable for high performance road applications.

iv) Air Voids

Air voids represent the percentage of air spaces within a compacted asphalt mix.

4.8.4 Effects of crumb rubber on Air voids of asphalt

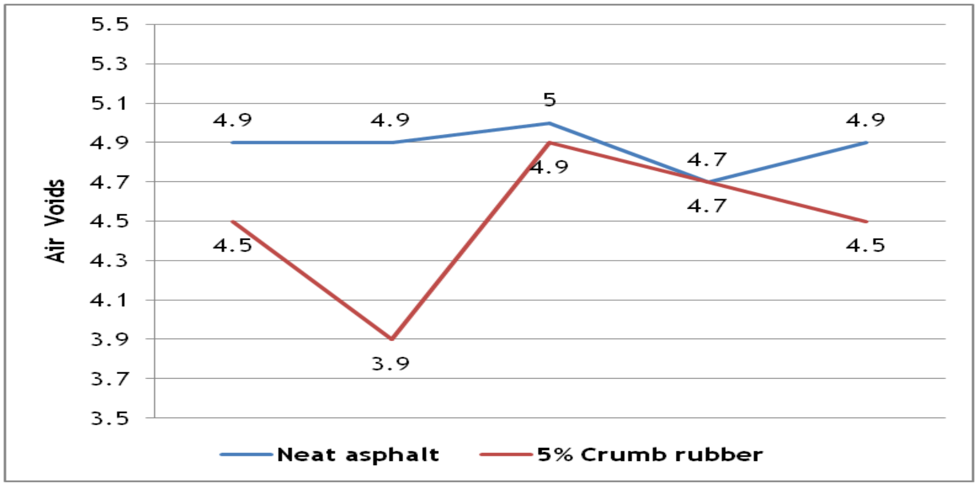


Figure 4:14 Comparison of %VMA of the neat asphalt and 5% CRMA

The air void content decreased from 4.9% in the unmodified mix to 4.5% in the 5% crumb rubber (CR) modified asphalt. This -0.08% reduction suggests that the CR-modified binder enhanced the coating of aggregates and improved the packing of particles, likely due to its elastic and viscous nature.

According to BS EN 13108-1, the acceptable range for air void content in asphalt mixtures lies between 3% and 5%. The obtained value of 4.5% is within this range, indicating that the CR-modified mix meets the standard requirements for durability and stability.

While three of the CR-modified samples showed air voids of 4.5%, 4.9%, and 4.7%, one sample showed a lower value of 3.7%. This variation could point to storage instability in the modified binder, where rubber particles may have settled due to density differences, leading to uneven distribution during mixing and compaction.

Overall, the reduction in air voids is a positive outcome, as it enhances durability by minimizing the exposure of the binder to air and moisture, thus reducing oxidation and aging. These results confirm that crumb rubber modification, when properly handled, can improve the internal structure of asphalt and support long-term pavement performance.

4.9 Storage stability test

The Kaolinite clay was mixed into the CRMB as explained in the methodology. The results tabulated below.

The storage stability test results of CR modified bitumen using different percentages of 0%, 1%, 1.5%, 2%, 2.5% of kaolinite clay are shown in the table below.

Table 4:9 Different kaolinite percentages added to 5% CR

%kaolinite	Top	Bottom	Difference(0C)	Specification	Remark
0	48.1	58.5	10.4	Max 10^{o}C	Not stable
1.0	49.8	57.2	7.4	Max 10^{o}C	Stable
1.5	51.5	54.7	3.2	Max 10^{o}C	Stable
2.0	52.0	53.9	1.9	Max 10^{o}C	Very Stable
2.5	52.3	54.6	2.3	Max 10^{o}C	Stable

The top portions of the modified bitumen samples exhibited a lower softening point compared to the bottom portions. This is because the softening point of CRMB is influenced by the concentration of rubber particles in the mix as seen in earlier tests using 5%, 10%, 15% and 20% rubber, each yielding different softening points. The variation in softening points is primarily due to segregation whereby rubber particles separate from the bitumen caused by the difference in their densities.

Rubber particles have a slightly higher density (1.15-1.20g/cm^3) than bitumen of (1.02-1.06g/cm^3), so they tend to settle at the bottom of the mix under the influence of gravity. This settling results in the lower part of the sample containing more rubber and therefore having a higher softening point.

Despite these differences, all kaolinite CRMB samples (except for 0% kaolinite blend) met the GDOT specification, which requires a softening point difference of no more than 10 ^oC between the top and bottom. Although most of the samples were within range, the 2% kaolinite sample had a slightly lower softening point difference of 1.9 ^oC, which is significantly better than the others.

According to findings by Mohd Ezree (2012), a softening point difference of less than 2.2 ^oC indicates that the blend is highly stable. Based on this, the 2% kaolinite sample was identified as the most effective at reducing phase separation in the CRMB. Therefore, it was concluded that 2% kaolinite is the optimum content for achieving a stable and well modified bitumen blend.

4.10 5%CRMB +2% kaolinite asphalt test result

Table 4:10 5%CRMB +2% Kaolinite AC results

Specimen	Gmb	Unit wt	%A.V	%VMA	%VFB	Stability	Flow	Stab/flow	Gmm
1	2.376	2.364	4.0	13.9	72.3	24.76	3.87	6.398	2.456
2	2.366	2.355	4.2	14.2	70.7	25.22	3.87	6.569	
3	2.361	2.349	4.0	14.4	70.0	23.91	3.88	6.16	2.458
4	2.374	2.363	4.1	13.9	72.5	26.92	3.84	7.465	
Average	**2.369**	**2.358**	**4.0**	**14.1**	**71.4**	**25.2**	**3.9**	**6.5**	**2.457**

4.10.1 Analysis of Marshall Flow and Stability Test

Based on the evaluation of the Marshall test results and volumetric analysis for three asphalt mixes neat asphalt, asphalt with 5% crumb rubber (CR), and asphalt with 5% CR and 2% kaolinite, it was observed that the performance of the mixes significantly improved with the inclusion of CR and further with the addition of kaolinite clay.

The incorporation of 2% kaolinite enhanced the storage stability of the CR-modified mix, resulting in a more uniform blend. This homogeneity led to more consistent values across parameters like air voids, stability, and flow, compared to the CR-only mix, which showed greater variation due to phase separation.

The Marshall stability test, which indicates the pavement's load-bearing capacity, revealed a progressive increase in stability:

- Unmodified asphalt: 12.8 kPa
- 5% CR-modified asphalt: 22.3 kPa

- 5% CR + 2% kaolinite-modified asphalt: 25.2 kPa

This represents a 74% improvement in deformation resistance for the CR-modified mix and a 97% increase for the CR and kaolinite-modified mix compared to the unmodified asphalt. While the stability gains from unmodified to CR-modified asphalt were attributed to the reinforcing effect of crumb rubber, the further enhancement in stability with the addition of kaolinite is primarily due to the increased mix homogeneity. Without kaolinite, the separation of rubber particles during storage resulted in uneven distribution—typically with lessmodifier in the upper layers—leading to lower average stability. Kaolinite's inclusion mitigated this issue, creating a more balanced and structurally sound asphalt mix.

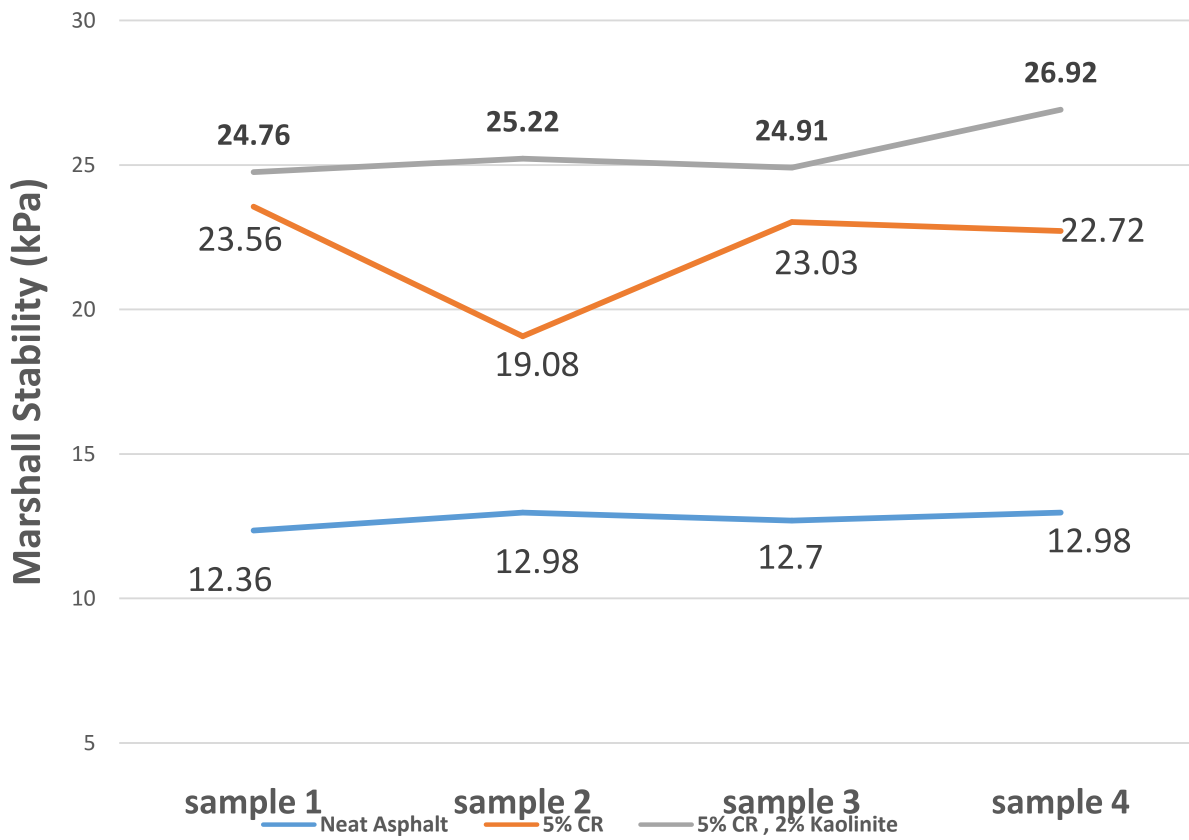


Figure 4:15 Marshall stability against CRMA

4.10.2 Implications of Marshall Stability on Load-Bearing Capacity

A higher Marshall Stability value directly correlates with increased resistance to pavement failure and allows for higher Million Equivalent Single Axle Loads (MESA), assuming a proportional relationship between stability and load capacity.

Based on the TRL Report (2019), the primary causes of deformation on the Kampala-Masaka Highway include excessive axle loads (actual growth rate of 8.5, compared to the maximum predicted (6.5) and excessive tire pressure (averaging 900 kPa, surpassing the recommended (550–700 kPa). The design MESA for the highway was 44.1 million, but by 2018, when early signs of cracking and structural failure were observed, the actual traffic load had reached 4.9 MESA.

From the Marshall test results, the modified asphalt (5% CR + 2% kaolinite) showed a 97% increase in stability compared to neat asphalt. Assuming that Marshall Stability scales proportionally with load capacity:

A 1.97× increase in stability translates to a 1.97× increase in MESA, implying:

$4.9 \times 1.97 = 9.65$ MESA

This means the modified asphalt could withstand nearly double the axle load of the neat asphalt, significantly enhancing its capacity under heavy traffic.

Assuming Marshall Stability also scales proportionally with tire pressure resistance, the upgraded mix could theoretically handle:

1.97×900 kPa = 1,773 kPa

This demonstrates that the modified asphalt can endure much higher tire pressures, further reducing the risk of rutting and plastic deformation, thus extending pavement life and reducing maintenance frequency.

4.11 Indirect Tensile Strength (ITS) and Resilient Modulus

a) Indirect Tensile Strength (ITS)

The Indirect Tensile Strength (ITS) test is a key method used to evaluate the tensile characteristics of asphalt mixtures, which are directly linked to their resistance to cracking. A higher ITS value indicates improved tensile resistance, meaning the material can endure greater tensile stress before failure. This makes it more resilient to both fatigue and low-temperature cracking.

Asphalt mixes capable of sustaining higher strain levels before failing are more crack-resistant than those that fracture under smaller strains. The ITS values obtained from this study are summarized in the table below:

Table 4:11 ITS values for both dry and wet samples

Type of asphalt	ITS (dry) kPa	ITS (wet) kPa
Unmodified	1194.3	1066
Modified with 5% CR	1619.2	1119.3
5% CR +2Kaolinite	1614	1097

All asphalt samples exhibited ITS values above the 1000 kPa threshold, indicating acceptable tensile performance. The modified mixtures, particularly those containing crumb rubber, demonstrated significantly higher strength than the neat asphalt. This improvement is attributed to the elastic and stiffening effects of the crumb rubber, as discussed earlier in this report.

b) Resilient Modulus Estimation

The resilient modulus (Mr) is a fundamental parameter in mechanistic pavement design, used to evaluate how pavement materials respond under repeated traffic loads. It also reflects the quality and stiffness of asphalt mixtures.

To estimate Mr, this study applied the empirical correlation developed by Barksdale et al. (2010), which has been shown to produce results comparable to those from Direct Modulus Tests (DMT). The parameters considered include:

Pc – Applied cyclic load (N)

δt – Horizontal recoverable deformation (mm)

t – Specimen thickness (mm)

μ – Poisson's ratio

The resilient modulus was computed using the formula:

$Mr = Pc / (\delta t \times t) \times (0.2339 + 0.7801\mu)$ **(Barksdale et al., 2010)**

The calculated results are shown below:

Table 4:12 Resilient Modulus values

Asphalt	ITS (kPa)	Pc (N)	Ave δt (mm)	Ave t (mm)	Poisson's ratio	Ave Elastic Modulus (Mpa)
unmodified	1194.3	1199500	2.21	63.0	0.44	4972.23
5% CRMA	1619.2	1628000	1.83	63.05	0.44	8143.281
5%CR+2% Kaolinite	1604.2	1615500	2.09	63.43	0.44	7033.106

The results show that:

The 5% CR-modified asphalt has the highest resilient modulus, confirming its superior stiffness and elastic response.

Although the 5% CR + 2% Kaolinite mix has a slightly lower modulus than the CR-only mix, it still offers significantly higher stiffness than the unmodified asphalt, with the added benefit of improved storage stability and homogeneity due to kaolinite's stabilizing role.

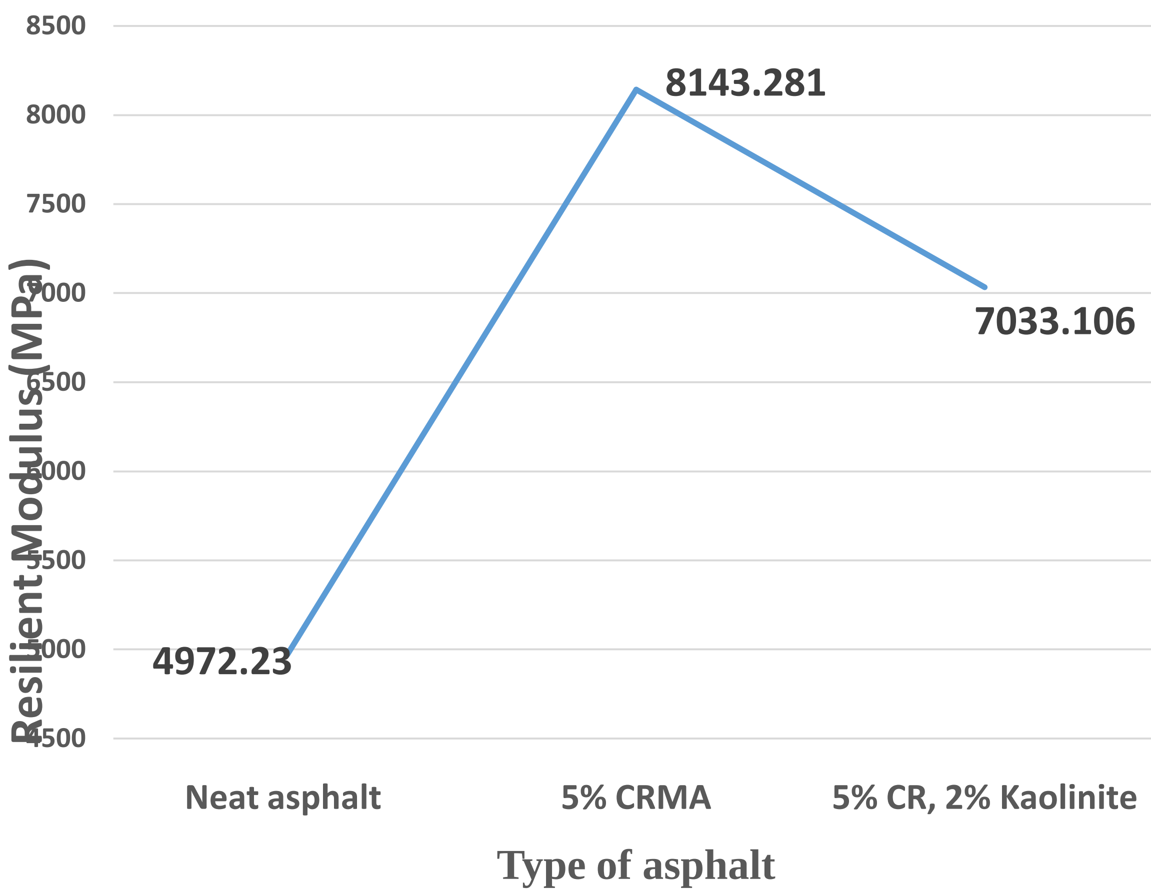


Figure 4:16 Resilient Modulus against CRMA

4.11.1 Analysis of Resilient Modulus Results

Fatigue Resistance Based on Pavement Composition

When comparing the fatigue performance of the different asphalt pavement structures, it was observed that:

Neat asphalt exhibited the lowest resistance to fatigue cracking. The pavement modified with 5% crumb rubber (CR) showed significant improvement in fatigue performance. Incorporating 2% kaolinite into the 5% CR mixture further enhanced fatigue resistance compared to the CR-only mix.

i) **Impact of Crumb Rubber on Resilient Modulus**

Introducing crumb rubber to the asphalt mix resulted in a 63% increase in the resilient modulus from 4972.23 MPa (neat asphalt) to 8143.28 MPa. This enhancement is primarily due to the polymeric composition of crumb rubber, particularly styrene-butadiene rubber (SBR), which increases the binder's elasticity and enables it to stretch and recover after load application.

This improvement suggests that crumb rubber modified asphalt (CRMA) offers:

- Higher stiffness
- Enhanced resistance to fatigue and cracking
- Potentially extended pavement life under repetitive loading

ii) Effect of Kaolinite on CRMA's Resilient Modulus

Adding 2% kaolinite to the 5% CR mix caused a slight reduction in the resilient modulus from 8143.28 MPa to 7033.11 MPa. This reduction may be attributed to kaolinite's tendency to:

- Absorb bitumen, slightly reducing binder availability
- Alter binder-aggregate adhesion, which can affect stiffness

Nonetheless, the modified asphalt still exhibited a 41.4% higher modulus than neat asphalt. This implies that the CR and kaolinite mix maintains a superior elastic response, enabling it to endure higher axle loads and elevated temperatures for longer durations compared to the conventional mix.

4.12 Correlating Modification Effects to Pavement Lifespan

The lifespan of asphalt pavements is directly influenced by their resistance to fatigue, rutting, and moisture damage. An increase in the resilient modulus (Mr) typically correlates with enhanced durability due to the following:

- Reduced rutting, especially under high temperatures typical in tropical regions
- Improved load distribution, resulting in lower stress transferred to underlying layers
- Lower tensile strain at the base of the asphalt layer, reducing the risk of fatigue cracking

According to the Mechanistic Empirical Pavement Design Guide, a higher Mr leads to longer pavement life by mitigating structural damage. Supporting this, Huang (2004) states that a 10% increase in Mr can extend pavement life by 8–15%.

Given that CR and kaolinite modification increases Mr by 41%, the projected improvement in lifespan could range from 30% to 60%, depending on traffic intensity and environmental conditions.

Assuming the Kampala–Masaka Highway was designed for a 20-year lifespan, a 30% increase would extend its life by approximately 6 years. This enhancement offers significant economic and operational benefits for Uganda's transport infrastructure.

4.13 Materials Required for Modifying the Kampala-Masaka Highway

The Kampala–Masaka Highway is divided into segments with varying asphalt layer thicknesses. This study focused on Section 5 (Km 51+950 to 52+100), a flat section showing signs of top-down cracking.

The total asphalt thickness in this section is 170 mm, consisting of: 53 mm wearing course and 117 mm binder course.

This segment is suitable for implementing modified asphalt mixtures due to its structural composition and visible surface distress, making it an ideal candidate for performance improvement using CR and kaolinite additives.

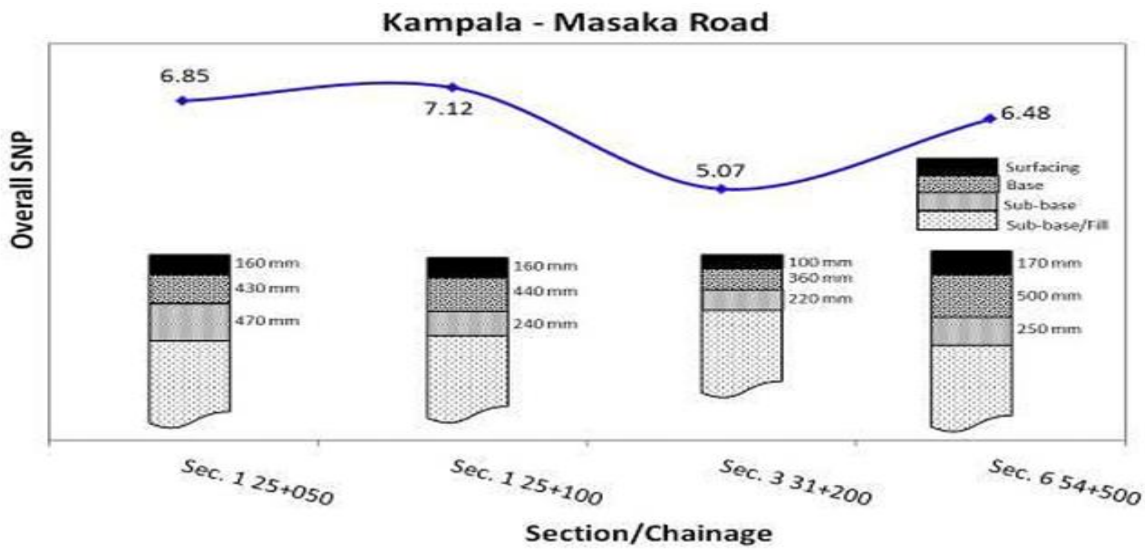


Figure 4:17 Kampala Masaka cross section

(adapted from TRL,2017)

4.13.1 Estimating Material Requirements and Cost for Modifying the Kampala-Masaka Highway

Since the top-down cracks observed on the Kampala–Masaka highway were found to originate within the wearing course, the material modification analysis focuses solely on this layer.

4.13.2 Estimating the Total Quantity of Asphalt

To determine the quantity of crumb rubber required, we begin by estimating the total weight of asphalt necessary to pave the 127 km stretch of the highway using a wearing course thickness of 53 mm (AC14 mix). Assuming a typical asphalt density of 2400 kg/m^3, the calculation for 1 m^2 of pavement is:

Volume of asphalt per m^2 = 1 × 0.053 = 0.053 m^3

Weight of asphalt per m^2 = 2400 kg/m^3 × 0.053 m^3 = 127.2 kg

However, based on mix properties and compaction, the actual weight per m^2 may average 74.2 kg, which is used in this study.

Assuming a consistent 2-lane road width of 8 meters (most common along the route), the total area becomes:

Total surface area = 127,000 m × 8 m = 1,016,000 m^2

Total asphalt weight = 1,016,000 m^2 × 74.2 kg/m^2 = 75,308,000 kg

4.14 Crumb Rubber Requirements

From the mix design, the asphalt composition includes:

Bitumen content = 4.9%

Air Voids = 3.5%

Filler = 4.5%

Aggregates = 87.1%

Therefore, bitumen weight in the entire asphalt volume is:

0.049 × 75,308,000 = 3,690,092 kg

To achieve the best performing mixture (as discussed in earlier sections), 5% crumb rubber (CR) by weight of bitumen was found to be optimal. So, the total CR required is:

0.05 × 3,690,092 = 184,504.6 kg

4.14.1 Converting Crumb Rubber from Truck Tires

We consider used truck tires (e.g., Dunlop), with an average tire weight of 70 kg, containing:

Rubber: ~45.5 kg

Steel: ~10.5 kg

Fillers/losses: ~14 kg

Assuming 65% of tire mass is usable rubber, the estimated number of tires needed is:

Tires needed = 184,504.6 kg ÷ 70 kg = 2,635.78 ≈ 2,636 truck tires

This translates to approximately 21 tires per kilometer of road.

This represents an excellent waste management opportunity, with scrap tires sourced from local junkyards (e.g., Bwaise) and tire shredding units such as City Tires Ltd., which processes 30+ truck tires per week.

4.14.2 Cost of Crumb Rubber

At 300 UGX per kg (for 0.75 mm CR size),

Total CR cost = 184,504.6 kg × 300 UGX = 55,351,380 UGX ≈ 55.5 million UGX

4.15 Kaolinite Clay Requirements

To improve binder homogeneity and storage stability, 2% kaolinite clay is added by weight of pure bitumen (excluding CR):

Bitumen without CR = 3,690,092 – 184,504.6 = 3,505,587.4 kg

2% of this = 0.02 × 3,505,587.4 = 70,111.75 kg of kaolinite

4.15.1 Cost of Kaolinite

At 3,000 UGX per kg (from Kabal Chemical Supplies Ltd),

Total cost = 70,111.75 × 3,000 UGX = 210,335,250 UGX ≈ 21.1 million UGX

4.16 Summary of Total Modification Cost

Table 4:13 Total Modification Cost

Material	Quantity (kg)	Unit Cost (UGX/kg)	Total Cost (UGX)
Crumb Rubber	184,504.6	300	55,351,380
Kaolinite clay	70,111.75	3000	210,335,250
Total cost			265,686,630 UGX

This cost is a modest investment considering the extended service life, improved performance, and environmental benefits such as tire waste reduction. The use of locally available materials further emphasizes the viability and sustainability of this modification approach.

4.17 Justification for the design

<table>
<tr>
<td>
Figure 4:18 Current profile along Section 5 (Km 51+950 – 52+100) of the Kampala–Masaka</td>
<td>
Figure 4:19 Redesigned pavement profile</td>
</tr>
</table>

a) **Pavement Profile Comparison and Economic Implications of Modified Asphalt**

Figure 4:18) illustrates the current pavement structure along Section 5 (Km 51+950 – 52+100) of the Kampala–Masaka highway. The profile consists of the following layers:

- Wearing Course (Asphalt Layer): 170 mm (black surface)
- Base Course (CRR - Crushed Rock): 500 mm (grey layer)
- Subbase Layer: 250 mm (natural brown color)
- Subgrade Layer: Infinite depth of lateritic material (foundation)

This section currently suffers from top-down cracking, primarily within the asphalt layer, as explained in previous chapters.

Figure 4:19) presents a redesigned pavement profile assuming the adoption of crumb rubber modified asphalt. While the asphalt thickness remains at 170 mm, the structural performance of the modified mix allows for a reduction in the lower pavement layers:

- Base Course Thickness reduced from 500 mm to 250 mm
- Subbase Layer reduced from 250 mm to 150 mm

These reductions are feasible due to the improved resilient modulus and tensile strain-absorbing capacity of the modified asphalt, which allows it to bear a greater proportion of traffic-induced stresses. This behavior has been thoroughly analyzed and supported by the resilient modulus and fatigue resistance data presented in preceding sections.

b) Economic and Structural Benefits

This revised pavement structure presents substantial cost-saving opportunities, particularly in the following areas:

Material savings: Reduced quantities of base and subbase materials such as crushed stone.

Transportation and hauling: Fewer truckloads of materials reduce fuel, time, and labor costs.

Construction processes: Lower costs in excavation, laying, and compaction.

Maintenance savings: Enhanced durability reduces the frequency and severity of future repairs.

Together with the extended pavement lifespan attributed to the enhanced properties of CR-Kaolinite modified bitumen, this design presents a cost-effective and technically superior solution for Uganda’s highway infrastructure.

This innovative approach not only enhances structural performance but also promotes environmental sustainability by utilizing waste materials such as scrap tires, contributing to better waste management practices in the country.

CHAPTER 5: CONCLUSION AND RECOMMANDATIONS

5.1 Conclusion

This study aimed to enhance the deformation resistance of asphalt by modifying bitumen using Crumb Rubber (CR) and Kaolinite clay.

1. The properties of bitumen, aggregates, crumb rubber and neat asphalt were within acceptable standard specifications of the Ministry of Works and Transport.

2. The addition of 5% Crumb Rubber (CR) to the bitumen produced the best results, showing an improvement in rheological properties, stability increased by 0.74% which is from 12.8KN to 22.3KN, flow increased by 0.17% from 3mm to 3.5mm and air voids decreased by -0.08% from 4.9% to 4.5%. However, variations in sample consistency were observed, particularly in samples where crumb rubber content was unevenly distributed.

3. Adding 2% Kaolinite clay to the 5% CR-modified bitumen resulted in improved storage stability and a more uniform mixture. Stability further increased from 22.3KN to 25.2KN, flowed increased from 3.5mm to 3.9mm and air voids decreased from 4.5% to 4.0%. This shows a positive impact from the addition of kaolinite in the mix design, which is improving the strength of CRMA.

4. The comparison of Indirect Tensile Strength (ITS) and Resilient Modulus (Mr) tests highlighted the advantages of CR and Kaolinite-modified asphalt in improving road longevity. The modifications increased the load-bearing capacity and lifespan of the pavement by at least 30%, potentially extending the road's life by 6 years, while also offering a sustainable way to recycle waste tires. This modification technique

provides both financial savings and environmental benefits, especially when applied to long roads like the Kampala-Masaka highway.

5.2 Recommendations

5.2.1 Based on findings

The incorporation of crumb rubber and kaolinite as modifiers for bitumen should be adopted for highway construction in Uganda as the economic and practical benefits have been clearly outlined in the preceding chapters.

5.2.2 Recommendations for further studies

1. Further research is needed to assess the feasibility of using passenger car tires for crumb rubber, as they differ from truck tires in their rubber composition. This would help determine if the modification effects are similar.
2. Additionally, studies should explore varying mixing conditions such as temperature, particle size of the rubber crumbs, and mixing duration to find the optimal parameters for bitumen modification.
3. Investigating the potential of using Montmorillonite clay as an alternative to Kaolinite clay would also be valuable, given their similar structural properties.
4. Lastly, it is recommended to conduct further tests, including long-term aging, Multiple Stress Creep Recovery (MSCR), Bending Beam Rheometer (BBR), and pavement performance simulations, to understand the behavior of modified bitumen under real-life conditions over extended periods.

REFERENCES

Airey GD, Rahman MM, C. A. (2003). Absorption of bitumen into crumb rubber using the basket drainage method. Int. J. Pavement Eng, 105–119.

Amirkhanian, S. and S. (2005). The influence of crumb rubber modifier (CRM) microstructures on the high temperature properties of CRM binders. The International Journal of Pavement Engineering,Vol.6, 265–271.

Ariyapijati, R. H., Hadiwardoyo, S. P., & Sumabrata, R. J. (2017). Contributions crumb rubber in hot mix asphalt to the resilient modulus. AIP Conference Proceedings, 1855(June 2017). https://doi.org/10.1063/1.4985475

Becker Y, Mendez MP, R. Y. (2001). Polymer modified asphalt. Vision Tecnologica, 39–50.

C. Thodesen, K. Shatanawi, S. Amirkhanian, and W. B. (2009). Development of an empirical model for determining G∗/sin ? in crumb rubber modified binders. In Construction and Building Materials,vol.23.

C.Billiter, R.R.Davison, C.J.Glover, A. A. B. (1997). Physical properties of asphalt-rubber binder,. Petroleum Science and Technology,Vol.15, 205–236.

Costa, O. . (2022). Investigation of cracks in flexible pavement on a section of Kampala– Masaka road.

Han, L.; Zheng, M.; Wang, C. (2016). Current status and development of terminal blend Tire rubber modified asphalt. Constr. Build. Mater, 128, 399–409.

Huang, T. H. (2004). Pavement Analysis and Design. 93 | P a g e

Huang Y, Bird RN, H. O. (2007). (2007). A review of the use of recycled solid waste materials in asphalt pavements. Resources, Conservation and Recycling,.

J. Shen, S. Amirkhanian, F. Xiao, and B. T. (2009). Influence of surface area and size of crumb rubber on high temperature properties of crumb rubber modified binders,. Construction and Building Materials,Vol.23,No.1, 304–310.

Lee SJ, Amirkhanian SN, S. K. (2006). (2006). Effect of reaction time on physical and chemical properties of rubber-modified binders.

Mahrez A, R. M. (2003). Rheological evaluation of aging properties of crumb rubber-modified bitumen. Journal of the Eastern Asia Society for Transportation Studied, 820–833.

Mahrez A, R. M. (2003. (2003). Rheological evaluation of aging properties of crumb rubber-modified bitumen. Journal of the Eastern Asia Society for Transportation Studied, 820–833.

N. Sunthonpagasit and M. R. Duffey. (2004). Scrap tires to crumb rubber: feasibility analysis for processing facilities.

P.Cong, P.Xun, M.Xing, A. C. (2013). Investigation of asphalt binder containing various crumb rubbers and asphalts. Con Struction and Building Materials,Vol.40, 632– 641.

Rolt, J., Hearn, G. J., Mukura, K., Otto, A. (2019). Final Investigation Report Investigation of Premature Pavement Failures in Uganda.

S. Liu, W. Cao, J. Fang, and S. S. (2009). Variance analysis and performance evaluation of different crumb rubber modified (CRM) asphalt. Variance Analysis and Performance Evaluation of Different Crumb Rubber Modified (CRM) Asphalt, 2701–2708.

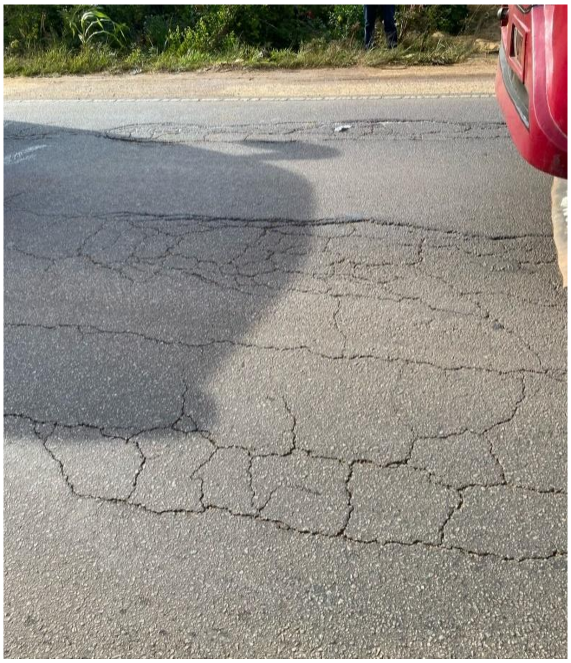
Walter H.F., E. (1993). Use of Waste Materials in Hot-mix Asphalt, ASTM Special Technical Publication. 1193.

Xiao F, Ameirkhanian SN, P. B. (2006. (2006). Laboratory investigation of dimensional changes of crumb rubber reacting with asphalt binder.

Zhang, B., Xi, M., Zhang, D., Zhang, H. and Zhang, B. 2009. (2009). The Effect Of Styrene–Butadiene–Rubber/Montmorillonite Modification on the Characteristics And Properties Of Asphalt. Construction and Building Materials., 3112–3117.

1.6 APPENDICES

1.6.1 Laboratory works

 appendix 1 Failed section along the highway	 appendix 2 Site visit to the failed section

appendix 3 Conditioned bitumen samples to be tested

appendix 4 Softening point test

appendix 5 Sieving aggregates

 appendix 6 10% FV test	 appendix 7 Different CR sizes


appendix 8 Weighing CR


appendix 9 Adding CR into bitumen


appendix 10 Adding CRMB into the batch


appendix 11 Manually stirring

<table>
<tr>
<td>

appendix 12 Kaolinite added into CRMB</td>
<td>
appendix 13 Storage stability test</td>
</tr>
</table>

Appendix 1: Laboratory Test Certificates

INSTITUTION	STUDENT'S NAME	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MAC DON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

BITUMEN TESTS

LOCATION		OPERATOR	Lab team
SUPPLIER		CONTAINER/DELIVERY NO	
	18-Dec-24	DESTINATION	
MATERIAL TYPE	60/70		

TEST NO	CX		I8		3	D	2	18'	AVERAGE	REMARKS
PENETRATION 100gr 5 sec 25 C	69 69 69		67 67 65		68 74 70	67 69 68	68 69 67	72 70 69	69	60-70
SOFTENING POINT (°C)		50		50					50	(49-56)°C
BITUMEN AFFINITY										>95
SUPECIFIC GRAVITY	1.008		1.015		1.014	1.017	1.013	1.016	1.014	1.01-1.06

Materials Engineer

STIRLING CIVIL ENGINEERING LTD

P.O. BOX 795, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MAC DON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

PROPERTY TESTS FOR BITUMEN

Testing method	EN 12596	VISCOCITY TEST	Operator : *Lab Team*
Date sampled:	5-Jan-25		
Date tested:	5-Jan-25		
Material Type	60/70		

Test No	1		2	3	AVERAGE	REMARKS
Viscocity at 135°C (mm^2/Sec)	320		319	322	**320**	Min 295

Remarks:

FOR TESTING LAB

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

Lab Technician

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MAC DON & PITIA ANTHONY	Stirling

PROJECT: ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

A.C.V. LABORATORY TEST RESULT FORM

(BS 812PART 110:1990)

LOCATION:	MUKONO SITE	Oparator	12/Jan/25
MATERIAL DESCRIPTION:	AGGREGATES FOR ASPHALT	Date	13/Jan/25

A.C.V

(A) WT BEFORE CRUSHING (gm)	2835		2820
(B) WT AFTER CRUSHING (gm)	2835		2820
(C) WT RETAINED AFTER CRUSHING (gm)	2395		2360
(D) WT PASSING SIEVE 2.36 mm	440.0		460
A.C.V(%) (D/B)*100	15.5		16.3
AVERAGE RESULTS %	15.9		
NB	more than B by 10gms repeat the test		

A.I.V

(A) WT BEFORE TEST (gm)	355	365	355.0
(B) WT AFTER TEST (gm)	355	364.5	355.0
(C) WT RETAINED AFTER TEST (gm)	305	310	300.0
(D) WT PASSING SIEVE 2.36 mm	50.0	55.0	55.0
A.I.V(%) (D/B)*100	14.1	15.1	15.5
AVERAGE RESULTS %	14.9		
NB	If c+d is more than B by 1gms repeat the test		

SPECIFIED LIMITS IN ACCORDANCE WITH TYPE OF MATERIAL

FOR CONTRACTOR

Lab Technician

Materials Engineer

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

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

In any Correspondence on this subject please quote No..................................

THE REPUBLIC OF UGANDA

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

DFD 035/2025
07th February 2025

MR. MAC DON AND MR. PITIA ANTHONY
REG NO. S21B32/109 & S21B32/033
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 crushed black tyre sample was submitted by MR. Mac Don, on 30th January 2025, and analysed on 04th February 2025. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	crushed black tyre substances packed in a black polythene bag	1	**SAMPLE A DFD 035/2025**

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 035/2025	FTIR SCREENING	Tencel, Kaolin with polythene chlorinated, methylcellulose, styrene butadiene rubber, polyisoprene, latex, hydrocarbons

Remarks

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

07/02/25

Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MAC DON & PITIA ANTHONY	Stirling

PROJECT :	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

A/C 14 ASPHALT NOT MODIFIED

SUMMARY OF A/C 14 TEST RESULTS

			BITUMEN CONTENT		4.9
AGGREGATE TESTS	ACHIEVED	SPECIFIED	MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
			MARSHALL FLOW	3.0	2—4
Sodium Soundness	2.1	<12%	MARSHALL STABILITY 75BLOWS	13.4	9-18
Water Absorption	0.4	< 2%	MARSHALL AIR VOIDS 75BLOWS	4.9	3—5
TFV Dry	293.7	>110kN	VOIDS IN MINERAL AGGREGATES	15.1	>14%
TFV Soaked Wet/Dry ratio	104%	>75%	VOIDS FILLED WITH BINDER	67.7	65—75%
Flakness Index	19.5	< 25%	INDIRECT TENSILE STRENGTH @ 25C	1,066	>800kpa
Plastic Index	N/P	< 4%	INDIRECT TENSILE WET STRENGTH	89	>80% of dry
LAA	17.8		BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
ACV	15.9		RATIO STABILITY/FLOW	4.4	>2.5
AIV	14.9				

TEST ON MATERIAL	ACHIEVED	SPECFIED		WITH OUT BITUMEN %	WITH BITUMEN %
BITUMEN TESTS			14/20	5	4.8
PENETRATION	#REF!	60-70	10/14	7	6.7
SOFTENING POINT	#REF!	49-56	6/10	18	17.1
SPECIFIC GRAVITY OF BITUMEN	#REF!	1.01--1.06	0/6	66	62.7
SPECIFIC GRAVITY OF AGGREGATES	2.592		FILLER	4	3.8
			BITUMEN CONTENT		4.9

STIRLING CIVIL ENGINEERING LTD
For CONTRACTOR
10 FEB 2025
Lab technician
KAMPALA (U)

1

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MAC DON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

Field Ref. No.:		Lab. no.		Chainage sample 1:		Sampling date:	03-Feb-23
Sample grade:	AC 14	Compaction:	75 blows	Chainage sample 2:	LAB TRIAL MIX EXPECTED PRODUCTION	Testing date:	04-Feb-23
Sample Description:				AC 14			

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

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

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

ASTM D6927Standard Method for Marshall Stability and Flow

Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Stability (KN) Adjusted	Flow (mm)	Ratio (Stab./Flow)
65.4	65.3	65.4	65.4	0.95	13.0	12.36	3.32	3.722
66.4	66.0	65.4	65.9	0.95	13.7	12.98	2.60	4.991
64.5	65.2	65.2	65.0	0.96	13.2	12.70	3.05	4.163
66.2	65.1	66.4	65.9	0.95	13.7	12.98	2.83	4.585
Average Sample 1			65.5	1.0	13.4	12.8	3.0	4.4
-	-	-	-	-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2								

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

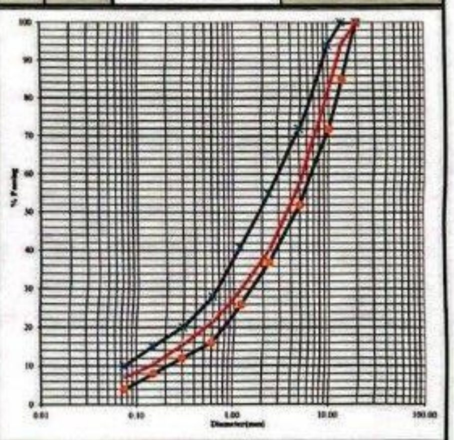
Mass (g)	Sample 1	Sample 2
Bowl	232.3	167.8
Bowl + Asphalt	1937.5	1869.0
Asphalt	1705.2	1701.2
Filter paper before extraction	29.3	31.8
Filter paper + Filler After extracti	30.8	33.1
Recovered Filler	1.5	1.3
Oven dry extracted Mtl (dry)	1619.6	1614.1
Oven dry extr. mtl + filler	1621.1	1615.4
Bitumen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

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

SAMPLE 1			SAMPLE 2		
(Pycnometer with Water)			(Pycnometer with Water)		
Temperature of water (°c)	25°C		Temperature of water (°c)	25°C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1288		Asphalt	1126.5	-
Pycn. + Water	7363		Pycn. + Water	7363	-
Pycnometer + Asph. + Water	8125.8		Pycnometer + Asph. + Water	8029.3	-
Volume of asphalt	525.2	-	Volume of asphalt	460.2	-
G_{mm}	2.452	-	G_{mm}	2.448	-
Av. G_{mm}	2.452		Av. G_{mm}	2.448	
Av. Gmm (Kg/m3) Sample 1& 2				2450	

Comment:

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



FOR CONTRACTOR

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 790, KAMPALA (U)

INSTITUTION	STUDENT'S NAME	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MACDON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

LOCATION	BITUMEN TESTS	OPERATOR Lab team
SUPPLIER		CONTAINER/DELIVERY NO
24-Jan-25		
MATERIAL TYPE 60/70	60/70 BITUMEN MODIFIED WITH 5% CRUMB RUBBER	DESTINATION

TEST NO	18		D		3	18'			AVERAGE	REMARKS
PENETRATION 100gr 5 sec 25 C	62 63 61		63 62 63		60 65 65	62 62 62			63	60-70
SOFTENING POINT (°C)		49		49					49	(49-56)°C
BITUMEN AFFINITY										>95
SUPECIFIC GRAVITY	1.020		1.021		1.021	1.023			1.021	1.01-1.06

Materials Engineer.

STIRLING CIVIL ENGINEERING LTD
P. O. BOX 253, KAMPALA (U)

INSTITUTION	STUDENT'S NAME	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MACDON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

LOCATION	BITUMEN TESTS	OPERATOR Lab team
SUPPLIER		CONTAINER/DELIVERY NO
24-Jan-25		
MATERIAL TYPE 60/70	60/70 BITUMEN MODIFIED WITH 10% CRUMB RUBBER	DESTINATION

TEST NO	9		4B		S2	4Z			AVERAGE	REMARKS
PENETRATION 100gr 5 sec 25 C	53 50 52		54 52 50		52 53 55	52 56 54			53	60-70
SOFTENING POINT (°C)		51		51					51	(49-56)°C
BITUMEN AFFINITY										>95
SUPECIFIC GRAVITY	1.024		1.029		1.021	1.028			1.025	1.01-1.06

Materials Engineer.

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

INSTITUTION	STUDENT'S NAME	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MAC DON & PITIA ANTHONY	Stirling

PROJECT: ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

LOCATION

SUPPLIER

24-Jan-25

MATERIAL TYPE 60/70

BITUMEN TESTS

OPERATOR Lab team

CONTAINER/DELIVERY NO

DESTINATION

60/70 BITUMEN MODIFIED WITH 15% CR

TEST NO	O		RM		6	SR			AVERAGE	REMARKS
PENETRATION 100gr 5 sec 25 C	48 50 50		51 50 50		51 49 52	47 48 41			49	60-70
SOFTENING POINT (°C)		52.5		52.5					53	(49-56)°C
BITUMEN AFFINITY										>95
SUPECIFIC GRAVITY	1.038		1.037		1.040	1.037			1.038	1.01-1.06

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
10 SEP 2025
P.O. BOX 796, KAMPALA (U)

INSTITUTION	STUDENT'S NAME	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MAC DON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

LOCATION SUPPLIER	BITUMEN TESTS	OPERATOR Lab team
24-Jan-25		CONTAINER/DELIVERY NO
MATERIAL TYPE 60/70	60/70 BITUMEN MODIFIED WITH 20% CR	DESTINATION

TEST NO	O8		M12		NG	BI			AVERAGE	REMARKS
PENETRATION 100gr 5 sec 25 C	45 46 46		47 43 44		44 45 46	47 47 45			45	60-70
SOFTENING POINT (°C)		65		65					65	(49-56)°C
BITUMEN AFFINITY										>95
SUPECIFIC GRAVITY	1.044		1.044		1.038	1.042			1.042	1.01-1.06

Materials Engineer

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

INSTITUTION	STUDENT'S NAME	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MACDON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

LOCATION	DUCTILITY BITUMEN TEST	OPERATOR Lab team
MATERIAL TYPE BITUMEN		DESTINATION

TESTING DATE: 10/01/2025 & 11/01/2025	NEAT BITUMEN				AVERAGE	REMARKS (mm)	Testing method
Mould No.	1		2		1167	>1000	ASTM D113
Time poured	11:50Am		11:50Am				
Time place in water bath	12:50Pm		12:50Pm				
Distance elongated (mm)	1165		1168				

TEST NO	5%CRUMB RUBBER				AVERAGE	REMARKS (mm)	Testing method
Mould No.					514	>500	DIN 52013 (For modified bitumen)
Time poured	2:30Pm		2:30Pm				
Time place in water bath	3:30Pm		3:30Pm				
Distance elongated (mm)	515		512				

TEST NO	10%CRUMB RUBBER				AVERAGE	REMARKS (mm)	Testing method
Mould No.					520	>500	DIN 52013 (For modified bitumen)
Time poured	3:10pm		3:10pm				
Time place in water bath	3:10pm		3:10pm				
Distance elongated (mm)	520		520				

TEST NO	15%CRUMB RUBBER				AVERAGE	REMARKS (mm)	Testing method
Mould No.					375	>500	DIN 52013 (For modified bitumen)
Time poured	9:00am		9:00am				
Time place in water bath	10:00Pm		10:00Pm				
Distance elongated (mm)	375		374				

TEST NO	20%CRUMB RUBBER				AVERAGE	REMARKS (mm)	Testing method
Mould No.					287	>500	DIN 52013 (For modified bitumen)
Time poured	2:40pm		2:40pm				
Time place in water bath	3:40pm		3:40pm				
Distance elongated (mm)	285		288				

CIVIL ENGINEERING LTD
For Stirling
P.O. BOX 793, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MAC DON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

PROPERTY TESTS FOR BITUMEN MODIFIED WITH 5% CRUMB RUBBER

Testing method	EN 12596	VISCOCITY TEST	Operator : *Lab Team*
Date sampled:	5-Jan-25		
Date tested:	5-Jan-25		
Material Type	60/70		

Test No	1			2	AVERAGE	REMARKS
Viscocity at 135°C (mm^2/Sec)	330			335	**333**	Min 295

Remarks:

FOR TESTING LAB

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	**MAC DON & PITIA ANTHONY**	Stirling

PROJECT	**ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION**

PROPERTY TESTS FOR BITUMEN MODIFIED WITH 10% CRUMB RUBBER

Testing method	**EN 12596**	VISCOCITY TEST	Operator : *Lab Team*
Date sampled:	5-Jan-25		
Date tested:	5-Jan-25		
Material Type	60/70		

Test No	1			2	AVERAGE	REMARKS
Viscocity at 135°C (mm^2/Sec)	350			355	**353**	Min 295

Remarks:

FOR TESTING LAB

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

Lab Technician

Materials Engineer

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MAC DON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

PROPERTY TESTS FOR BITUMEN MODIFIED WITH 15% CRUMB RUBBER

Testing method	EN 12596	VISCOCITY TEST	Operator : *Lab Team*
Date sampled:	22-Jan-25		
Date tested:	22-Jan-25		
Material Type	60/70		

Test No	1			2	AVERAGE	REMARKS
Viscocity at 135°C (mm^2/Sec)	375			371	373	Min 295

Remarks:

FOR TESTING LAB

STIRLING CIVIL ENGINEERING LTD
P. O. BOX 793, KAMPALA (U)

Materials Engineer

Lab Technician

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	MAC DON & PITIA ANTHONY	Stirling
PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION	

PROPERTY TESTS FOR BITUMEN MODIFIED WITH 20% CRUMB RUBBER

Testing method	EN 12596	VISCOCITY TEST	Operator : Lab Team
Date sampled:	22-Jan-25		
Date tested:	22-Jan-25		
Material Type	60/70		

Test No	1			2	AVERAGE	REMARKS
Viscocity at 135°C (mm^2/Sec)	424			425	425	Min 295

Remarks:

FOR TESTING LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
P.O. BOX 793, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MAC DON & PITIA ANTHONY	Stirling

PROJECT :	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

5% CRUMB RUBBER

SUMMARY OF A/C 14 JOB MIX TEST RESULTS

BITUMEN CONTENT		4.9
MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW	3.9	2—4
MARSHALL STABILITY 75BLOWS	17.1	9-18
MARSHALL AIR VOIDS 75BLOWS	4.6	3—5
VOIDS IN MINERAL AGGREGATES	15.1	>15%
VOIDS FILLED WITH BINDER	69.5	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,097	>800kpa
INDIRECT TENSILE WET STRENGTH	68	>80% of dry
BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
RATIO STABILITY/FLOW	4.6	>2.5

TESTING LAB

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MAC DON & PITIA ANTHONY	Stirling

PROJECT

ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

Field Ref. No.		Lab. no.		MIX	5% CRUMB RUBBER	Sampling date:	31-Jan-25	Test Type	Done by	Test Type	Done by
Sample grade	AC 14	Compaction:	75 blows			Testing date:	01-Feb-25	B.R.D	lab team	B.C/Grad.	lab team
Sample Description:					AC 14			T.M.R.D.	lab team	Stab. & Flow	lab team

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

Marshall specim.	Mass in air	Mass in Water	Saturated surface Dry in air	Bulk S.G (G_{mb})	Unit Wt. (Kg/m³)	% Air Voids	% VMA	% VFB
1	1201.1	693.20	1201.80	2.362	2.350	4.4	14.9	70.7
2	1200.1	690.80	1201.00	2.352	2.341	4.7	15.2	68.9
3	1187.6	684.60	1188.70	2.356	2.345	4.6	15.1	69.6
4	1197.4	688.50	1197.80	2.351	2.340	4.8	15.3	68.7
Average Sample 1				2.355	2.344	4.6	15.1	69.5
-				-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2				2.355	2.344	4.6	15.1	69.5

ASTM D6927 Standard Method for Marshall Stability and Flow

Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Stability (KN) Adjusted	Flow (mm)	Ratio (Stab./Flow)
62.2	62.6	62.0	62.3	1.02	17.1	17.45	3.87	4.509
62.7	62.2	62.0	62.3	1.06	17.8	18.87	3.98	4.741
62.0	62.0	61.9	62.0	1.03	16.6	17.15	3.87	4.430
61.7	62.1	62.2	62.0	1.05	16.9	17.72	3.74	4.738
Average Sample 1			62.1	1.0	17.1	17.8	3.9	4.6
-	-	-	-	-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2								

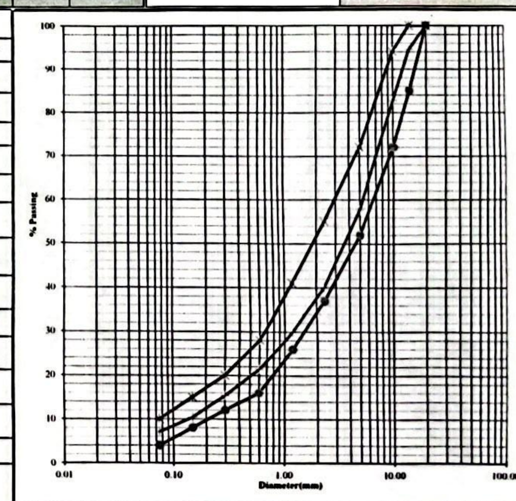
ASTM D 2172- Standard Test Method for Quantitative Extraction of Bitumen from Asphalt Mixtures

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

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

SAMPLE 1			SAMPLE 2		
(Pycnometer with Water)			(Pycnometer with Water)		
Temperature of water (°c)	25°C		Temperature of water (°c)	25°C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1353		Asphalt	924.2	-
Pycn. + Water	8553.15		Pycn. + Water	8553.15	-
Pycnometer + Asph. + Water	9355.3		Pycnometer + Asph. + Water	9101.4	-
Volume of asphalt	550.85	-	Volume of asphalt	375.95	-
G_{mm}	2.456	-	G_{mm}	2.458	-
Av. G_{mm}	2.456		Av. G_{mm}	2.458	
Av. Gmm (Kg/m3) Sample 1& 2			2.457		

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



Comment:

STIRLING CIVIL ENGINEERING LTD
FEB 2025
P.O. BOX KAMPALA (U)

FOR TESTING LAB

Materials Engineer

INSTITUTION		STUDENTS		Testing Lab	
UGANDA CHRISTIAN UNIVERSITY		MACDON & PITIA ANTHONY		Stirling	
PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION				
TEST	BITUMEN STORAGE STABILITY TEST				
Test Reference No.:		Lab. Reference No.:			
Test method	ASTM D5926		Technician :	Lab team	
Grade	60-70		Sampling date:	23-Jan-25	
Source of the sample	STOCKPILE		Testing date:	24-Jan-25	
MIX	5% CRUMB RUBBER & KAOLINETE CLAY				
% KAOLINE	TOP	BOTTOM	DIFFERENCE (Degrees)	SPEC	Remark
0	48.1	58.50	10.40	Max 10(°C)	Not stable
1	49.8	57.20	7.40	Max 10(°C)	Stable
1.5	51.5	54.70	3.20	Max 10(°C)	Stable
2	52	53.90	1.90	Max 10(°C)	Very Stable
2.5	52.3	54.60	2.30	Max 10(°C)	Stable

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MAC DON & PITIA ANTHONY	Stirling

PROJECT :	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

5% CRUMB RUBBER & 2% KAOLINETE BITUMEN

SUMMARY OF A/C 14 JOB MIX TEST RESULTS

	BITUMEN CONTENT	4.9
MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW	3.4	2—4
MARSHALL STABILITY 75BLOWS	21.7	9<
MARSHALL AIR VOIDS 75BLOWS	4.4	3—5
VOIDS IN MINERAL AGGREGATES	15.2	>15%
VOIDS FILLED WITH BINDER	71.0	65—75%
INDIRECT TENSILE STRENGTH @ 25C	999	>800kpa
INDIRECT TENSILE WET STRENGTH	87	>80% of dry
BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
RATIO STABILITY/FLOW	6.6	>2.5

TESTING LAB

Lab technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	MAC DON & PITIA ANTHONY	Stirling

PROJECT	ACCESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION

Field Ref. No:		Lab. no.		MIX	5% CRUMB RUBBER & 2% KAOLINETE BITUMEN	Sampling date:	10-Mar-25	Test Type	Done by	Test Type	Done by
Sample grade	AC 14	Compaction:	75 blows			Testing date:	11-Mar-25	B.R.D	lab team	B.C/Grad.	lab team
Sample Description:					AC 14			T.M.R.D.	lab team	Stab. & Flow	lab team

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

Marshall specim.	Mass in air	Mass in Water	Saturated surface Dry in air	Bulk S.G (G_{mb})	Unit Wt. (Kg/m^3)	% Air Voids	% VMA	% VFB
1	1192.7	689.30	1193.40	2.366	2.355	3.9	14.7	73.7
2	1192.6	685.50	1195.90	2.337	2.325	5.1	15.8	67.9
3	1196.1	692.10	1196.70	2.370	2.359	3.7	14.6	74.6
4	1199.6	689.90	1203.20	2.337	2.326	5.0	15.8	68.0
Average Sample 1				2.353	2.341	4.4	15.2	71.0
-				-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2				2.353	2.341	4.4	15.2	71.0

ASTM D6927Standard Method for Marshall Stability and Flow

Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Stability (KN) Adjusted	Flow (mm)	Ratio (Stab./Flow)
62.0	62.6	61.7	62.1	1.04	22.7	23.56	3.65	6.456
63.0	62.9	63.1	63.0	1.01	19.9	20.08	2.90	6.925
61.3	62.0	61.7	61.7	1.05	22.9	24.03	3.48	6.906
63.2	63.4	63.2	63.3	1.01	21.5	21.72	3.45	6.295
Average Sample 1			62.5	1.0	21.7	22.3	3.4	6.6
-	-	-	-	-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2								

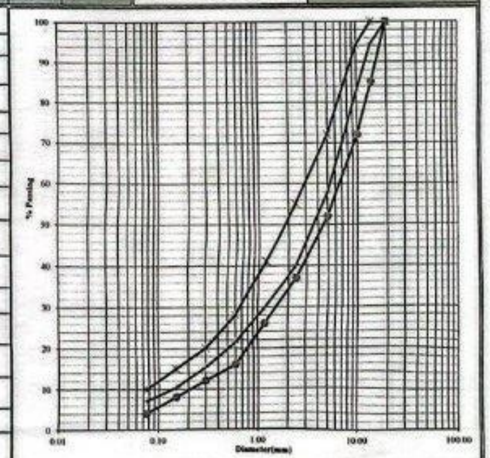
ASTM D 2172- Standard Test Method for Quantitative Extraction of Bitumen from Asphalt Mixtures

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

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

SAMPLE 1			SAMPLE 2		
(Pycnometer with Water)			(Pycnometer with Water)		
Temperature of water (°c)	25°C		Temperature of water (°c)	25°C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1245		Asphalt	1258.6	-
Pycn. + Water	8554.2		Pycn. + Water	8554.2	-
Pycnometer + Asph. + Water	9290.9		Pycnometer + Asph. + Water	9299	-
Volume of asphalt	508.3	-	Volume of asphalt	513.8	-
G_{mm}	2.449	-	G_{mm}	2.450	-
Av. G_{mm}	2.449		Av. G_{mm}	2.450	
Av. Gmm (Kg/m3) Sample 1 & 2			2.449		
Comment:					

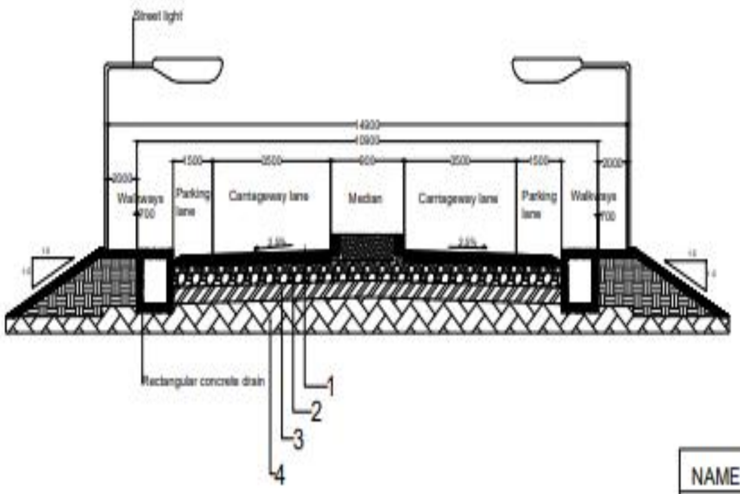
Sieve (mm)	Smpl Mass retained	Smp2 Mass retained	Av. Mass retained	% Av. Retained	% Av. passing	JMF Lower	JMF Upper
20	0.0	0.0	0.0	0.0	100	100	100
14	97.9	80.4	89.2	5.5	94	85	100
10	185.0	196.7	190.9	11.8	83	72	94
5	388.0	420.0	404.0	25.0	58	52	72
2.36	287.9	282.1	285.0	17.6	40	37	55
1.18	170.0	160.2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



FOR TESTING LAB
Materials Engineer

STIRLING CIVIL ENGINEERING LTD
11 MAR 2025
P. O. BOX 736, KAMPALA (U)

Appendix 2: Engineering drawing of the Kampala Masaka Highway



TYPICAL CROSS-SECTION TOWARDS LUKAYA TOWN

PAVEMENT LAYER DETAILS		
PAVEMENT LAYER	THICKNESS (mm)	MATERIAL USED
ASPHALT LAYER,1	53	AC14 HMA wearing course modified with 5% CR and 2% kaolinite clay
	117	AC20 HMA binder course
BASE COURSE,2	250	Crushed rock stone CBR(unsoaked) ≥ 80%
SUBBASE,3	200	Natural gravel of CBR unsoaked ≥ 40% and compacted ≥ 95% MDD

NAME	MAC DON & PITIA ANTHONY
TITLE	ASSESSING THE USE OF CRUMB RUBBER AND KAOLINITE CLAY TO THE RESISTANCE OF ASPHALT TO DEFORMATION
CASE STUDY	KAMPALA - MASAKA HIGHWAY
SUBMITTED TO	FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, UCU
DATE	16/04/2025