INVESTIGATING THE USE OF POLYPROPYLENE IN HOT MIX ASPHALT ON THE MIX DESIGN OF FLEXIBLE PAVEMENTS

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

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ABSTRACT

A Flexible pavements is a road constructed with its wearing course made up of Aggregates, Fillers and Bitumen as their binder. This research was aimed at investigating the use of Polypropylene in Hot Mix Asphalt on the mix design of flexible pavements. The main methods employed were Mechanical tests on the Density of Polypropylene, Penetration Test on Bitumen, Ten percent Fines Value for the Aggregates, Marshal Mix Design, Marshall Test, Indirect Tensile Strength and Volumetric analysis of the Asphalt Concrete.

Results showed that at an Optimal Bitumen Content of 4.9%, the addition of 1.5% Polypropylene in AC14 Mix design led to enhancements in; stability by 0.146%, Flow by 0.133%, Indirect Tensile Strength by 0.088% and Air Voids by 0.045%.

In conclusion Polypropylene enhances the Strength and Volumetric properties of Asphalt Concrete behaving like an antistripping agent therefore it is scientifically and practically applicable to be used in the Mix Design of Hot Mix Asphalt to minimize the occurrence of premature failure of the wearing course in Flexible pavements. It is recommended for a Cost Benefit analysis to be carried out to show the economic advantage of the Polypropylene Asphalt Concrete Mix Design over the conventional Asphalt.

DECLARATION

I WASSWA MARVIN DEO, hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for any award.

WASSWA MARVIN DEO

Signature ………………………………………… Date………………………………

APPROVAL

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

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

AGUTI JOSEPINE.

Department of Engineering and Environment

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ABBREVIATIONS AND ACRONYMS

AC - Asphalt Concrete

ACV - Aggregate Crushing Value

AIV - Aggregate Impact Value

HMA - Hot Mix Asphalt

ITSR - Indirect Tensile Strength Ratio

PE - Polyethylene

PET - Polyethylene Terephthalate

PP - Polypropylene

TFV - Ten Percent Fines Value

UV - Ultra-Violet

VFB - Voids Filled with Bitumen

VIM - Voids in Mix

VMA - Voids in Mineral Aggregates

VOC - Vehicle Operating Cost

TERMS AND DEFINITIONS

Aging: This is an attribute of asphalt pavements that results in cracking at low temperatures or rutting at high temperatures because of oxidation, heat, and ultraviolet (UV) light (Shafabakhsh put& Ani, 2015).

Asphalt mixture durability: This is the compacted asphalt concrete's ability to withstand environmental damage and traffic loads without losing structural integrity over the course of its anticipated service life (Didier & Jack, 2013).

Bitumen: Binding material the road construction Sector (Jamal, 2017).

Bituminous mix: A mixture of a bituminous binder and aggregate (The Republic of Uganda, 2000).

Moisture damage: this is the deterioration of strength and durability in asphalt mixtures brought on by the presence of water (Ahmed & Behiry, 2012).

Pavement: The upper layers of the road normally comprising the base and bituminous surfacing for flexible pavements (The Republic of Uganda, 2000).

Pavement deterioration: this is method by which pavement distresses arise as a result of both environmental factors and traffic load (Adlinge & Gupta, 2009).

A road is a route made over land for the transportation of vehicles, people, and animals. Roads offer trustworthy routes for transporting people and cargo from one location to another (Brockenrough, 2023)

Rutting: Longitudinal, persistent surface depressions on a flexible pavement's wheel tracks (Mazurowski, 2021).

Stripping: This is the process where the bond between the asphalt and aggregate is broken by the action of water (Asphalt Institute, 2014).

CHAPTER 1: INTRODUCTION

1.1. Background of Research

Roads are constructed in layers called pavements, which are engineered based on the traffic volume using the road and the geotechnical and hydrological conditions on site. Pavements are categorized as Flexible or Rigid, which are made of Asphalt Concrete and Portland Cement Concrete repetitively.

The Uganda Road network is constructed using Flexible pavements consisting of bituminous materials that are a mix of Aggregates (course & fine) and Bitumen in addition of other materials like lime, cement and plastics which are well proportioned for Traffic application in the Asphalt mix design (Handbook, Highway Engineering, 2023).

Despite the Mix design preparations, this layer experiences pre-mature pavement failure due to exposure to moisture, oxygen, temperature variation, excessive loading and many other factors weakening the bitumen, resulting into ruttings, cracks and potholes. This affects the social and economic development of the country.

Considering that Polypropylene is known for its durability and resistance to degradation, hence persist in the environment for a long time, recycling and reusing is the most feasible method to reduce polypropylene's detrimental effects.

1.2. Problem Statement

The reduced Road capacity due to loss in strength of Asphalt wearing course yields Alligator Cracks, Rutting and potholes as seen along Nasser Road Kampala City. This could be caused by oxidation, ultra- violet rays, and water & temperature effects on the Bitumen leading to its strip from the aggregates (Juma, 2023) hence reduced durability of the pavement. (Akshatha et al., 2019). The Deteriorations can be minimized by the use of geosynthetic materials to enhance tensile strength of the pavement, incorporating polymer modifiers in asphalt Mix to enhance its resistant to rutting, addition of an antistripping agent in the Mix design, Regular pavement maintenance and drainage improvement.

According to Akora 2022 in an investigation on the Use of Polyethylene Coated Aggregates to the Durability of Flexible Pavement, the Marshall flow increased from 3mm to 3.4mm, Stability from 13.4KN to 16KN, Air Voids reduced from 4.9% to 3.8%, Voids in Mineral Aggregate reduced from 16.3% to 16.2%, Void Filled with Binder increased from 69.9% to 76.2%, indirect Tensile Strength increased from 1098.1Kpa to 1,150.5KPa which indicated improved durability of asphalt mixtures. It was recommended that further research should be done on the application other plastics like Polypropylene in Hot Mix Asphalt (Akora, 2022).

Tapkın 2008 researched the effects of polypropylene fiber in asphalt and discovered that there was a significant improvement in stability from 15411Kg to 2434Kg (58% increase), flow reduced from 5.59mm to 2.31 (142% decrease) and the polypropylene fibers prolonged the fatigue life by 27% which helped to develop a new generation of high performance paving products (Tapkın, 2008).

A study by Zhang 2012 investigated the impact of polypropylene fiber on the fatigue resistance of hot mix asphalt which indicated that the addition of polypropylene fibers enhanced the fatigue resistance of the asphalt mix, thereby improving its durability. The study concluded that addition of Polypropylene can extend the service life of asphalt pavements in high-traffic areas (Zhang, 2012).

Therefore this research was done to investigate the use of polypropylene in Hot Mix Asphalt on the mix design of flexible pavements.

1.3. Objectives of Research

Main Objective.

To investigate the use of polypropylene in hot mix asphalt on the mix design of flexible pavements.

Specific Objectives

1. To determine the mechanical properties of polypropylene, Bitumen and Aggregates and their viability.
2. To determine the Optimum Bitumen Content of Asphalt Concrete (OBC)
3. To determine the Strength and Volumetric properties of Hot Mix Asphalt with varied Polypropylene content.

4. To obtain the optimal polypropylene content for Asphalt Concrete Mix design at the established OBC

1.4. Research Questions

1. What are the mechanical properties of polypropylene, Bitumen and Aggregates?
2. What is the Optimum Bitumen Content of Asphalt Concrete?
3. How are the Strength and Volumetric properties of Asphalt Concrete affected when Polypropylene is added to Hot Mix Asphalt?
4. What is the optimal polypropylene content for Asphalt mix design at the established OBC?

1.5. Scope of Research

1.5.1. Content scope

Investigating the use of polypropylene in hot mix asphalt on the mix design of flexible pavements.

1.5.2. Geographical scope

The scope of this study was Nasser Road in Kampala City.

1.5.3. Time scope

This research and design project took a period of 8 months, starting September 2023 to April 2024.

1.6. Justification

The incorporation of polypropylene to hot mix Asphalt is a well-founded and an effective strategy, as it contributes to improved crack resistance as it behaves like crack-retarding agent, rutting & deformation resistance as a result of improved structural integrity, fatigue resistance as the mix will be able to withstand heavy traffic loads over time, durability as the modified mix design will be able to withstands environmental factors, that is ; oxygen and water as polypropylene behaves like an anti-striping agent hence overall sustainability of the asphalt pavement. The incorporation of polypropylene will yield construction of more robust, long-lasting road surfaces that will better withstand the challenges posed by traffic and environmental conditions (Tapkın, 2008).

1.7. Significance

Considering that road infrastructure is crucial for economic development and accessibility, conducting research on the use of polypropylene in hot mix asphalt (HMA) to enhance its strength and durability properties is highly significant and multifaceted.

- It has the potential to enhance road infrastructure as Polypropylene improves the strength and longevity of pavements particularly regarding load-bearing capacity, reducing the need for frequent repairs and ensuring safer and more reliable transportation networks (Choudhary, 2018).
- Climate resilience and sustainability as these polymers can enhance the resistance of HMA to environmental stressors, ensuring that roads remain reliable

even in adverse weather conditions (Hossain et al., 2016), while also addressing cost-effectiveness and the utilization of locally available materials.

This research can contribute to safer, more durable roads, facilitating economic development and improving the overall quality of life for Ugandans.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter reviewed literature on Road pavments, Fexible pavemnt design, Material chatericiatics for Aggregates, Bitmen, fillers & antistripping agents and the mechanism of action of polypropylene.

2.2. Road Pavements

A road pavement is composed of layers of processed materials layered over a natural soil subgrade, is to distribute the vehicle loads that are applied to the subgrade. The structure of the pavement should be able to offer a surface with good riding quality, sufficient resistance to skidding, favorable light-reflecting properties, and minimal noise pollution. Road Pavements ensure that transmitted stresses brought on by wheel load are sufficiently decreased to avoid going beyond the subgrade's bearing capacity (Tom and Rao, 2007).

The foundation of Uganda's transportation networks is its road network. Road transportation makes up more than 90% of all passenger and freight transit, making it the most common mode of transportation. The overall lane length of Uganda's road network has expanded from 20,856 km to 21,010 km, a gain of 154.43 km (UNRA, 2020).

An upgrade to the network inventory conducted in 2019 confirmed 75% of the road network is made of gravel, and 25% is paved to bituminous standards (UNRA, 2020). Although roads built in accordance with bituminous standards are inherently long-lasting, unexpected events often cause them to fail over their lifetime.

Road Pavements are categorized as;

a) Rigid Pavements

Portland cement concrete (PCC) is used to make the wearing course. The flexural strength of rigid pavements is high enough to transfer wheel load strains to a larger area below. Unlike flexible pavement, rigid pavement is put either directly on the prepared sub-grade or on a single layer of stabilized or granular material. There is only one layer of material, known as the base or sub-base course, between the concrete and the sub-grade. (Tom, 2007). The thickness of the concrete slab is between 6 and 14 inches (152.4 and 355.6 mm).

In rigid pavement design, fatigue cracking is considered the main cause of failure. The ratio of stress between the flexural tensile stress and the concrete's modulus of rupture dictates the maximum number of load repetitions that could lead to fatigue cracking. Pumping is identified as a major failure condition. It occurs when soil slurry is forced through joints and fissures in cement concrete pavement as the slab moves downhill under heavy wheel loads. The primary distresses in rigid pavements are degradation, spalling, and faulting (Tom, 2007).

b) Flexible Pavements

The wearing course is made up of Asphalt concrete, an engineered mixture of aggregates and bitumen.

2.3. Flexible Pavements

Flexible pavement is comprised of multiple layers of materials designed to provide strength, durability, and flexibility. Commonly used in highways, roadways, parking lots, and various transportation infrastructure projects, this type of pavement utilizes asphalt-based bituminous materials.

2.3.1. Design and Performance Requirements for Flexible Pavements

a) **Load-Bearing Capacity.** It is essential to ensure that pavements can withstand the traffic loads they will encounter throughout their service life. The traffic loads are determined through traffic counts and Assessment of the subgrade through the CBR tests (Hoel, 2023).

b) **Smoothness and Ride Quality.** Achieving a smooth and comfortable ride is a paramount objective in pavement design. Pavement surface characteristics play a vital role in ride quality (Brockenrough, 2023).

c) **Durability and Resistance to Distresses.** Pavement durability is crucial to minimize maintenance and repair costs over the pavement's lifecycle. Durability includes resistance to common distresses such as rutting and cracking. This can be archived through proper manufacture and placement of the pavement layers (Fwa, 2006).

d) **Drainage and Moisture Control.** Adequate drainage is imperative to prevent moisture-related pavement damage, including moisture-induced cracking and rutting. This is usually archived through a minimum road camber and drainage design for storm water disposal from the road lanes (Highway Engineering Hand Book , 2023).

e) **Skid Resistance.** Skid resistance is a critical aspect of pavement safety, especially in adverse weather conditions (TRL, 2002).

f) **Material Selection and Layer Thickness.** The selection of pavement materials and layer thickness is a key design consideration as it account for the structural integrity of the pavement (Fwa, 2006).

g) **Environmental Sustainability.** Sustainable pavement design, with a focus on minimizing environmental impact, is increasingly important. By using green technologies in the manufacture and construction of flexible pavements (TRL, 2002).

2.3.2 Material Performance Characterization for Flexible Pavement Construction

The lifespan and performance of the road pavements will entire depend of the materials used and it is based on;

1. When analyzing pavements with linear elastic characteristics, it's essential to define the elastic moduli and Poisson's ratio for the subgrade and each layer.
2. In cases where the elastic modulus of a material changes with loading time, the resilient modulus, representing the material's elastic modulus under repeated loads, should be chosen based on the load duration corresponding to the speed of the vehicle.
3. If a material exhibits non-linear elastic behavior, it's necessary to furnish the constitutive equation that correlates the resilient modulus with the stress state.

4. However, many of these material properties are used in visco-elastic models just like that of Bitumen (Transport, 2010).

2.3.3. Structure of a Flexible Pavement

Flexible pavements are engineered with the assumption that the load's intensity diminishes as it travels downward from the surface. This occurs due to the load spreading over a larger area as it penetrates deeper into the ground through successive layers of granular material. In essence, the load is dispersed over a broader area (Tom & Rao, 2007). The layer material composition depends on the road design by the Engineer as shown in Table 2.1

Table 2. 1 : Material Characterization for Flexible pavements

Flexible Pavement Layers	**Material Characteristic**
Wearing Course	Strongest Layer, Asphalt Concrete AC14
Binder Course	Asphalt Concrete AC14
Base Course	Crushed Rock Stones CRS / CRR
Subbase	Gravel G30 or 45
Subgrade	Gravel G15
Road Bed	Existing Ground or Rock Fill

1. **Surface Course:** Positioned as the uppermost layer in flexible pavement systems, the wearing course holds the highest standard of quality as it faces the most significant stress and abrasion. Its primary roles include withstanding applied

loads, preventing water infiltration into lower layers, and ensuring a skid-resistant travel surface. Composed typically of bitumen adhered to filler rocks ranging from 25 mm to 0.75 mm in size, it typically measures between 25 to 50 mm in thickness.

2. **Binder Course:** Responsible for effectively distributing wheel loads from the surface to the base course, the binder course constitutes a bitumen-bound aggregate layer of nominal size. Its thickness ranges between 50 and 100 mm.
3. **Base Course:** Constructed predominantly with hard crushed aggregates, the base course serves as the foundational layer of flexible pavement systems. Spanning between 100 mm and 300 mm in thickness, it provides essential structural support.
4. **Sub-base Course:** Following the base course, the sub-base course enhances subsurface drainage and furnishes supplementary structural stability. Typically, it's an optional layer, omitted if the base course material exhibits high quality. Its thickness typically ranges between 100 mm and 300 mm.
5. **Sub-grade:** Occupying the lowest position in the flexible pavement structure, the sub-grade typically comprises naturally compacted earth. Its primary function involves absorbing the stresses imposed by the layers above it (TRL, 2002).

2.3.4. Causes of Failures in Flexible Pavements

The failures in wearing course are attributed to the following reasons:

- **Inadequate mix design**: A bituminous surface will not perform poorly when subjected to traffic if the mix design does not account for enough binder content
- **Poor quality control:** In bituminous construction, a high level of quality control is required during the production, and laying of the Asphalt concrete to minimize occurrence of pavement failure.
- **Binder volatilization and oxidation**: The bituminous surface becomes fragile as a result of binder volatilization and oxidation. By doing so, it causes the pavement's surface to fracture, which makes it possible for precipitation to soak through and harm the layers beneath (Concrete, 2021).

2.3.5. Mechanisms of Failures in Flexible Pavements and their Mitigation Measures

a) Rutting

This occurs when tire tracks start to sink into the pavement, creating depressions in the roadway.

Cause: This is due to using Bitumen of Low Softening Point and excessive Binder Content is the asphalt mix.

Mitigation Measure: Limiting the vertical compressive strain on the top of wearing surface and Improving Drainage of the road. Softening point Test on Bitumen, Marshal Mix design to obtain optimal Binder Content to archive a stability of 8-18 and a Flow of 2-4 are quality measure to reduce rutting occurrence (Fwa, 2006).

b) Alligator Cracking

Alligator cracking typically results in a series of interconnected cracks that look like the scales on an alligator's back.

Cause: Poor preparation of the Subbase, Subgrade Layers.

Mitigation Measure: proper material selection of materials for the Subgrade and Subbase layers. Ensures compaction is done to Maximum dry density and the Optimum Moisture content is archive at each layer in addition to improving the drainage. On site, Gravel must have a specified California Bearing Ratio (CBR) for subgrade and subbase layers Soils Tested for MDD, CBR, and Aterbag Limits. Compaction can be verified using the Nuclear Gauge and Sand Cone replacement Methods (Brockenrough, 2023).

c) Potholes

This is a depression in the road surface where the Traffic has removed the Broken Pieces of the pavement.

Cause: These result from Poor Gradation of Aggregates used in Asphalt Mix. Bitumen strip form aggregates Inadequate Binder during Mix design and Thin pavement Layers.

Mitigation Measure: On Site, Sampling and testing Asphalt Concrete at Design, Production and Field Verification stage, adding a Binder course in the assembly, individual and Combined Gradation of the fine and Course Aggregates. Marshall

Test to obtain the binder content by extraction. Coring to verify thickens and Voids ratios in the mix (Brockenrough, 2023).

d) **Railroad / Transverse Cracking**

This is another fatigue cracking characterized by a series of cracks that run perpendicular to the pavement's centerline.

Cause: Extreme traffic load and poor drainage or other factors.

Mitigation Measure: Seal the cracks with a hot-applied sealant to prevent moisture from getting into the cracks and causing further damage would solve this problem (Fwa, 2006).

Basing on the above mitigation measures, when carefully followed during design, construction and usage of flexible pavements, their expected design life and structural performance can be archived.

2.4 Material Composition of Asphalt Concrete

Asphalt Concrete is a mixture of bitumen, and mineral aggregate that designed and manufactured to be applied in flexible pavements as the wearing course and Binder course.

2.4.1 Bitumen

Bitumen is a broad category of amorphous, dark-colored, cementitious substances, whether naturally occurring or synthetically produced, primarily consisting of soluble carbon disulfide of high molecular weight (ASTM D8-83, 1984). In the realm of geochemistry, bitumen is commonly utilized to denote highly viscous petroleum, aligning conceptually with the aforementioned definition.

Bitumen is a hydrocarbon product derived from crude oil through a process known as distillation. During the refining process, bitumen is separated from other components of crude oil, and it goes through further treatment to improve its properties. This includes removing impurities and adjusting its characteristics to meet specific grade requirements (Speight, 2016).

Bitumen exists in various types and grades. The classification of bitumen is based on penetration, viscosity, and performance grades. Penetration grade bitumen is categorized by its penetration value, which represents its hardness. Viscosity grade bitumen is classified according to its viscosity at a specific temperature. Performance grade bitumen is determined by its rheological properties, making it suitable for modern asphalt mix designs (NCHRP, 2004).

a) Properties of Bitumen

Bitumen exhibits several key properties, including viscoelasticity, temperature susceptibility, ductility, and adhesion. Bitumen's viscoelastic behavior allows it to deform under load and return to its original shape when the load is removed. The temperature susceptibility of bitumen is crucial for its performance in different climate conditions. Ductility refers to its ability to deform without breaking. Adhesion to aggregates is essential for maintaining the integrity of asphalt mixtures (Huang et al., 2004).

b) Chemical Composition of Bitumen

The composition can vary depending on the source of crude oil and the refining process, but typically includes the following components (RAHAbitumen, 2016);

- **Asphaltenes**: High molecular weight aromatic compounds containing sulfur, nitrogen, and oxygen. Asphaltenes contribute to the viscosity and stiffness of bitumen.
- **Maltenes**: Lower molecular weight fractions consisting of saturated and aromatic hydrocarbons. Maltenes are responsible for the adhesion and flexibility of bitumen.
- **Resins**: Intermediate molecular weight compounds that provide cohesion and elasticity to bitumen. Resins also contribute to the adhesion properties of bitumen.
- **Saturates**: Saturated hydrocarbons such as alkanes and cycloalkanes. Saturates enhance the stiffness and temperature susceptibility of bitumen.
- **Trace Elements**: Bitumen may also contain trace amounts of metals such as nickel, vanadium, and iron, as well as heteroatoms like sulfur and nitrogen.

c) Bitumen in Asphalt Mix Design

Bitumen is a fundamental component in asphalt mix design, influencing the performance and durability of road surfaces. In mix design, bitumen binds the aggregates together and provides flexibility and resistance to temperature-induced stress. The choice of bitumen type and grade, as well as the optimal mix design, is essential for achieving the desired performance characteristics of asphalt pavements (Brown and Stroup-ardiner, 2012).

d) Quality Control Tests performed on Bitumen

1. **Penetration Test**

   This is the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in five seconds to determine the bitumen hardness or softness (CMLT, 2000).

2. **Ductility Test**

   Ductility refers to the capacity of bitumen to undergo significant deformation or elongation without fracturing. It is quantified as the distance, in centimeters, that a standard sample or briquette of the material can stretch before breaking (Fwa, 2006).

3. **Softening Point Test**

   The softening point indicates the temperature at which bitumen achieves a specific degree of softness as per test specifications. This examination is conducted utilizing a Ring and Ball apparatus (Laboratory Testsing Manual, 2000).

4. **Specific Gravity Test**

   The density of bitumen serves as a basis for its classification and is heavily influenced by its chemical composition. The presence of aromatic mineral impurities correlates with an increase in specific gravity (Brockenrough, 2023).

5. **Viscosity Test**

   This quantifies a bituminous material's resistance to flow and describes its fluid behavior. This characteristic has a major effect on the strength of the paving mixes that are produced at the application temperature. Vessel viscosity variations during compaction or mixing have been linked to lower stability values (RAHA, 2023).

2.4.2. Aggregates

Aggregate utilized in asphalt road mix is comprised of sturdy minerals categorized based on their physical attributes and size, as dictated by the mix design. These aggregates can be either natural or manufactured. Natural aggregates encompass crushed stone, gravel, or synthetic materials like black cinder. Natural aggregates are sourced from river beds, lake perimeters, quarries, and remain unaltered except for processes like crushing, washing, and classification. Typically, aggregates such as crushed stone, sand, and gravel are combined with bitumen, a viscous and waterproof substance, to form asphalt.

a) **Physical Properties of Aggregates**

Aggregate physical properties are easily observable and have a significant impact on the performance of aggregates, whether they are used as constituents in pavement materials or as standalone base or subbase materials. The key physical properties of aggregates commonly assessed include Gradation and size, Toughness and Abrasion Resistance, Durability and soundness, Particle shape and surface texture, Cleanliness and presence of deleterious materials, and Moisture Content (Roberts et al., 1996).

b) Chemical Properties of Aggregates

In Hot Mix Asphalt (HMA), the chemical composition of aggregate surfaces plays a crucial role in determining the adhesion of asphalt cement binder. Inadequate adhesion, known as stripping, can lead to premature structural failure. In Portland Cement Concrete (PCC), aggregates containing reactive forms of silica can undergo expansive reactions with the alkalis present in the cement paste. This expansion can result in various forms of damage such as cracking, surface pop-outs, and spalling. It's important to note that certain chemical properties of aggregates may change over time, particularly after the aggregate has been crushed. For instance, freshly crushed aggregate may exhibit different water affinity compared to the same aggregate that has been crushed and stored in a stockpile for an extended period. Stripping and Alkali-Aggregate Reaction are typical chemical properties of aggregates

c) Quality Control Tests Performed on Aggregates

1. Aggregate Crushing Value

The aggregate crushing value offers a relative indication of resistance to crushing under gradually applied load. It is crucial for aggregates used in road construction to withstand the pressure from traffic wheel loads. Weak aggregates can compromise the integrity of the pavement structure. The Aggregate Crushing test is utilized to measure the strength of coarse aggregates (Mathew, 2010).

2. **Los Angeles Abrasion Test**

The abrasion test assesses the hardness property of aggregates to determine their suitability for various pavement construction projects. The Los Angeles abrasion test, standardized in India (IS: 2386 part-IV), is a preferred method for evaluating hardness. It determines the percentage wear resulting from the rubbing action between the aggregate and steel balls used as an abrasive charge (Mathew, 2010).

3. **Aggregate Impact Test**

The aggregate impact test evaluates the resistance of aggregates to impact. Aggregates passing through a 12.5 mm sieve and retained on a 10 mm sieve are placed in a cylindrical steel cup attached to a metal base of an impact testing machine. Strong aggregates are essential for withstanding crushing under traffic wheel loads, as weak aggregates can jeopardize the pavement structure (Mathew, 2010).

4. **Soundness Test**

The soundness test examines the resistance of aggregates to weathering by subjecting them to accelerated weathering test cycles. Porous aggregates exposed to freezing and thawing conditions are prone to premature disintegration (Mathew, 2010).

5. **Specific Gravity and Water Absorption**

Specific gravity and water absorption are crucial characteristics essential for formulating concrete and bituminous mixes. Specific gravity indicates the proportion of an aggregate's mass to that of an equivalent volume of distilled water at a defined temperature. Due to the potential presence of water-permeable voids within aggregates, two specific gravity measurements are employed: apparent specific gravity and bulk specific gravity (Mathew, 2010).

2.4.3. Performance Requirements for Asphalt Concrete

According (Transport, 2010), the asphalt concrete must deliver a waterproof surface with robust resistance to deformation and aging, alongside acceptable fatigue properties and skid resistance. The following characteristics are essential for AC mixes used in surfacing:

- Offer adequate resistance to plastic deformation and cracking to endure anticipated traffic loading.
- Possess ample workability to facilitate efficient laying and compaction of the mix without segregation.
- Maintain adequate air voids within the mix to prevent bleeding or loss of deformation resistance post-compaction under traffic conditions.
- Contain an adequate amount of suitable binder and appropriate aggregate grading to ensure the creation of a durable and nearly impermeable layer.

Ministry of Works and Transport Asphalt Concrete performance requirement as shown in Table 2.2.

Table 2. 2 : MOWT AC14 Specification

Material Properties	**Mix type**		
	AC 20	**AC 14**	**AC 10**
Notes – use of the different mix types	Primarily binder course Wearing course in severely loaded area Chapter 7.9.2 Preferably to be surface dressed when used as wearing course.	Wearing course in areas with normal traffic loading	Wearing course, but only under conditions with moderate traffic loading
Layer thickness (mm)	Compacted (50-80)	Compacted (40-60)	Compacted 30 -40
Aggregate Properties	Coarse aggregates shall be made of crushed fresh rock or stones. Fine aggregate, passing the 5mm sieve, can be a material such as sand, gravel or crushed stone. All aggregate shall be durable and free from soft or unsound particles, clay or other deleterious matter. Coral rock can be used provided the materials are carefully selected. Addition of a separate type of fines is normally needed.		
Water absorption (%)	Max 2		
Aggregate strength	TFV $_{soaked}$: min 75% of TFV $_{dry}$ TFV $_{dry}$: min 110kN		
Requirements for the filler	The filler shall be hydrated lime, Portland cement, limestone dust or other suitable types proven to give acceptable results in AC mixes under the prevailing conditions. % passing 0.075mm: 70 – 100%, all material shall pass the 0.600 mm sieve size		

Grading, sieve sizes	(% passing)		
28	100		
20	80-100	100	
14	60-80	85-100	100
10	50-70	72-94	85-100
5	36-56	52-72	55-72
2.36	28-44	37-55	38-57
1.18	20-34	26-41	27-42
0.600	15-27	16-28	18-32
0.300	10-20	12-20	13-23
0.150	5-13	8-15	9-16
0.075	2-6	4-10	4-10
Bitumen type			
Normal loading conditions:	60/70 or 40/50 penetration grade		
Severely loaded areas	Chapter 7.9.2 40/50 penetration grade or modified binders		
Marshall (2 x 75 blow) Mix requirements			
Stability (N)	Severely loaded areas: min 9000 Chapter 7.9.2 Traffic TLC 20 and TLC 50: min 8000 max 18000 Traffic TLC 10 and TLC 3: min 7000 max 15000 Traffic TLC 1 and lower: min 4000 max 1000		
Flow (mm)	Min 2 max 4		
Air Voids (%)	Min 3 max 6		
Voids in Mineral Aggregate (%)	Min 14 for AC20	Min 15 for AC 14	Min 16 for AC 10
Refusal lab. Compaction	Air voids shall be min. 3% after refusal lab. Compaction for severely loaded areas Chapter 7.9.2		
Indirect tensile strength (kPa)	Min 800 tested at 25^{0} C		
Immersion index (%)	Min 75		

2.4.4. Materials used to improve the Performance of Asphalt Concrete

A. Filler Materials

Fillers are fine materials, typically mineral powders, added to asphalt mixtures to improve properties such as workability, durability, and stability. The choice of fillers depends on specific project requirements and local materials availability. Proper filler selection and characterization are essential to achieve high-performance asphalt mixtures. Filler serves a two-fold function in bituminous mixes; the larger filler particles act as inert components while also filling the gaps between the larger aggregates in the mixes. This contributes to enhancing the strength and impermeability of the mix (Asphalt Institute- 2017).

1. **Common Fillers**

   a) **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.

   b) **Portland cement:** Portland cement is sometimes employed as a filler to improve asphalt mix properties.

   c) **Hydrated Lime:** Hydrated lime is utilized as a filler to enhance asphalt mix durability and workability.

   d) **Polypropylene fibers** are synthetic materials with properties that make them suitable for use in HMA. These fibers are typically added to the asphalt mix in small quantities to improve various aspects of pavement performance.

2) Effects of Fillers in Bituminous Mixes

- **Improved Rutting Resistance:** Fillers, particularly calcium-based fillers like limestone and hydrated lime, enhance the resistance of asphalt mixes to rutting, a common pavement distress.
- **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.

3) Properties of Filler Materials

- **Gradation:** The gradation of fillers is crucial to ensure compatibility with the asphalt mixture and to avoid particle segregation. Proper filler gradation contributes to uniform mix properties.
- **Chemical Composition:** The chemical composition of fillers can affect the adhesion between the asphalt binder and aggregate. Calcium-based fillers, such as limestone and hydrated lime, often interact with the asphalt binder, resulting in improved asphalt mix performance.
- **Particle Shape**: The particle shape of fillers can impact mix workability and compact ability. Angular or elongated particles may lead to reduced workability, while rounded particles can enhance compact ability.

4) Application of Fillers in HMA

In asphalt mix design, the process of adding a filler involves two main methods: dry mix and wet mix.

a) **Dry Mix Method**

In the dry mix method, the filler, often referred to as mineral filler or fine aggregate, is added directly to the aggregate materials before the introduction of asphalt binder. This method involves blending the dry aggregate and filler components without any added moisture. The dry mix is achieved by thoroughly combining the aggregates, filler, and any required additives in a precise ratio. ((APAO), 2004)

b) **Wet Mix Method**

In the wet mix method, the filler is mixed with the asphalt binder before being introduced to the aggregate materials. This involves creating a filler-asphalt blend, which is then combined with the aggregate. (Monismith, 2001). The wet mix method allows for better dispersion of the filler within the asphalt binder, leading to improved coating of the aggregates (Asphalt Institute- 2017).

The choice of method depends on the specific project requirements, local practices, and the desired performance characteristics of the asphalt mixture. Engineers and mix designers consider factors such as aggregate gradation, binder type, environmental conditions, and traffic loads when selecting the appropriate mix design method.

B. Anti-striping Agents

These strengthen the bond between the asphalt binder and aggregates and lessen the chance of moisture-induced stripping. The efficacy of antistripping compounds varies and can be categorized as;

a) **Hydrate lime**

Hydrated lime accelerates and strengthens the bond between the aggregate and binder when it is added to the asphalt mixture (Eskandarsefat, 2021).

b) Liquid antistrip

These additions are known as surfactants, or surface-active agents. By lowering surface tension, they enable the bituminous binder to coat the aggregate surface more uniformly. Adsorbed water on or near the aggregate surface can be replaced at the same time by the bituminous binder. This lessens peeling and the deterioration of the asphalt by increasing the strength and frequency of the binder to aggregate adhesion (Eskandarsefat, 2021).

1. **Iterlene 400 IN** is amino-based and has a recommended dosage of 0.2% to 0.4% by weight of the bitumen.
2. **Iterlene PE-31**is more thermostable in the bitumen, and is based on phosphoric acids with a recommended dosage of 0.2% to 0.4% by weight of the bitumen.
3. **Vegetable-based** with a dose of 0.2% to 0.6% based on the weight of the bitumen; Iterlene BIO 180, which is now listed in the ADR as non-dangerous.
4. **Silica-based** Iterlene 100 SL and Iterlene BIO 180 are both considered non-hazardous by the current ADR regulations, with a suggested dosage of 0.05% to 0.15% on bitumen weight (Eskandarsefat, 2021).

c) Effect of an Antistripping Agent on Asphalt Concrete Properties

i. **Stability:** Enhances the overall stability of the asphalt mixture by reducing the likelihood of aggregate stripping, which can lead to premature pavement failure (Kandhal, 2014).

ii. **Flow:** Improves the flow characteristics during asphalt mixing and compaction, resulting in better workability (Shayegan, 2016)

iii. **Indirect Tensile Strength (ITS)**: Increases ITS due to better adhesion between asphalt binder and aggregate particles (Kandhal, 2014).

iv. **Air Voids:** May help in reducing the potential for air voids in the asphalt mixture, contributing to improved durability and resistance to moisture damage (Shayegan, 2016).

v. **Voids in Mineral Aggregate (VMA)**: A well-designed antistripping agent can help maintain the desired VMA in the asphalt mixture, ensuring proper binder coverage and aggregate interlock (Kandhal, 2014).

vi. **Voids in Bituminous Mixtures (VMB)**: Similar to VMA, effective antistripping agents contribute to achieving and maintaining the desired VMB, which is crucial for long-term performance and durability of asphalt pavements (Shayegan, 2016).

These effects collectively contribute to the overall performance and longevity of asphalt pavements by mitigating moisture damage and improving adhesion between asphalt binders and aggregate (Shayegan, 2016).

d) Mechanism of Action of an Antistripping Agent

The mechanism of action of antistripping agents involves surface modification, adhesion promotion, moisture resistance, and improved mixture properties, all working together to mitigate the effects of moisture-induced damage and enhance the durability of asphalt concrete pavements.

a. **Surface Modification**: Antistripping agents modify the surface chemistry of both the aggregate and asphalt binder. They form a chemical bond or interact with functional groups on the surface of the aggregate and the asphalt binder, enhancing their affinity for each other.

b. **Adhesion Promotion**: By modifying the surface properties, antistripping agents promote better adhesion between the asphalt binder and aggregate particles. This improved adhesion prevents the formation of a water film between the two surfaces, reducing the likelihood of moisture-induced damage.

c. **Moisture Resistance**: Antistripping agents act as barriers against moisture intrusion into the asphalt mixture. By enhancing the adhesion between asphalt binder and aggregate, they create a more waterproof and durable pavement structure, reducing the penetration of water into the pavement layers.

d. **Aggregate Coating**: Some antistripping agents form a thin film or coating on the surface of the aggregate particles. This coating helps to seal the surface and prevent moisture from penetrating into the asphalt mixture, further reducing the risk of aggregate stripping.

e. **Improved Mixture Properties**: Antistripping agents can also improve the overall properties of the asphalt mixture, such as stability, rut resistance, and fatigue resistance. By preventing moisture damage, they help maintain the integrity of the asphalt pavement structure over time.

2.5. Polypropylene

Polypropylene (PP) is a Thermoplastic material based on the monomer CnH2n, produced from propylene gas in the presence of a catalyst such titanium chloride, and having a linear structure. It is a by-product of the procedures involved in refining oil. PP has a greater melting point and tensile strength than polyethylene and a level of crystallinity that is halfway between low density polyethylene (LDPE) and high density polyethylene (HDPE) (Kiron, 2021).

2.5.1. Structure of Polypropylene

The chemical structure of polypropylene can be represented aC_3H_6) $(C_3H_6)n$ where n represents the number of repeating units in the polymer chain. In polypropylene, each repeating unit consists of three carbon atoms and six hydrogen atoms. This structure gives polypropylene its characteristic properties, including high strength, chemical resistance, and heat resistance.

In polypropylene, there exist both crystalline and non-crystalline sections. Spherulites originating from a nucleus can vary in size from tiny fractions of a micrometer to centimeters. The chain axis is evenly dispersed within planes perpendicular to the radial direction, where the a-axis of the crystal unit cell aligns. Each crystal is surrounded by non-crystalline material. During fiber spinning and drawing, both crystalline and amorphous regions can be oriented. When subjected to extension of less than 0.5%, spherulites deform elastically without structural disruption; otherwise, they align strongly in the direction of the force, ultimately forming microfibrils. These highly anisotropic microfibrillar structures contribute to the anisotropic qualities of the fiber.

(Nikolovska, 2022).

2.5.2. Physical Properties of Polypropylene

The Physical properties of Polypropylene are summarized as shown in Table 2.3 (AdrecoPlastics, 2022).

Table 2. 3 : Physical Properties of Polypropylene

Parameter (Units)	**Values Range**
Tensile strength (gf/den)	3.5 to 5.5
Elongation (%)	40 to 100
Abrasion resistance	Good
Moisture absorption (%)	0 to 0.05
Softening Point (°C)	140
Melting point (°C)	160
Chemical resistance	Generally excellent
Relative density	0.90 +/- 0.01
Thermal conductivity	6.0 (with air as 1.0)
Electric insulation	Excellent
Resistance to mildew, moth	Excellent

2.5.3. Thermal Properties of Polypropylene

The melting point of polypropylene (PP) is 165˚C, with a softening point at approximately 140˚C. PP maintains its impressive elasticity even at temperatures as low as -70°C or below. The mechanical characteristics of PP fibers remain largely unaffected even at elevated temperatures. Among all commercial fibers, PP exhibits the lowest heat conductivity, making it the most insulating fiber in this aspect (AdrecoPlastics, 2022).

2.5.4. Application of Polypropylene in Hot Mix Asphalt

Polypropylene is typically added to the bitumen during befor both of them are mixed with aggregates. The interaction between the two hydrocarbons primarily involves physical blending rather than chemical bonding. The polypropylene melts at high temperatures and disperses evenly throughout the bitumen matrix. This blending process results in a homogeneous mixture where the long hydrocarbon chains of polypropylene become incorporated within the bitumen structure. The physical interaction between polypropylene and bitumen enhances the mechanical properties of the bitumen, including its tensile strength, cohesion & adhesion, toughness, and resistance to deformation (Shen, 2019).

This mixture has more hydrocarbons per unit area hence improving of various asphalt concrete properties which reduces the occurrence of premature pavement failure on application in road construction.

a) Advantages of using Polypropylene

- Polypropylene is a thin fiber with the lowest density of all synthetic fibers (0.91 g/cm3).
- It does not take in moisture. This indicates that the fiber's wet and dry qualities are the same. Low moisture regain is not viewed negatively because it aids in

rapid conveyance of moisture, which is needed in special applications like babies' always-dry diapers.

- It has outstanding chemical resistance. The majority of acids and alkalis are extremely resistant to polypropylene fibers.
- Since PP has a lower heat conductivity than other, it can be employed in thermal wear applications.

Basing on the above literature review, Tests in Table 2.4 were conducted in this research.

Table 2. 4 : Tests conducted in Research

Materials	Test Method	Parameter & Value Tested For	Purpose
To determine the mechanical properties of polypropylene fiber, Bitumen and Aggregates and their viability.			
Polypropylene	*Density*	Density	To assess the suitability of the Polymer.
Bitumen	Penetration test	Consistency	To Know the consistency and grade of the Bitumen.
	Softening point test	Temperature susceptibility	Establish the Temperate Tolerance.
	Specific Gravity of Bituminous Binder	Specific Gravity	To determine the relative density and Specific gravity of the Bitumen
Aggregates	Particle Size Distribution (psd)	Aggregate composition by Percentage of total mass	To obtained the individual and combined gradation of the aggregates.
	Specific Gravity and Water Absorption Test	SG and water Absorption	To determine the absorption rate fluid by the aggregate
	Aggregate Crushing Value Test	ACV	To measure of resistance of aggregates to crushing when load is applied
	Aggregate Impact Value Test	AIV	To measure the resistance of an aggregate to Sudden impact.
	Ten Percent Fines Value Test	TFV	To measure hardness of coarse Aggregates.
To determine the Optimum Bitumen Content (OBC) of Asphalt Concrete using Marshall Mix Design **AC14** Mix design should conform to the Ugandan General specifications for Road and Bridge works Series 400 and Ministry of Works and Transport Volume III Pavement Design Manual Part 1: Flexible Pavement Design Guide section 6.8 on Asphalt Concrete *Optimum Bitumen Content (OBC) – Value*			
To determine the Strength and Volumetric properties of Hot Mix Asphalt with varied Polypropylene fiber content.			

<table>
<tr><td colspan="5">Cut the PP to pass 5.0mm Sieve and be retained on 2.3mm Sieve.</td></tr>
<tr><td colspan="5">Heat the PP with Optimal bitumen content to melt (Wet Mix) Then add mixture to the Blended aggregates.
%PP addition is in relation to Mass of OBC</td></tr>
<tr><td>Control Mix
OBC +0% PP</td><td>Specimen 1
OBC+2.5%PP</td><td>Specimen 2
OBC+5%PP</td><td>Specimen 3
OBC+7.5%PP</td><td>Specimen 4
OBC+10%PP</td></tr>
<tr><td colspan="5">Tests on Above Specimens</td></tr>
<tr><td colspan="2">Test</td><td colspan="3">Parameter & Value / Purpose</td></tr>
<tr><td colspan="2" rowspan="2">Marshal Test
(ASTM D 1559-89)</td><td colspan="3">➢ Stability</td></tr>
<tr><td colspan="3">➢ Flow</td></tr>
<tr><td colspan="2">Indirect Tensile Strength Test
(ASTM D3203)</td><td colspan="3">ITS – Value
To predict the strength, moisture and oxygen susceptibility of the asphalt concrete</td></tr>
<tr><td colspan="2">Density and Volumetric Analysis(ASTMD3203)</td><td colspan="3">• Bulk Density of saturated Surface dry Asphalt GMB
• Maximum Theoretical Density of Asphalt Mix GASTMD2041-95, D4469-85AASHTO T209-94 GMM
• Volumetric analysis of Bituminous Mix ASTM D3203 AASHTO Designation PPl9-93 – GMSB
➢ The void content - VA
➢ The voids in mineral aggregate - VMA
➢ The voids filled with binder -VMB</td></tr>
<tr><td colspan="5">Obtain the Optimal Polypropylene content for Asphalt Concrete mix design at the established OBC
Mass & Percentage of Optimal PP Content</td></tr>
</table>

CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter highlights the methods that were used in the in the research and justiciation of choice of test in the research.

3.2 Research Design

This study is a Quantitative applying experimental and comparative Design.

3.2. Material Selection and Preparation

1. Polypropylene

Polypropylene was sourced from Africa Polysack Limited in Namanve. The martial was cut into short fibers to pass 5.0mm Sieve and be retained on 2.3mm Sieve.

They were heated to melt in the optimal bitumen there after mixed in the aggregates

2. Bitumen

The grade of Bitumen used was 60/70 because of its good thermos-elastic properties, durability when exposed to heavy Traffic loading and its pervious application in the Tropical climates here in Uganda.

3. Aggregates

Aggregates used were those to make AC14 which means that the nominal size of Aggregate is 14mm.

3.3 Primary Data Collection Methods

This was collected by carrying out laboratory tests in duplicates and Triplicates for the various parameters and a single average value obtained for each.

3.3.1. Density of Polypropylene

The density of Polypropylene was used for various to qualify the suitability of the fiber for application in the mix design.

3.3.2. Penetration Test

The penetration test was employed to evaluate the consistency of bituminous materials, quantified by the distance in tenths of a millimeter that a standard needle vertically penetrates a sample of the material under specified conditions of loading, loading time, and temperature. This consistency determination serves the purpose of identifying the grade of the bitumen utilized.

Standard : ASTM D5, AASHTO T49, EN 1426

3.3.3. Softening Point Test

The softening point test was selected to identify the temperature at which bituminous binders begin to display fluidity. This is crucial for quality control of shipments and gauging the material's propensity to flow under the elevated temperatures experienced during service.

Test Standard : ASTM D36

3.3.4. Specific Gravity of Bituminous Binder

A bituminous material sample was introduced into a calibrated pycnometer, which was then weighed. The pycnometer was subsequently filled with distilled water at 25°C and weighed again. These measurements were utilized to compute the relative density, specific gravity, and density of the material.

Test Standard : ASTM D70

3.3.5. Specific Gravity and Water Absorption of Aggregates

This test was selected as it dertemines the absorption rate of fluid by the aggregate hence the moisture vulnerability of the concerte.

Test Standard : ASTM C127

3.3.6. Aggregate Crushing Value (ACV)

The Aggregate Crushing Value (ACV) was opted for as it provides a relative indication of an aggregate's ability to withstand crushing when a weight is applied gradually. The material that passes through a particular sieve after being crushed under a 400 KN stress is measured to find the ACV.

Test Standard : ASTM C131

3.3.7. Aggregate Impact Value (AIV)

The selection of the Aggregate Impact Value (AIV) was based on its provision of a relative measure of an aggregate's resistance to sudden shock or impact. Aggregates employed in road construction need to possess sufficient strength to withstand crushing under traffic wheel loads, which can be assessed through crushing or impact tests.

Test Standard : BS 812-112:1990

3.3.8. Ten Percent Fines Value (TFV)

The Ten Percent Fines Value (TFV) was chosen because it provides a relative measure of an aggregate's resistance to crushing under a gradually applied load, thus assessing the strength of the aggregates. In pavement design, specific TFV requirements for materials are established, tested both in dry and soaked conditions.

Test Standard : BS 812-111:1990

3.3.9. Particle Size Distribution

This test was selected to determine whether the aggregates and filler consisted of pre-dominantly gravel, sand, silt or clay sizes and to what extent limited extent, which of these size ranges were to control the mechanical properties of the aggregates. This ensured that there was good grain to gran contact in the asphalt Mix

Test Standard : ASTM C136

3.4. Marshall Mix Design

The Marshall Mix Design process was to determine the ideal binder content within a mixture where the aggregate grading and type of bituminous binder were already established. The outcomes of the Marshall Mix Design were utilized to establish the formulation for asphalt mixtures. The binder content was adjusted incrementally, usually by 0.5%, around an estimated optimal binder content. Through this process, the binder content that best met the criteria for Marshall Stability, flow, void content, binder-filled voids, and density for the specific mixture under investigation was identified.

Test Standard : ASTM D6927

3.4.1. Marshall Test

The Marshall test was chosen to evaluate the physical characteristics of asphalt samples, concentrating on their ability to deform plastically in asphalt mixtures. Asphalt mixtures with a maximum aggregate size of 25.4 mm or less that contain bitumen or bitumen cutback are suitable for the Marshall test. In order to quantify the resistance of asphalt specimens to plastic flow, a Marshall loading head is used to load the specimens on their cylindrical side edges at predetermined loading rates and temperatures.

Test Standard : ASTM D1559

3.4.2. Indirect Tensile Strength Test

The Indirect tensile strength test was chosen to assess the comparative quality, moisture sensitivity and strength of materials, as well as for its application in pavement design, evaluation, and analysis. This testing procedure aimed to ascertain the indirect tensile strength and E-modulus of bituminous mixes.

A cylindrical test specimen was subjected to loading on two diametrically opposite sides, inducing tensile stress within the specimen. The test was conducted at a constant deformation speed until failure, with the maximum load recorded for the calculation of indirect tensile strength.

Test Standard : ASTM D6931

3.4.3. Volumetric Analysis

This method was chosen to determine the void content, voids filled with binder, and voids in mineral aggregate for bituminous mixes. Its purpose was to quantify the coating effect on asphalt mixes.

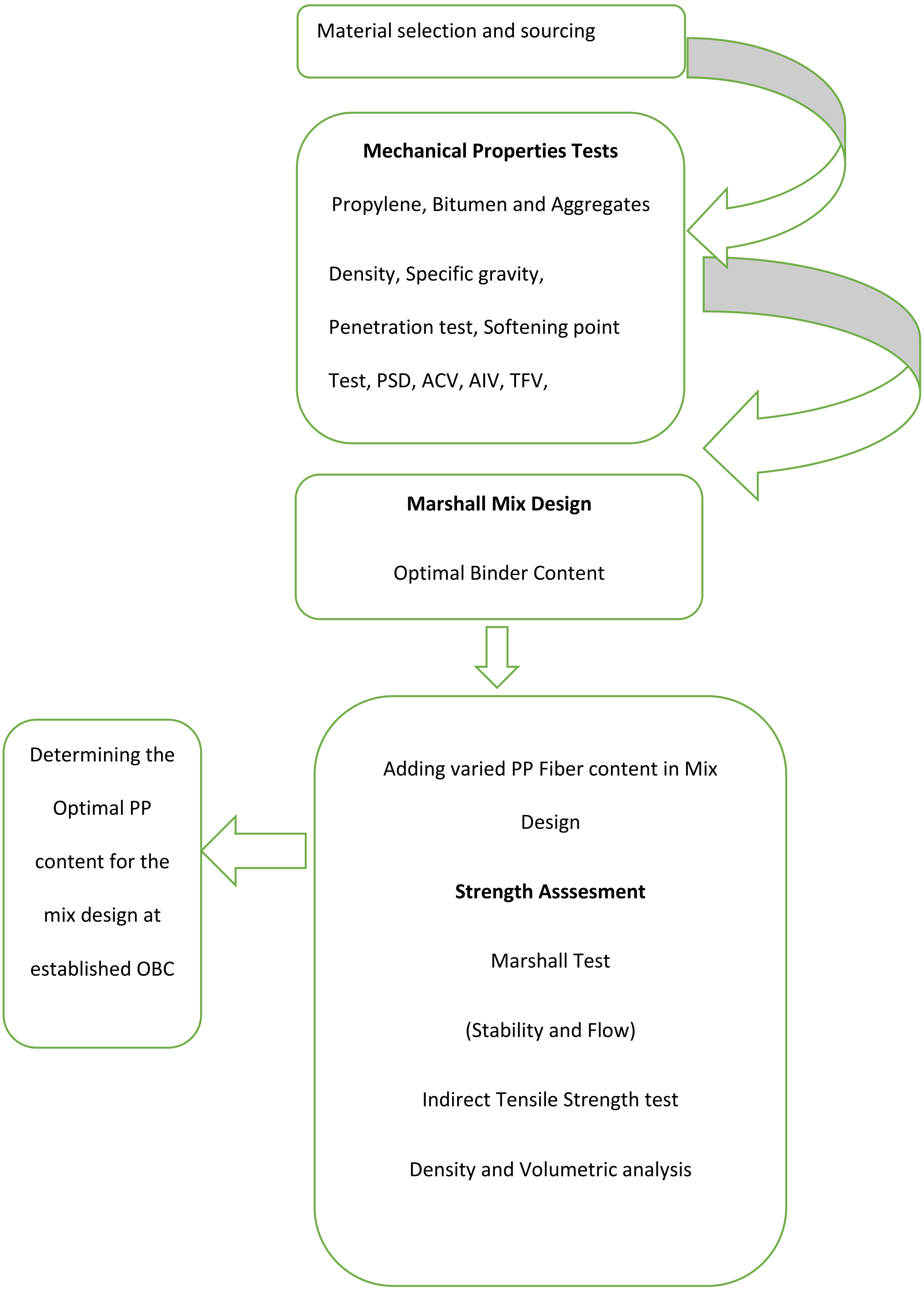
Air void content refers to the percentage of volume in a sample that remains unfilled by aggregate or binder at a temperature of 25°C.

Voids in mineral aggregate (VMA): indicate, as a percentage of the mix's bulk volume, the difference between the mix's bulk volume and the volume occupied by mineral aggregates.

Voids filled with binder: indicates the amount of effective binder in the mixture, given as a percentage of the aggregates' volume of voids (VMA).

Test Standard : AASHTO T 166

METHODOLOGY FOW CHART



3.5. Secondary Data Collection Methods

This was obtained from the Ministry of Works and Transport 2010 Design Manual and General Specification for Road Construction in Uganda which were used as the standard for the Preliminary and Final Mix Design in Research.

3.6. Data Analysis

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 polypropylene content to establish the optimal value.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Introduction

This chapter present the Results from the above tests carried out. The data was analyzed and discussed in relation to the AC14 Standards by the Ministry of Works and Transport Manual Uganda and General Specification for road construction.

4.2 Results for Mechanical Properties of Polypropylene, Bitumen and Aggregates

Table 4. 1 : Summary of Mechanical Property Test Results

Material	**Test**	**Specification**	**Value Obtained**	**Remarks**
Polypropylene	Density (g/cm^3)	0.89 – 0.91	0.9018	Suitable
Bitumen	Penetration (mm)	60 -70	61.5	Suitable
	Softening point ^0C	49 - 56	49	Suitable
	Specific Gravity	1.01 – 1.06	1.03	Suitable
Aggregates	Combined Specific Gravity	2.5 – 2.8	2.642	Suitable
	Water Absorption (%)	0.2 - 0.3	0.3	Suitable
	ACV (%)	< 45%	16.9	Suitable
	AIV (%)	<30	15.8	Suitable
	TFV (KN)	>110	234.2	Suitable
	Particle Size Distribution (Individual Gradation)	Grading envelop	Combine gradation is with the envelope	Suitable

4.2.1. Density of Polypropylene

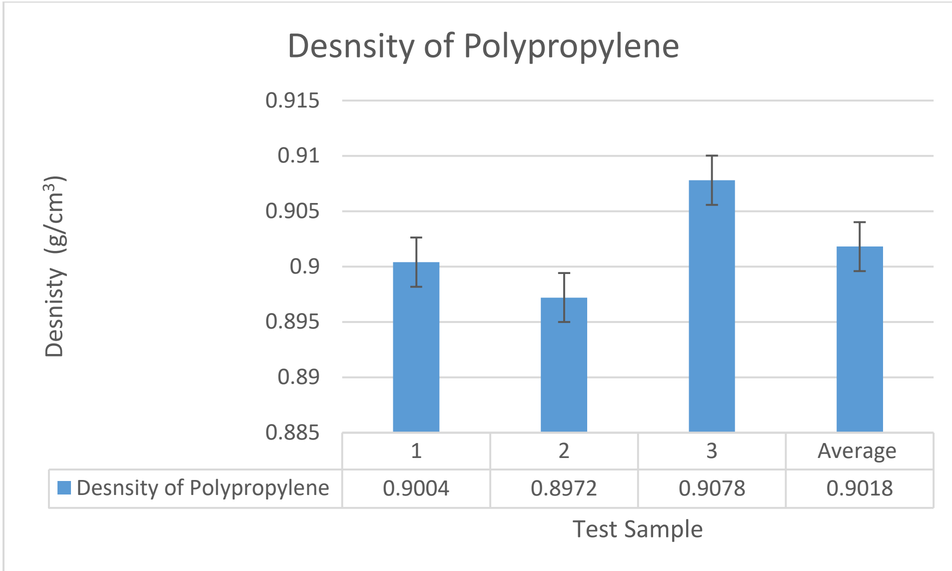


Figure 4. 1 : Density of PP Results

The Polypropylene Density of 0.9018g/cm^3 as see in Figure 4.1 lies within the expected density of 0.89 – 0.91g/cm^3 (AdrecoPlastics, 2022) which implies that the Polypropylene is dense enough to effectively improved the adhesion of Bitumen to the Aggregates hence protect to the Asphalt concrete from moisture and oxygen damage.

4.2.2. Penetration Test

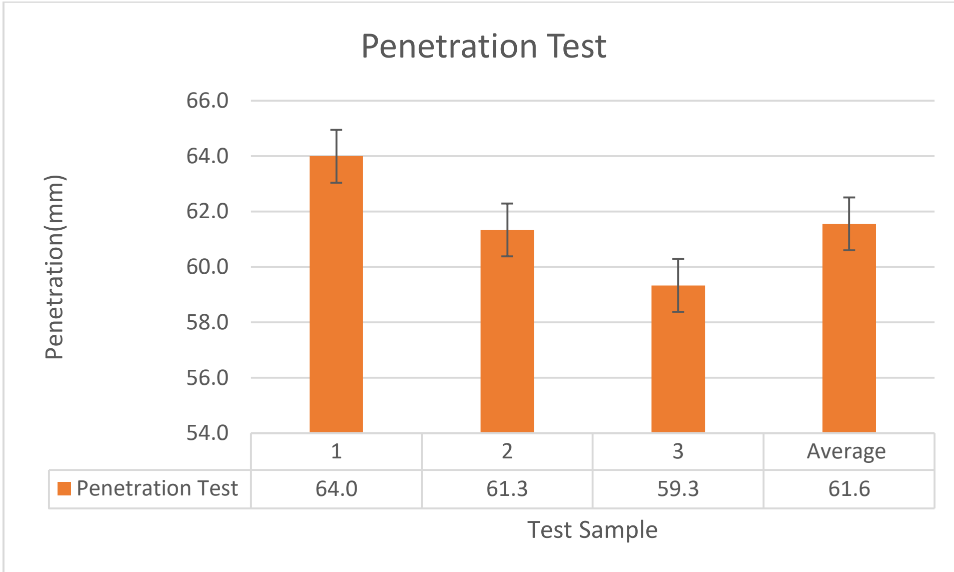


Figure 4. 2 : Penetration Test Results

The Bitumen Consistency of 61.6mm as seen in Figure 4.2 from Table 4.3 categorizes it to be of Bitumen Grade 60 – 70 (CMLT, 2000). This implies that the bitumen can withstand the environmental conditions experienced in Tropical countries hence suitable for Asphalt Concrete production.

4.2.3. Softening Point Test

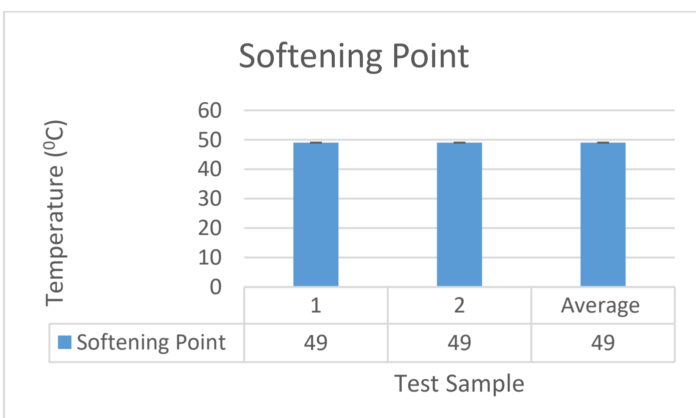


Figure 4. 3 : Softening Point Results

The temperature tolerance of 49^{0}C as seen in Figure 4.3 from Table 4.4 lies within the allowable range of 49 – 56 ^{0}C (CMLT, 2000) which means that the bitumen would not liquefy until the surface temperature was above 49^{0}C when used road Construction. Considering that maximum road Temperature in tropical counties is about 36^{0}C, the Bitumen suitable to make Asphalt Concrete for Road construction in the Tropical Climates.

4.2.4. Specific Gravity of Bitumen

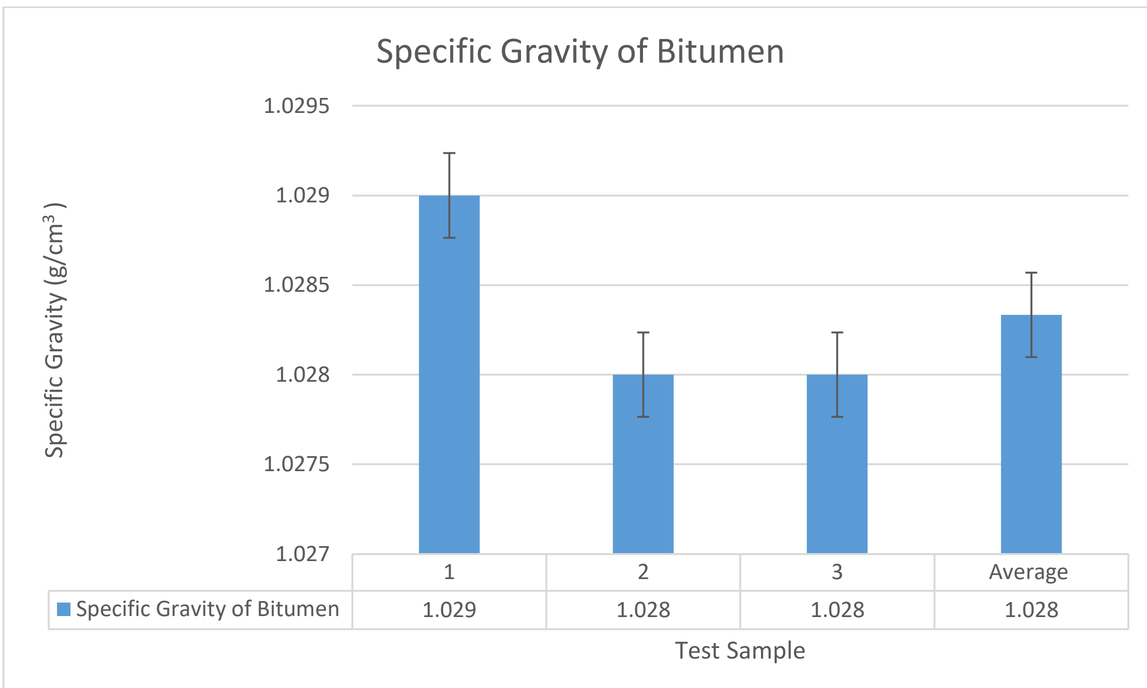


Figure 4. 4 : Specific Gravity of Bitumen Results

Bitumen Specific Gravity of 1.028 as seen in Figure 4.4 from Table 4.5 lies with in recommended range of 1.01 – 1.06 hence it could adequately coat the Aggregates in the Asphalt Mix (TRL, 2002). This would effectively contribute to the strength and durability of the pavement after compaction as there would be adequate adhesion and cohesion between the various blended aggregates yielding formation of high quality Asphalt Pavement.

4.2.5. Combined Specific Gravity and Water Absorption of Aggregates

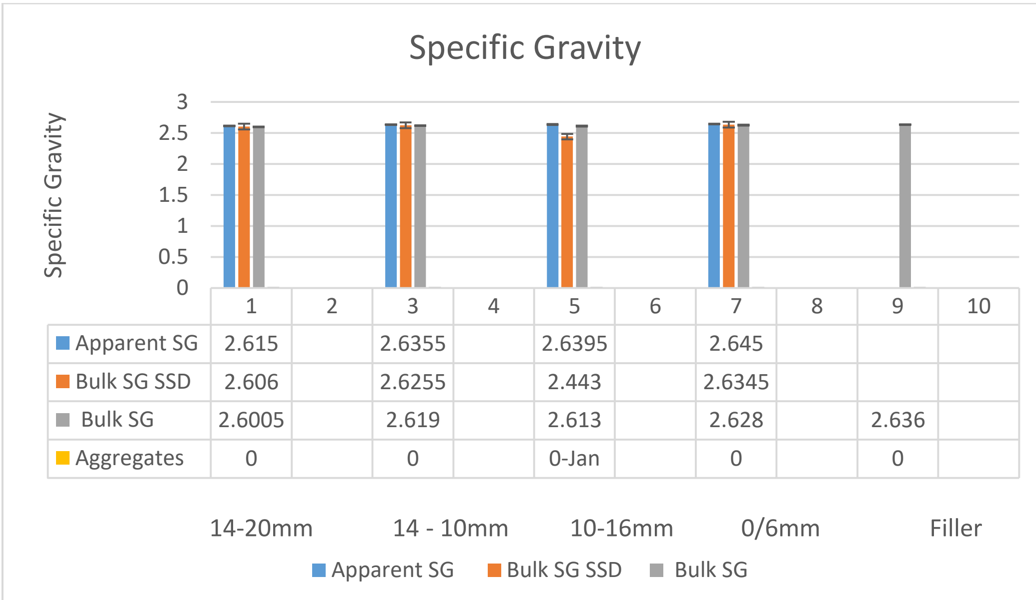


Figure 4. 5 : Aggregate Specific Gravity Results

The Course Aggregates Specific Gravity; Bulk, at Saturated Surface Dry and Apparent results as seen in Figure 4.5 from Table 4.6 lie with the acceptable range of 2.5 – 2.8 required for Asphalt Concrete production in Tropical climatic regions. The Fine Aggregates Specific Gravity of 2.636 was with the acceptable range of 2.6 – 2.7 required for Asphalt Concrete production in Tropical climatic region (MOWTU 2010). This ensures formation of a strong dense mix that can resist deformation and rutting when used in Asphalt Concrete.

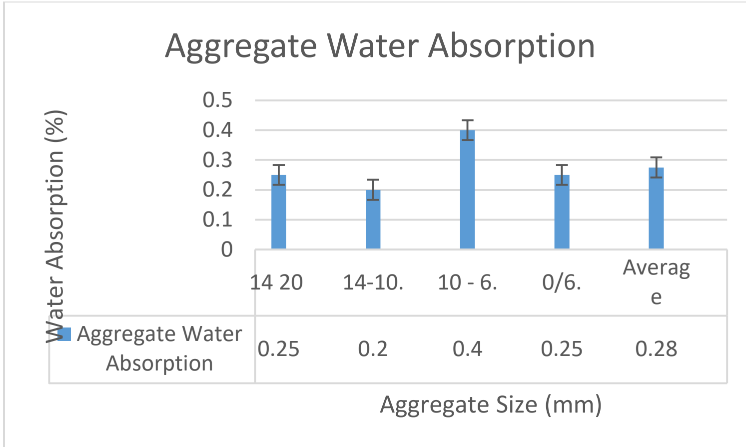


Figure 4. 6 : Agg Water Absorption Results

Average Water Absorption of Aggregates of 0.28% as seen in Figure 4. 6 lies within 0.2 - 0.3% hence is suitable for Asphalt Concrete production (MOWTU, 2010). This Low water absorption of Aggregates minimizes the risk of moisture induced damage and ensures Long term strength and durability of the pavement.

4.2.6. Aggregate Crushing Value (ACV)

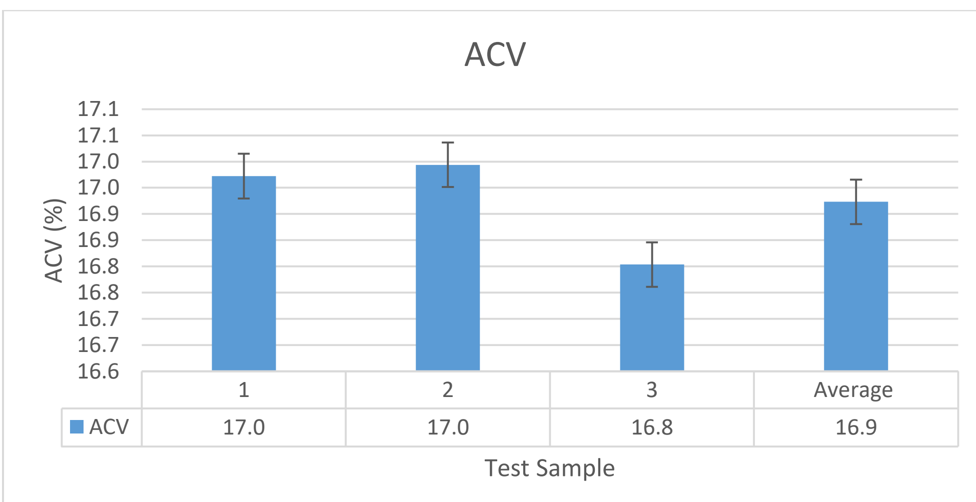


Figure 4. 7 : ACV Results

The ACV of 16.9% as seen in Figure 4.7 from Table 4.7 lies within the required range of < 45% for Asphalt Concrete production hence the aggregates are strong enough to withstand traffic loading on a wearing course (MOWTU, 2010). The Lower the ACV, the Higher the Aggregate Strength. This implies that the Aggregates are strong enough to withstand stand traffic loading when used in Asphalt Concrete production.

4.2.7. Aggregate Impact Value (AIV)

Figure 4. 8 : AIV Results

The AIV of 15.8% as seen in Figure 4.8 from Table 4.8 was less than the maximum allowable of 30% hence Aggregates can with stand sudden impact of Traffic when used in the manufacture of asphalt concrete (TRL, 2002). Aggregates with a low AIV will have a high resistance to Wear and Tear hence make strong asphalt pavements.

4.2.8. Ten Percent Fines Value (TFV)

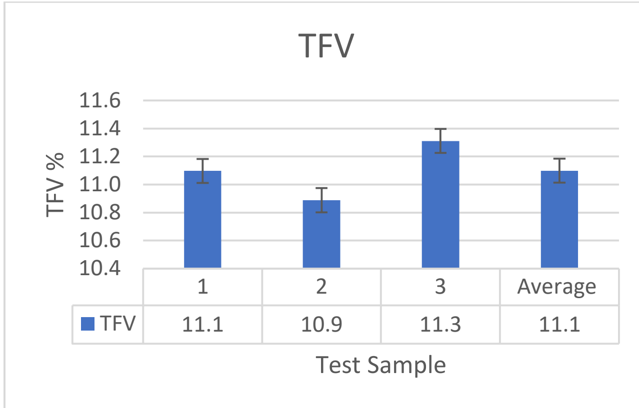


Figure 4. 9 : TFV Results

The Crushed Aggregate of 11.1% as seen in Figure 4.9 lies within the acceptable range of 7.5 – 12.5 % hence the TFV can be calculated using the F and M values in Table 4.10.

Table 4. 2 : TFV Calculation

F (KN)	253	Specification
M (%)	11.1	
TFV DRY (14F/M+4) (KN)	234.2	>110
TFV Wet (KN)	227.9	
(WET/DRY)X100	97.3%	>75%

Since the TFV dry of 234.32 KN as seen in Table 4.10 is greater than the required load bearing capacity of the aggregates 110KN. The TFV Wet of 97.3% was greater that the required 75% for Asphalt Aggregates in Ministry of works and Transport Road design Manual and General Specification (MOWTU, 2010). This TFV result implies the aggregates are Tough and can resist abrasion when exposed to traffic hence the Aggregates are suitable to produce Asphalt Concrete for Road construction in Uganda.

4.2.9. Particle Size Distribution

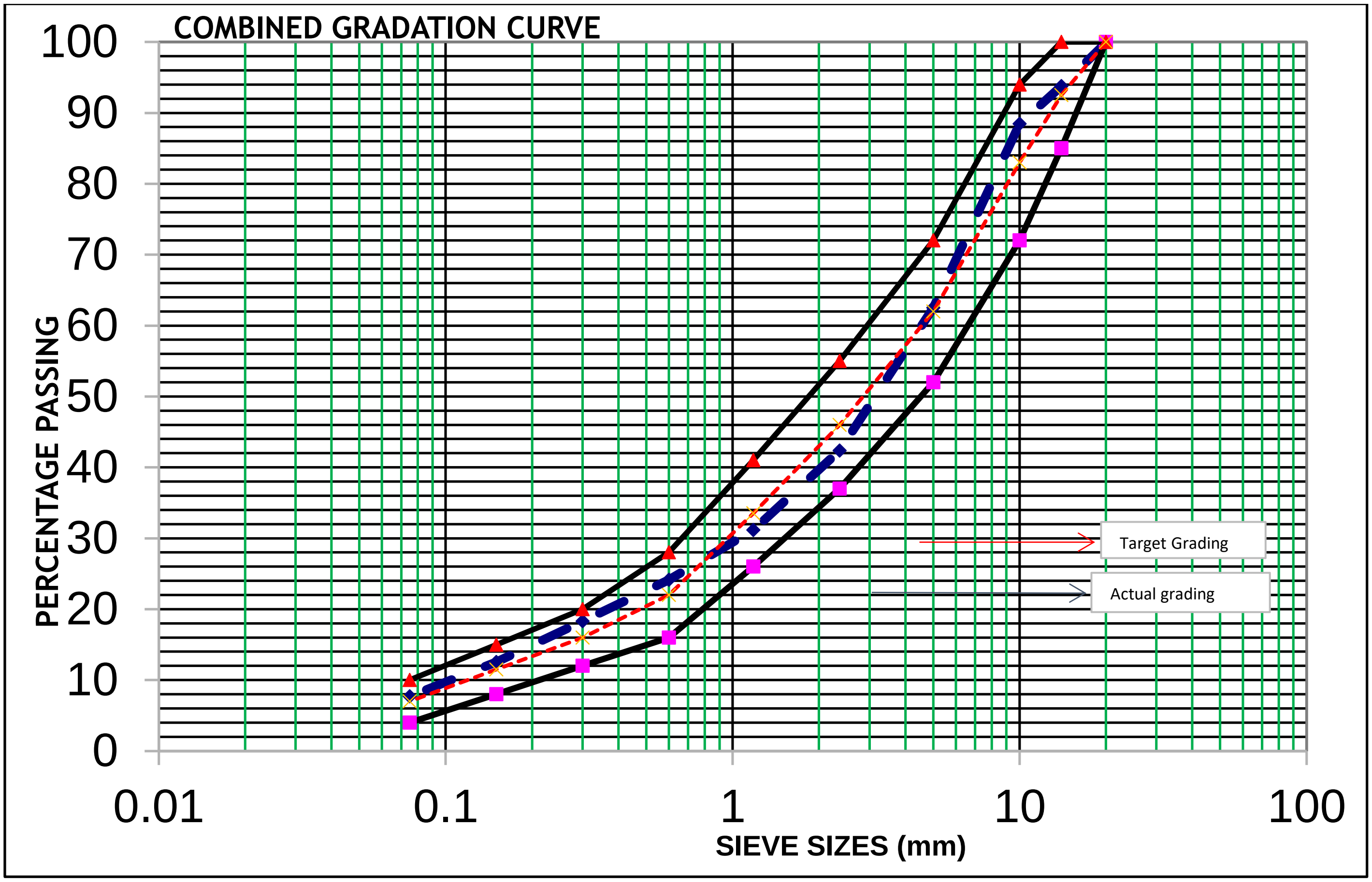


Figure 4. 10 : PSD Results

Basing on the above results as seen in in Figure 4. 10, the combined gradation of the various aggregate sizes was fit and qualifies to make AC 14 asphalt concrete as required by the Ministry of works and Transport Road design Manual and General Specification (MOWTU, 2010).This implies that the Blending proportions in Table 4.11 ensure a dense, well-graded asphalt mix with optimal voids content and good aggregate interlocking. This results in improved Stability, Strength and durability hence resistance to rutting & deformation of the pavement.

4.3 Marshall Mix Design

A combined gradation of Aggregates composed on 14/20mm, 14/10mm 6/10mm 0/6mm and filler were blended According to job mix Table 4.4.

Table 4. 3 : AC14 Job Mix

Job Mix	
Aggregate Size (mm)	Blending Proportions
14/20	5.0
14/10	7.0
6/10	15
0/6	68
Filler	5.0
Total	100

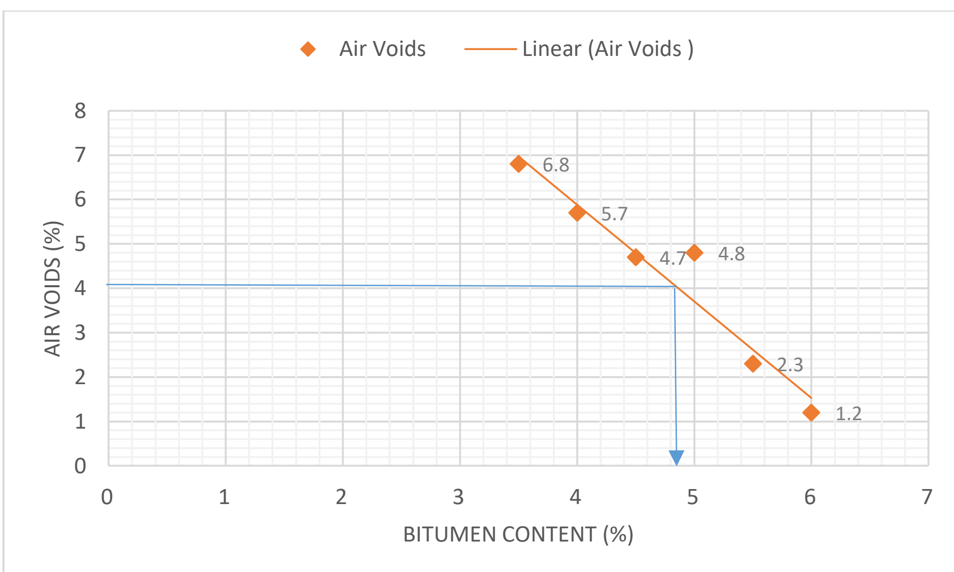


Figure 4. 11 : OBC - Air voids

At 4% Air Void as required for Ugandan roads, the optimum bitumen content was established as is 4.9% (MOWTU, 2010) as seen in Figure 4.11.

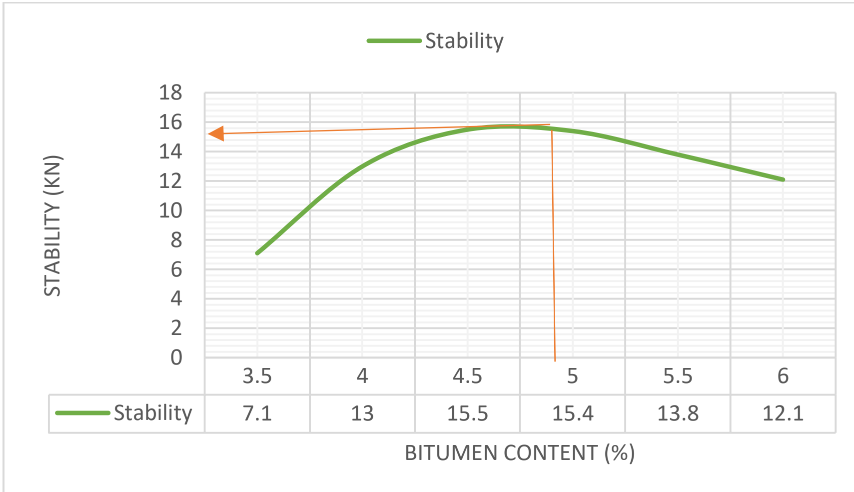


Figure 4. 12 : OBC - Stability

The stability at 4.9% Bitumen Content was 15KN as seen in Figure 4.12 lies within the required range of 8 – 18 KN (MOWTU, 2010). This means the asphalt concrete is strong and adequately designed to carry the maximum traffic loadings > 10 x 10^6 esa's as experienced with in Uganda’s road network.

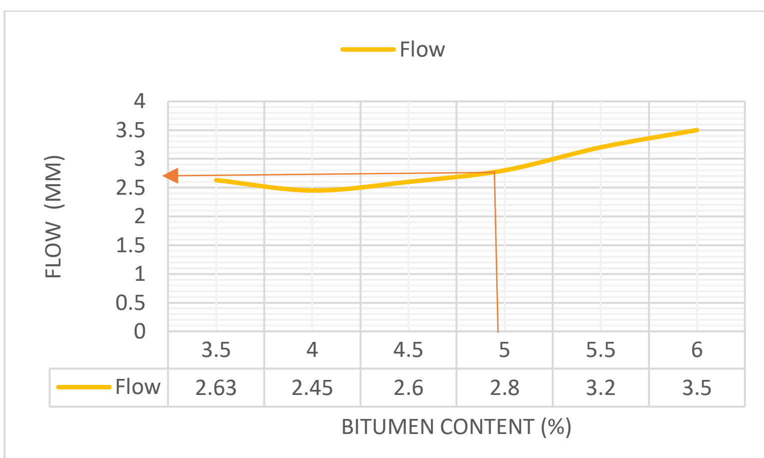


Figure 4. 13 : OBC - Flow

The Flow at 4.9% Bitumen Content was 2.6mm as seen in Figure 4.13 lies within the required 2-4mm by Ugandan Standards (MOWTU, 2010) which implies the Asphalt concrete can be paved and compacted with ease to meet the required pavement strength and density as it has good workability.

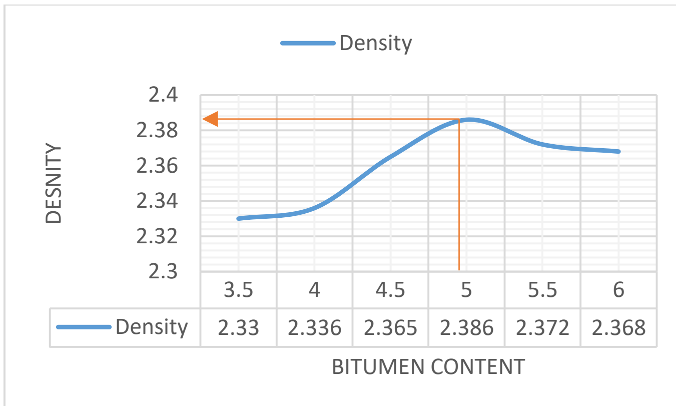


Figure 4. 14 : OBC - Density

Asphalt Density of 2.38g/cm^3 as seen in Figure 4.14 is within the required of 2.3 – 2.5 g/cm$^{3.}$ This implies there is good grading and adequate aggregate interlocking for the Asphalt concrete pavement.

In a nutshell, Optimum Bitumen Content for the Mix was therefore obtained as 4.9 % yielded the required Air Voids of 4%, Stability 15KN and Flow 2.6mm which conformed to the Ministry of works and Transport Road Design Manual and General Specification (MOWTU, 2010).

Asphalt Mix Design

The Control Asphalt Mix Design of the Research is as seen in Table 4.14.

Table 4. 4 : AC14 Mix Design (Control Mix)

Aggregate Size (mm)	**Blending Proportions without Bitumen**	**Percentage Composition of Asphalt Concrete (%)**	**Mass in the Mix (g)**
Bitumen	-	4.9	735
14/20	5.0	4.8	713
14/10	7.0	6.7	999
6/10	15	14.1	2140
0/6	68	64.7	9700
Filler	5.0	4.8	713
Total	100	100%	15000

4.4 Results for the Strength and Volumetric Properties of Hot Mix Asphalt with Varied Polypropylene Content

5 test samples of AC14 containing 0%, 2.5%, 5%, 7.5% and 10% of Polypropylene (PP) were mixed. Basing on the lab results Table 4.6, AC14 with 5% PP content conformed to almost all performance parameter requirements except Stability.

Table 4. 5 : AC14 Performance at Varied Polypropylene Content

AC14		Polypropylene added (%)					Standards
Performance Parameter	Neat (0)	1.5	2.5	5	7.5	10	MOWT U
Stability (KN)	15.7	18	25.5	27.5	25	30.3	8 -18
Flow (mm)	3	3.4	4	3.9	3.7	3.8	2 – 4
ITS (Kpa)	1066	1160	1097	1555	1725	1842	>800
Air Voids (%)	4.9	4.68	4.2	4.9	4.5	4.5	3 – 5
VMA (%)	15.1	15	14.1	15.1	14.8	14.9	>15
VMB (%)	67.7	68.5	70.4	67.5	69.7	69.8	65 – 75

Therefore, the maximum allowable Value of 18KN Stability was used to obtain the Optimal Polypropylene content for AC14 Mix Design in Table 4.6 as 1.5% graphically.

At 1.5% Polypropylene content, the Flow, Indirect Tensile Strength, Air Void, Void filled with Bitumen and Voids Filled with Mineral Aggregates were obtained. They not only conformed to all performance parameter requirements but were also enhanced as seen in Table 4.7.

Table 4. 6 : Analysis of AC14 +1.5% PP

AC14	Polypropylene Content		Analysis	Specification
Performance Parameter	**Neat (0)**	**1.5%**	**% Enhancement**	**MOWT**
Stability (KN)	15.7	18	0.146	8 -18
Flow (mm)	3	3.4	0.133	2 - 4
ITS (Kpa)	1066	1160	0.088	>800
Air Voids (%)	4.9	4.68	-0.045	3 - 5
VMA (%)	15.1	15	-0.007	>15
VMB (%)	67.7	68.5	0.012	65 - 75

4.4.1. Stability

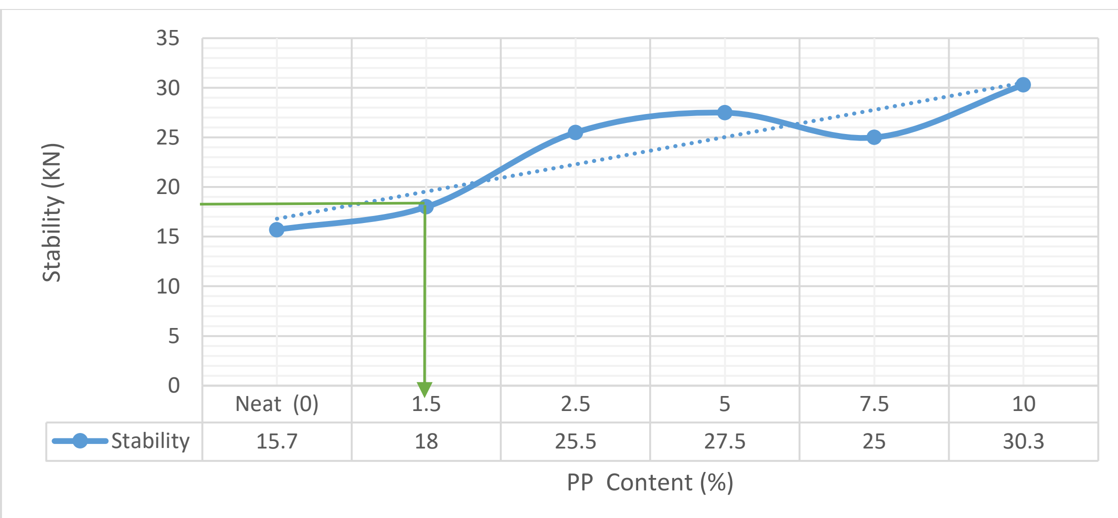


Figure 4. 15 : AC14 & PP - Stability

Stability of the Asphalt concrete increased by 0.146 % from 15.7KN to 18KN as seen in Figure 4.15. This implies that polypropylene increases the Strength, structural integrity, load bearing capacity and binder adhesion in the asphalt concrete.

4.4.2. Flow

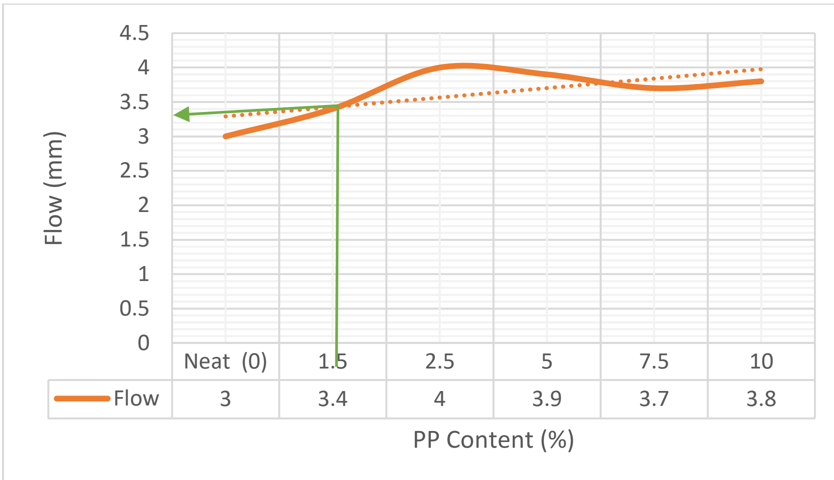


Figure 4. 16 : AC14 & PP - Flow

The Flow increased by 0.133% from 3mm to 3.4mm as seen in Figure 4.16 on addition of Polypropylene indicating better workability and compactability of asphalt concrete during road construction hence improved compaction and density of the mix. Enhanced flow indicates that there will be proper placement and compaction of the pavement leading to improved Pavement Srength, longevity and resistance to plastic deformation.

4.4.3. Indirect Tensile Strength (ITS)

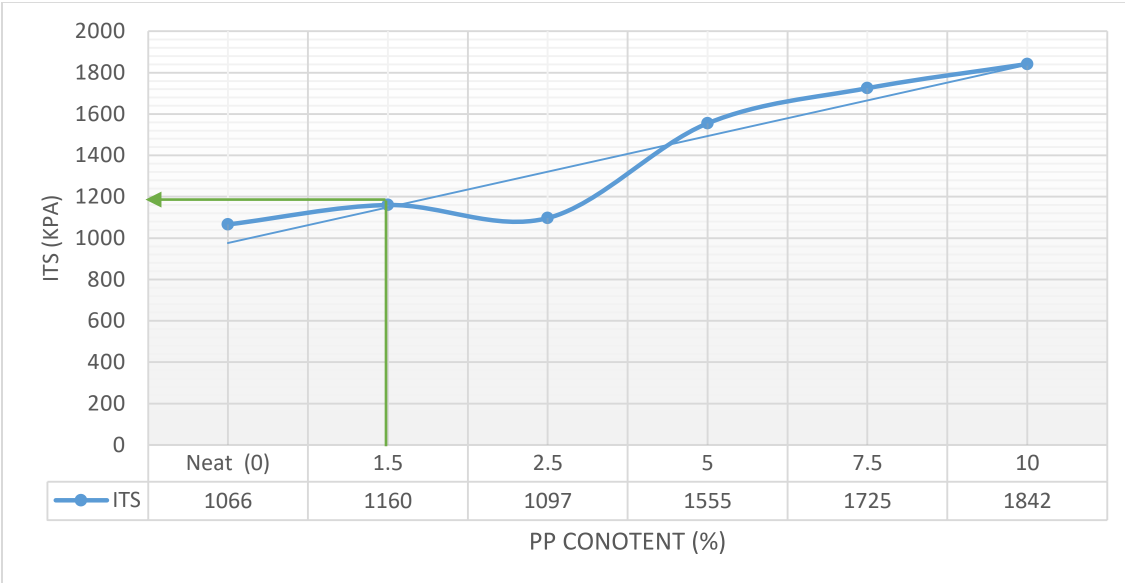


Figure 4. 17 : AC14 & PP - ITS

Indirect Tensile Strength increased of 0.088% from 1066 Kpa to 1160 Kpa as seen in Figure 4.17. This indicates improved Strength, crack, fatigue, moisture and Oxygen deformation resistance of the pavement. The pavement will have better performance under dynamic loading conditions and will be less susceptible to moisture and oxygen effects hence reduced striping for bitumen leading to the strength and durability of the pavement.

4.4.4. Air Voids

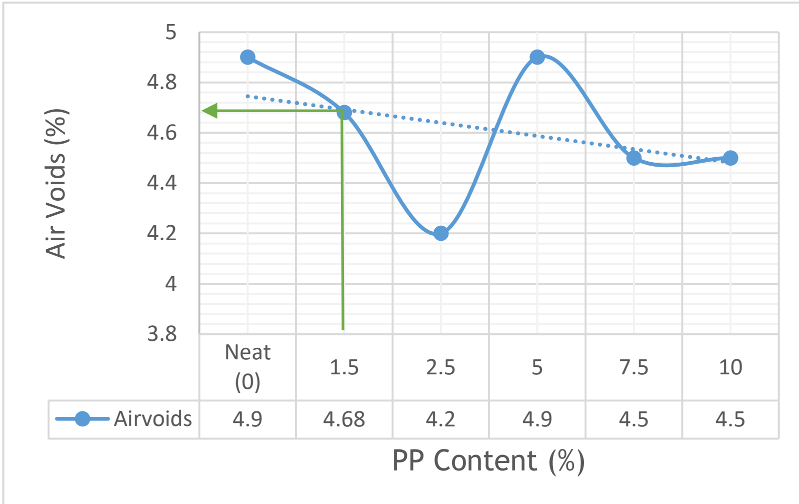


Figure 4. 18 : AC14 & PP - Air Void

Air voids reduced by 0.045% from 4.9mm to 4.68mm as seen in Figure 4.18 which means there is adequate binder coating and aggregate interlocking in the mix hence enhanced cracking, moisture and oxidation effect resistance on the asphalt. This implies the asphalt Concrete can sufficiently expand and Contract without cracking of the pavement.

4.4.5. Voids Filled with Mineral Aggregates (VMA)

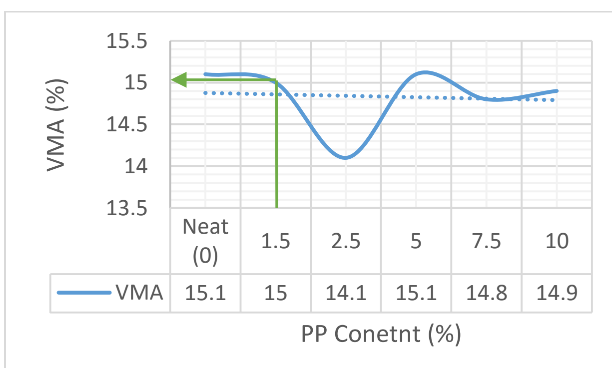


Figure 4. 19 : AC14 & PP - VMA

Void Filled with Mineral Aggregates reduced by 0.007% from 15.1% to 15% as seen in Figure 4.19 which implies the polypropylene does not react when added to the mix design hence takes up more space in the mix, relatively reducing the space filled by the Aggregates in AC14.This indicates adequate coating and homogenous mixing of the polymer in the Asphalt concrete.

4.4.6. Void Filled with Bitumen (VMB)

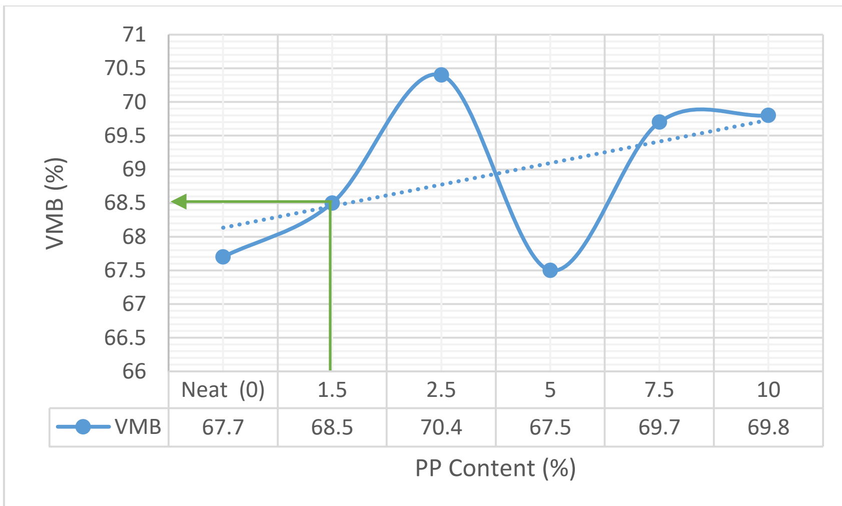


Figure 4. 20 : AC14 & PP - VMB

Void Filled with Bitumen (VMB) increased by 0.012% from 67.7% to 68.5% as seen inn Figure 4.20. This means there is more binder effectively filling the voids with in the asphalt concrete indicating improving Binder aggregate adhesion and cohesion in the mix hence enhanced strength and durability on addition of Polypropylene.

4.5 AC14 - Polypropylene Mix Design.

1.5% Polypropylene Content as a percentage of Bitumen which amounts to 11.025g is the Optimal Polypropylene Content for AC14 hence the Mix design for AC14 with Polypropylene is composed as shown in Table 4.8

Table 4. 7 : AC14 _ Polypropylene Mix design

Aggregate Size (mm)	**Aggregate Blending Proportions**	**Percentage Composition of Asphalt Concrete (%)**	**Mass in the Mix (g)**
Polypropylene (1.5%)			11.025
Bitumen	-	4.9	735
14/20	5.0	4.8	713
14/10	7.0	6.7	999
6/10	15	14.1	2140
0/6	68	64.7	9700
Filler	5.0	4.8	713
Total	100	100%	15,011.025

The Application of 1.5% Polypropylene in AC14 Asphalt concrete increased the; stability by 0.146 % from 15.7 - 18KN , Flow by 0.133% from 3 - 3.4mm, Indirect Tensile Strength by 0.088% from 1066 - 1160Kpa, Void Filled with Bitumen (VMB) by 0.012% from 67.7

- 68.5%. And Reduced the; Air Void by 0.045% from 4.9 - 4.68%, & Void Filled with Mineral Aggregates by 0.007% from 15.1 - 15%.

CHAPTER 5: CONCLUSIONS AND RECOMENDATIONS

5.1. Conclusions

From the Study it was concluded that;

1. The Polypropylene, Bitumen and Aggregates selected had the desirable mechanical properties for Asphalt Concrete Production hence viable to be used in the study.
2. The Optimal Binder content for the AC14 Job mix blend was 4.9%
3. Polypropylene enganches the Strength and Volumetric properties of Asphalt Concrete and its resepons is like that of an Antistripping agent for AC14. Threfore it is scientifically and practically applicable to be used in the Mix Design of Hot Mix Asphalt to minimize the occurrence of premature failure of the wearing course in Flexible pavements.
4. The AC14 Mix Design with 1.5% Polypropylene (PP) in Table 4.17 conforms to the Asphalt Concrete Performance requirement as specified by Ministry of Works and Transport Uganda. Basing on the above findings, the application of Polypropylene in Hot Mix Asphalt will result into construction of strong and durable flexible pavements, with longer design life using the same materials while recycling and reusing Polypropylene which is non-biodegradable hence reducing waste contamination in the environment.This will effectively reduce the Budget and frequency for Road Rehabilitation due to premature Flexible Pavement Failure.

5.2. Recommendations

5.2.1 Recommendations Based on Conclusions

1. Since the mass of the asphalt briquette should be 15000g, with Polypropylene (PP) addition, the Mix design at 1.5% PP content added, the mass of 0/16mm aggregates should be reduced to 9688.975g but ensure the job Mix design is within the AC14 Grading envelope.
2. Despite 1.5% being the Optimal Polypropylene Content for AC14 basing on the Uganda Road specifications, 5% is recommended as it has a better Strength and overall performance basing on the results Table 4.15. Hence the Upper limit of stability in the specification should be ignored and AC14 + 5% Polypropylene Mix Design should be adopted.

5.2.2 Recommendations for Future Studies

1. Research can be carried out with Polypropylene partially replacing the identified Bitumen content to predict the performance of the pavement.
2. Research using the same methodology should be carried out using other plastics like polyethylene, Polyvinyl Chloride and Ethylene Vinyl Acetate to ascertain the viability for application in Asphalt concrete production as they are common non-degradable plastics that can be recycled through road construction.
3. Cost benefit analysis for road construction with the above Polypropylene Asphalt Concrete Mix Design in comparison to the Normal Asphalt Concrete should be carried.

4. Studies for AC20 Mix Design with Polypropylene should be carried out, basing on the results, the none-biodegradable Polymer would have a wider application in the road construction industry.

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APPENDICES

Appendix 1 : Material Preparation

Measuring Polypropylene

Heating and Melting Polypropylene in Bitumen

Mixing AC14 Samples

Appendix 2 : AC14 Tests

Marshall Stability and Flow Measurement

ITS Measurement

Modified AC14 Samples

ANNEXES

Annex A: Mechanical Properties Test Results

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT		
TEST	DETERMINING DENSITY OF POLYPROPYLENE FIBER		
Sample no:			Lab team
SOURCE OF SAMPLE:		TESTING DATE	1/14/2024
TEMPERATURE OF TEST:	25°C		

					USING A CONTAINER			
TEST No.					1	2	3	Units
Weight of CUP IN AIR	A				102.5	99.6	102.5	g
Weight of CUP FILLED WITH POLYPROPYLENE FIBER	B				552.7	548.2	556.4	g
Weight of POLYPROPYLENE FIBER	C=B-A				450.2	448.6	453.9	g
VOLUME OF CUP	D				500	500	500	cm^3
DENSITY OF POLYPROPYLENE FIBER	C/D				0.9004	0.8972	0.9078	g/cm^3
AVERAGE DENSITY OF POLYPROPYLENE FIBER						0.9018		g/cm^3
AVERAGE DENSITY OF POLYPROPYLENE FIBER						*0.9018*		

FOR TESTING LAB	*FOR STUDENTS*
Lab Technician	
Materials Engineer	

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

LOCATION	BITUMEN TESTS	OPERATOR	Lab team
SUPPLIER			
TEST METHOD: EN 12591-2000			
16-Jan-24			
BITUMEN TYPE 60/70			

TEST NO	9		IFF		4Z	7	RM	CM	AVERAGE	TEST METHODS	REMARKS
PENETRATION 100gr 5 sec 25 C	59 58 60		60 60 60		64 63 65	60 62 62	58 59 62	60 63 63	61	ASTM D5	60-70
SOFTENING POINT (°C)		49.0		49.0					49.0	ASTM D36	(49-56)°C
BITUMEN AFFINITY									>95		>95
SPECIFIC GRAVITY	1.027		1.027		1.029	1.028	1.028	1.021	1.03	ASTM D70	1.01-1.06

Materials Engineer.

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

INSTITUTION	CLIENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT: INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

A.C.V. LABORATORY TEST RESULT FORM

(BS 812PART 110:1990)

LOCATION:	MUKONO SITE	Oparator	12/Jan/24
MATERIAL DESCRIPTION:	AGGREGATES FOR ASPHALT	Date	13/Jan/24

A.C.V

(A) WT BEFORE CRUSHING (gm)	2748.2	2685.8	2750.5
(B) WT AFTER CRUSHING (gm)	2748	2685.1	2750
(C) WT RETAINED AFTER CRUSHING (gm)	2281.8	2229.5	2288.4
(D) WT PASSING SIEVE 2.36 mm	466.4	456.3	462.1
A.C.V(%) (D/B)*100	17.0	17.0	16.8
AVERAGE RESULTS %	16.9		
NB	more than B by 10gms repeat the test		

A.I.V

(A) WT BEFORE TEST (gm)	343	362.1	350.8
(B) WT AFTER TEST (gm)	342.8	362	349.8
(C) WT RETAINED AFTER TEST (gm)	288.1	305.2	295.6
(D) WT PASSING SIEVE 2.36 mm	54.9	56.9	55.2
A.I.V(%) (D/B)*100	16.0	15.7	15.8
AVERAGE RESULTS %	15.8		
NB	If c+d is more than B by 1gms repeat the test		

SPECIFIED LIMITS IN ACCORDANCE WITH TYPE OF MATERIAL

FOR TESTING LAB		

Lab Technician

Materials Engineer

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

INSTITUTION	NAMES	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling
PROJECT:	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT	

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

(BS 812PART 111:112:1990)

LOCATION:	Lab	OPERATOR	
		DATE SAMPLED	12 January 2024
MATERIAL DESCRIPTION:	AGGREGATES FOR ASPHALT	DATE TESTED	13 January 2024

10% FINE VALUE DRY

TEST NO	1	2	3
CRUSHING FORCE (KN)	253	253	253
WT. OF AGGREG (gm)after crushing (M1)	2767.3	2733.1	2,715.8
WT. OF AGGREG. RETAINED ON SIEVE 2.36 mm (M3)	2460.2	2435.5	2408.6
WT.AGGREG.(gm) PASSING SIEVE 2.36 mm (M2)	307.1	297.6	307.2
TEN % FINE VALUE (M=M2/M1*100)	11.1	10.9	11.3
AVERAGE RESULTS % (M)		11.1	
AVERAGE CRUSHING FORCE (F)		252.6	

$F = \frac{14\ F}{M\ +\ 4}$ 234.2 DRY 234.2 KN

10% FINE VALUE SOAKED

TEST NO	1	2	3
CRUSHING FORCE (KN)	253	253	253
WT. OF AGGREG (gm)after crushing (M1)	2772.7	2814.7	2793.5
WT. OF AGGREG. RETAINED ON SIEVE 2.36 mm (M3)	2457.7	2489.2	2468.7
WT.AGGREG.(gm) PASSING SIEVE 2.36 mm (M2)	315.0	325.5	324.8
TEN % FINE VALUE (M=M2/M1*100)	11.4	11.6	11.6
AVERAGE RESULTS % (M)		11.5	
AVERAGE CRUSHING FORCE (F)		252.6	

$F = \frac{14\ F}{M\ +\ 4}$ 227.9 SOACKED WET/DRY(%)= 97

SPEC >110 SPEC >75%

f= Maximum force (KN)

of material passing the 2.36mm sieve at the maximum force

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

TESTING LAB

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

Materials Engineer

INSTITUTION	CLIENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (	Stirling

PROJECT	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT
TEST	**SPECIFIC GRAVITY**
TEST METHOD	**ASTM:C128-97**

Sample Ref:	**AC 14 MM**	Technician :	
SOURCE:	**Mukono Stirling quarry**	Sampling date:	1/12/2024
Aggregate size :	**COMBINED**	Testing date:	1/14/2024
Description of aggregates:	**HOT BINS**		

Aggregate size :	**20-14**	**14-10**	**10-6.0**	**6.0-0**	**FILLER**
GS bulk :	2.601	2.619	2.613	2.628	2.636
PROPORTIONS:	5	7	18	66	4
COMBINED SG :	2.624				
WATER ABSOPTION	0.2	0.2	0.4	0.2	
COMBINED WATER ABSOPTION	0.3				

REMARKS

FOR CONTRACTOR

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling
PROJECT	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT	

SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES

(AASHTO ; T85—91)

ASTM DESIGNATION ; C127—88

LOCATION: Mukono Quarry	OPERATOR:
SAMPLE No	SAMPLE DATE: 1/12/2024
TYPE: 14-20 mm	TESTING DATE: 1/14/2024

TEST NO			A	B	C
[A] wt. of oven dry sample in air	(gm)		2276.8		2383.0
[B] wt. of saturated surface dry sample in air	(gm)		2282.9		2386.6
[C] wt of saturated sample in water	(gm)		1399.9		1478.2
Bulk Specific Gravity on oven dry basis		A / (B-C)	2.578		2.623
Bulk Specific Gravity on saturated surface dry basis		B / B-C	2.585		2.627
Apparent Specific Gravity		A / A-C	2.596		2.634
Water Absorption(%)=		100(B-A) / A	0.3		0.2

AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.601
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.606
APPARENT SPECIFIC GRAVITY	2.615
WATER ABSORPTION	0.2

FOR TESTING LAB

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling
PROJECT	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT	

SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES

(AASHTO ; T85—91)

ASTM DESIGNATION ; C127—88

LOCATION:	Mukono Quarry	OPERATOR:	
SAMPLE No		SAMPLE DATE:	1/12/2024
TYPE:	14-10 mm	TESTING DATE:	1/14/2024

TEST NO		A	B	C
[A] wt. of oven dry sample in air	(gm)	1279.2		1635.6
[B] wt. of saturated surface dry sample in air	(gm)	1282.2		1639.5
[C] wt of saturated sample in water	(gm)	794.5		1014.1
Bulk Specific Gravity on oven dry basis	A / (B-C)	2.623		2.615
Bulk Specific Gravity on saturated surface dry basis	B / B-C	2.629		2.622
Apparent Specific Gravity	A / A-C	2.639		2.632
Water Absorption(%)=	100(B-A) / A	0.2		0.2

AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.619
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.625
APPARENT SPECIFIC GRAVITY	2.635
WATER ABSORPTION	0.2

FOR TESTING LAB

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling
PROJECT	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT	

SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES

(AASHTO ; T85—91)

ASTM DESIGNATION ; C127—88

LOCATION: Mukono Quarry	OPERATOR:
SAMPLE No	SAMPLE DATE: 1/12/2024
TYPE: 10 - 6 mm	TESTING DATE: 1/14/2024

TEST NO			A	B	C
[A] wt. of oven dry sample in air	(gm)		1883.1		1937.9
[B] wt. of saturated surface dry sample in air	(gm)		1890.8		1945.0
[C] wt of saturated sample in water	(gm)		1170.6		1202.8
Bulk Specific Gravity on oven dry basis		A / (B-C)	2.615		2.611
Bulk Specific Gravity on saturated surface dry basis		B / B-C	2.625		2.621
Apparent Specific Gravity		A / A-C	2.643		2.636
Water Absorption(%)=		100(B-A) / A	0.4		0.4

AVERAGE RESULTS	
BULK SPECIFIC GRAVITY	2.613
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.623
APPARENT SPECIFIC GRAVITY	2.640
WATER ABSORPTION	0.4

FOR TESTING LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
JAN 2024
P.O. BOX 790, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling
PROJECT	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT	

SPECIFIC GRAVITY & WATER ABSORPTION FINE AGGREGATES

(AASHTO ; T84—00)

ASTM DESIGNATION ; C128—97

LOCATION:	OPERATOR:
SAMPLE No	SAMPLE DATE: 1/12/2024
TYPE: QUARRY DUST (O/6 mm)	TESTING DATE: 1/14/2024

TEST NO		1		K
[A] wt. of oven dry sample in air	(gm)	565		549.8
[B] wt. of pycnometer filled with water	(gm)	1805.71		1770.2
[C] wt. of pycnometer with specimen and water	(gm)	2157.22		2112.02
[S] wt of saturated surface dry sample	(gm)	566		551.5
Bulk Specific Gravity on oven dry basis	(B-C) / (B+S-C)	2.634		2.622
Bulk Specific Gravity on saturated surface dry basis	S / (B+S-C)	2.639		2.630
Apparent Specific Gravity	A / 100(B-A)	2.646		2.644
Water Absorption(%)=	A / A	0.2		0.3

BULK SPECIFIC GRAVITY	2.628
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.635
APPARENT SPECIFIC GRAVITY	2.645
WATER ABSORPTION	0.2

FOR TESTING LAB

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling
PROJECT:	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT	

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

LOCATION: Mukono Lab	OPERATOR:
SAMPLE No	SAMPLE DATE: 1/12/2024
TYPE: Filler	TESTING DATE: 1/14/2024

	Beaker K		Beaker 1
[A) Wt. OVEN dry sample (gm	339		340
[B) Wt. of Pycnometer containing water alone (gm)	1805.71		1771.19
[C] Wt of Pyconometer containing Sample and water (	2014.7		1983.6
SPECIFIC GRAVITY OF FILLER $\frac{A}{A+(B-C)}$	2.607		2.665
AVERAGE	2.636		

FOR TESTING LAB

Lab Technician

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

Materials Engineer

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT	INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

JOB ASPHALT MIX DESIGN

LOCATION MUKONO LAB

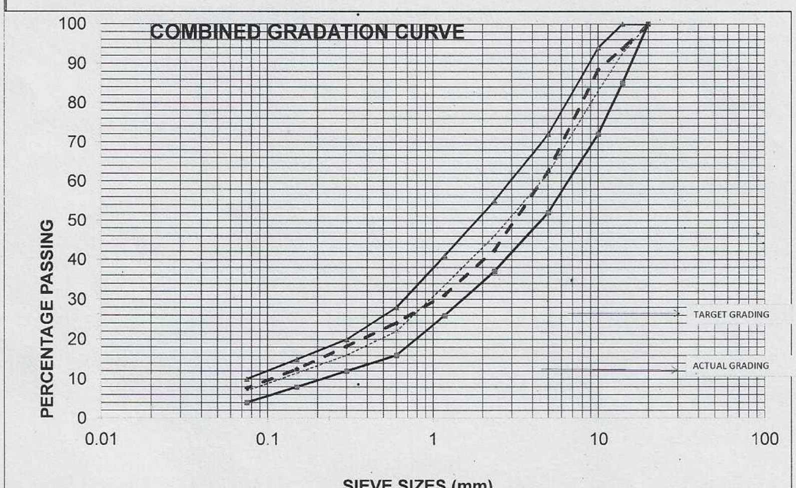
JOB MIX GRADING COMPOSITION

SUPPLIER HOTBIN

DATE 1/14/2024

MATERIAL AC 14 INDIVIDUAL GRADATION

	14/20MM		10/14MM		6/10MM		0/6MM		FILLER		actual	TARGET GRADING	SPEC
		5.0		7.0		15.0		68.0		5.0	100.0		
20	98.6	4.9	99.4	7.0	100.0	15.0	100.0	68.0	100.0	5.0	100	100	100
14	18.7	0.9	70.3	4.9	99.4	14.9	100.0	68.0	100.0	5.0	94	93	85—100
10	1.6	0.1	18.7	1.3	93.9	14.1	100.0	68.0	100.0	5.0	88	83	72—94
5	0.4	0.0	1.3	0.1	6.6	1.0	83.0	56.4	100.0	5.0	63	62	52—72
2.36	0.4	0.0	0.9	0.1	5.1	0.8	53.7	36.5	100.0	5.0	42	46	37—55
1.18	0.4	0.0	0.8	0.1	4.3	0.6	37.4	25.4	100.0	5.0	31	34	26—41
0.6	0.4	0.0	0.7	0.0	3.6	0.5	27.3	18.5	99.8	5.0	24	22	16—28
0.3	0.4	0.0	0.6	0.0	3.0	0.5	19.1	13.0	95.8	4.8	18	16	12—20
0.15	0.4	0.0	0.5	0.0	2.5	0.4	12.0	8.1	79.7	4.0	13	12	8—15
0.075	0.4	0.0	0.4	0.0	2.2	0.3	6.5	4.4	58.4	2.9	8	7	4—10



FOR CONTRACTOR

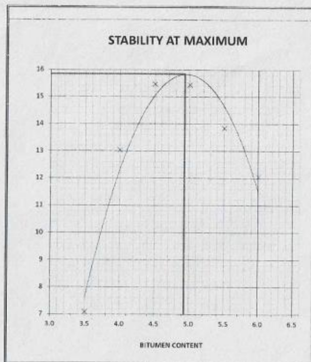
Technician

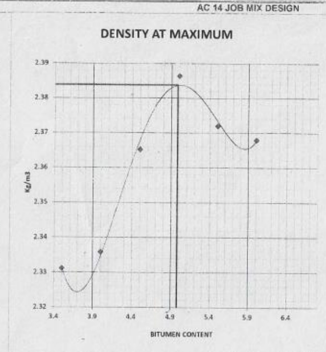
Materials Engineer

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

Annex B: Marshall Mix Design Results

AC 14 JOB MIX DESIGN





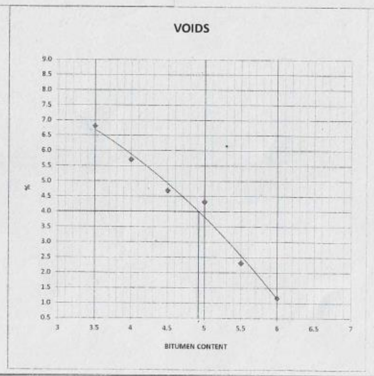
DATE: 18-01-2024

Optimum Bitumen

Stability	4.9	%
Density	5.0	%
Voids	4.9	%
Average	4.9	

MIX PROPORTION

FILLER	5	%
Q / Dust	68	%
10mm	15	%
14mm	7	%
20mm	5	%
TOTAL	100	



Summary for Optimum BitumenContent Determination Data

BITUMEN %	3.5	4	4.5	5	5.5	6	
DENSITY	2.33	2.336	2.365	2.386	2.372	2.368	
STABILITY	7.1	13.0	15.5	15.4	13.8	12.1	
FLOW	2.63	2.45	2.6	2.8	3.2	3.5	
VOIDS	6.8	5.7	4.7	[illegible]	2.3	1.2	

Signed:

Contractor:

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

ANNEX C: PP Modified Asphalt Test Results

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT : INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

NEAT ASPHALT

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	3.0	2—4
MARSHALL STABILITY 75BLOWS	15.7	9-18
MARSHALL AIR VOIDS 75BLOWS	4.9	3—5
VOIDS IN MINERAL AGGREGATES	15.1	>14%
VOIDS FILLED WITH BINDER	67.7	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,066	>800kpa
INDIRECT TENSILE WET STRENGTH	89	>80% of dry
BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
RATIO STABILITY/FLOW	5.1	>2.5

STIRLING CIVIL ENGINEERING LTD
TESTING LAB
Lab technician
Materials Engineer
P.O. BOX 798, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT — INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

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

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

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

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

ASTM D6927Standard Method for Marshall Stability and Flow

Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Adjusted	Flow (mm)	Ratio (Stab./Flow)
65.4	65.3	65.4	65.4	0.95	16.4	15.60	3.32	4.697
66.4	66.0	65.4	65.9	0.95	15.0	14.23	2.60	5.473
64.5	65.2	65.2	65.0	0.96	16.6	15.96	3.05	5.232
66.2	65.1	66.4	65.9	0.95	15.0	14.23	2.83	5.028
Average Sample 1			65.5	1.0	15.7	15.0	3.0	5.1
-	-	-	-	-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2								

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

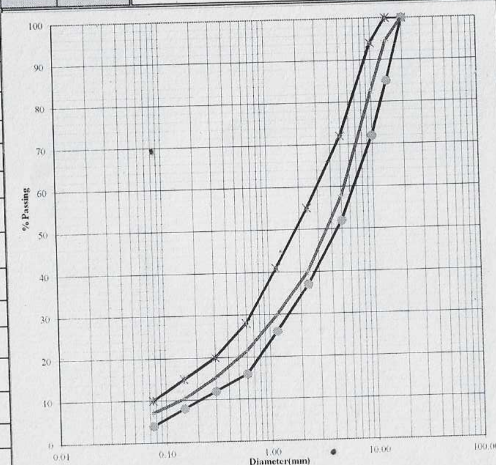
Mass (g)	Sample 1	Sample 2
Bowl	232.3	167.8
Bowl + Asphalt	1937.5	1869.0
Asphalt	1705.2	1701.2
Filter paper before extraction	29.3	31.8
Filter paper + Filler After extracti	30.8	33.1
Recovered Filler	1.5	1.3
Oven dry extracted Mtl (dry)	1619.6	1614.1
Oven dry extr. mtl + filler	1621.1	1615.4
Bitumen	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 (Pycnometer with Water)			SAMPLE 2 (Pycnometer with Water)		
Temperature of water (°c)	25°C		Temperature of water (°c)	25°C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1288		Asphalt	1126.5	-
Pycn. + Water	7363		Pycn. + Water	7363	-
Pycnometer + Asph. + Water	8125.8		Pycnometer + Asph. + Water	8029.3	-
Volume of asphalt	525.2		Volume of asphalt	460.2	-
G_{mm}	[illegible]	-	G_{mm}	2.448	-
Av. G_{mm}	2.452		Av. G_{mm}	2.448	
Gmm (Kg/m3) Sample 1&2	2.450				

Comment:

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				



FOR TESTING LAB

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT: INVESTIGATING THE USE OFPOLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

INDIRECT TENSILE STRENGTH

BITUMINOUS MIXTURE SAMPLED ON 1/21/2024 | 102 | GMM 2.450 | Bit.content,% 4.9 | NO.OF BLOWS 54

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

INDIRECT TENSILE STRENGTH

DRY SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD,P	SINGLE TENSILE STRENGTH,S_t	AVERAGE TENSILE STRENGTH,S_t	WET SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD,P	SINGLE TENSILE STRENGTH,S_t	AVERAGE TENSILE STRENGTH,S_t		WET/DRY
	div	kn/div	kn	spec min 800 kPa			div	kn/div	kn	kPa	kPa	S_t =2P/∏tD where P= maximum load(N) t=specimen thickness(mm) D=specim	spec 80%
2	57	0.217	12.4	1,169.3	1,194.3	1	50	0.217	10.8	1,025.7	1,066		89
5	58	0.217	12.6	1,196.5		4	53	0.217	11.5	1,104.6			
6	59	0.217	12.8	1,217.1		3	52	0.217	11.3	1,067.8			

FOR TESTING LAB

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT :	INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

2.5% POLYPROPYLENE FIBER

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	4.0	2—4
MARSHALL STABILITY 75BLOWS	25.5	9-18
MARSHALL AIR VOIDS 75BLOWS	4.2	3—5
VOIDS IN MINERAL AGGREGATES	14.1	>15%
VOIDS FILLED WITH BINDER	70.4	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	6.6	>2.5

TESTING LAB

Lab technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT

INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

Field Ref. No.:	Lab. no.		MIX	2.5% POLYPROPYLENE FIBER	Sampling date:	21-Jan-24
Sample grade: AC 14	Compaction:	75 blows			Testing date:	22-Jan-24
Sample Description:			AC 14			

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

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

Marshall specim.	Mass in air	Mass in Water	Saturated surface Dry in air	Bulk S.G (G_{mb})	Unit Wt. (Kg/m^3)	% Air Voids	% VMA	% VFB
1	1190.0	686.60	1191.70	2.356	2.345	4.8	14.6	67.5
2	1182.9	684.60	1183.40	2.371	2.360	4.1	14.0	70.6
3	1187.4	689.90	1189.50	2.377	2.365	3.9	13.9	71.8
4	1196.4	693.80	1197.20	2.377	2.365	3.9	13.9	71.7
Average Sample 1				2.370	2.359	4.2	14.1	70.4
-				-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2				2.370	2.359	4.2	14.1	70.4

ASTM D6927Standard Method for Marshall Stability and Flow

Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Stability (KN) Adjusted	Flow (mm)	Ratio (Stab./Flow)
62.2	62.7	63.1	62.7	1.02	24.8	25.33	3.94	6.428
61.1	61.4	61.7	61.4	1.06	26.7	28.28	4.00	7.069
62.0	62.7	62.5	62.4	1.03	26.1	26.84	4.14	6.484
61.3	61.7	61.8	61.6	1.05	24.4	25.64	3.91	6.557
Average Sample 1			62.0	1.0	25.5	26.5	4.0	6.6
-	-	-	-	-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2								

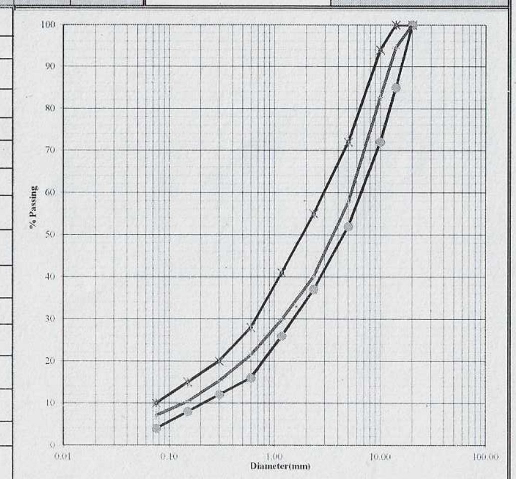
ASTM D 2172- Standard Test Method for Quantitative Extraction of Bitumen from Asphalt Mixtures

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 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 (^{0}c)	25^{0}C		Temperature of water (^{0}c)	25^{0}C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1166.5		Asphalt	1178.2	-
Pycn. + Water	8553.5		Pycn. + Water	8553.5	-
Pycnometer + Asph. + Water	9245.6		Pycnometer + Asph. + Water	9253.6	-
Volume of asphalt	474.4	-	Volume of asphalt	478.1	-
G_{mm}	2.459	-	G_{mm}	2.464	-
Av. G_{mm}	2.459		Av. G_{mm}	2.464	
Av. Gmm (Kg/m3) Sample 1& 2		2.462			

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



Comments

FOR TESTING LAB

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT: INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

INDIRECT TENSILE STRENGTH

BITUMINOUS MIXTURE SAMPLED ON 1/21/2024 | 102 | GMM 2.462 | Bit.content,% 4.9 | NO.OF BLOWS 54

SAMPLE NO.	THICKNESS: HEIGHT 1 (mm)	HEIGHT 2 (mm)	HEIGHT 3 (mm)	Av. Thickness (mm)	Weight of Core in Air (g) A	Weight of Core in Water (g) B	Weight of Core in SSD condition (g) C	Volume of Core (cc) D=(C-B)	Bulk Density (g/cm³) E=(A/D)	GMM (maximum theoretical density) (g/cm³) F	VOLUME OF AIR	SATURATED SPECIMEN	VOLUME OF WATER	DEGREE OF SATURATION	VIM, AIR VOIDS (%) =100*(F-E)/F spec min 3.0% G
MIX	2.5% POLYPROPYLENE FIBER														
WET															
1	64.2	64.1	64.3	64.2	1191.6	680.0	1197.2	517.2	2.281	2.462	37.969	1219.5	27.900	73.482	7.3
2	64.1	63.8	64.7	64.2	1201.4	686.7	1206.9	520.2	2.286	2.462	37.027	1222.3	20.900	56.445	7.1
DRY															
3	64.8	65.0	64.7	64.8	1205.5	691.2	1212.2	521.0	2.291	2.462	36.178				6.9
4	63.7	63.5	63.2	63.5	1195.3	684.1	1199.7	515.6	2.295	2.462	34.881				6.8

INDIRECT TENSILE STRENGTH

DRY: SPECIMEN No.	GAUGE READING (div)	LOAD RING FACTOR (kn/div)	MAXIMUM LOAD,P (kn)	SINGLE TENSILE STRENGTH,S_t (spec min 800 kPa)	AVERAGE TENSILE STRENGTH,S_t	WET: SPECIMEN No.	GAUGE READING (div)	LOAD RING FACTOR (kn/div)	MAXIMUM LOAD,P (kn)	SINGLE TENSILE STRENGTH,S_t (kPa)	AVERAGE TENSILE STRENGTH,S_t (kPa)	S_t =2P/∏tD where P= maximum load(N) t=specimen thickness(mm) D=specim	WET/DRY (spec 80%)
3	84	0.2052	17.2	1,675.0	1,604.0	1	49	0.2052	10.1	977.1	1,097		68
4	76	0.2052	15.6	1,533.0		2	61	0.2052	12.5	1,216.4			

FOR TESTING LAB

Lab Technician:

Materials Engineer:

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT :	INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

5% POLYPROPYLENE FIBER

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	27.5	9-18
MARSHALL AIR VOIDS 75BLOWS	4.9	3—5
VOIDS IN MINERAL AGGREGATES	15.1	>15%
VOIDS FILLED WITH BINDER	67.5	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,555	>800kpa
INDIRECT TENSILE WET STRENGTH	209	>80% of dry
BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
RATIO STABILITY/FLOW	7.3	>2.5

TESTING LAB

Lab technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT

INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

Field Ref. No.:	Lab. no.	MIX	5% POLYPROPYLENE FIBER	Sampling date:	21-Jan-24		
Sample grade: AC 14	Compaction: 75 blows			Testing date:	22-Jan-24		
Sample Description:			AC 14				

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

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

Marshall specim.	Mass in air	Mass in Water	Saturated surface Dry in air	Bulk S.G (G_{mb})	Unit Wt. (Kg/m^3)	% Air Voids	% VMA	% VFB
1	1193.4	687.00	1195.30	2.348	2.337	4.7	14.9	68.5
2	1171.5	673.30	1173.50	2.342	2.331	4.9	15.1	67.4
3	1186.6	682.30	1189.90	2.338	2.326	5.1	15.3	66.5
4	1192.0	685.40	1193.90	2.344	2.333	4.8	15.0	67.8
Average Sample 1				2.343	2.332	4.9	15.1	67.5
-				-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2				2.343	2.332	4.9	15.1	67.5

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)
62.6	62.7	63.0	62.8	1.02	28.3	28.88	4.01	7.203
61.7	61.9	61.7	61.8	1.04	28.9	30.09	4.53	6.643
62.5	62.8	62.7	62.7	1.02	26.1	26.58	3.44	7.727
62.9	63.2	62.7	62.9	1.02	26.7	27.21	3.58	7.600
Average Sample 1			62.5	1.0	27.5	28.2	3.9	7.3
-	-	-	-	-	-	-	-	-
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

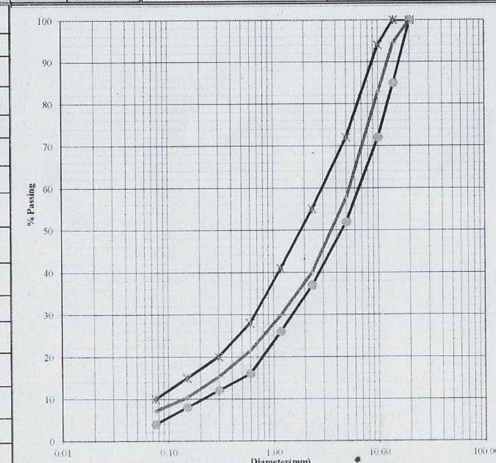
SAMPLE 1 (Pycnometer with Water)			SAMPLE 2 (Pycnometer with Water)		
Temperature of water (^{0}c)	25°C		Temperature of water (^{0}c)	25°C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1207.2		Asphalt	1180.3	-
Pycn. + Water	8553.5		Pycn. + Water	8553.5	-
Pycnometer + Asph. + Water	9267.9		Pycnometer + Asph. + Water	9252.8	-
Volume of asphalt	492.8	-	Volume of asphalt	481	-
G_{mm}	2.450	-	G_{mm}	2.454	-
Av. G_{mm}	2.450		Av. G_{mm}	2.454	
Av. Gmm (Kg/m3) Sample 1&2	2.452				

Comment:

FOR TESTING LAB

Materials Engineer

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				



INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT: INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

INDIRECT TENSILE STRENGTH

BITUMINOUS MIXTURE SAMPLED ON 1/21/2024 | 102 | GMM 2.452 | Bit.content,% 4.9 | NO.OF BLOWS 54

SAMPLE NO.	THICKNESS: HEIGHT 1 (mm)	HEIGHT 2 (mm)	HEIGHT 3 (mm)	Av. Thickness (mm)	Weight of Core in Air (g) A	Weight of Core in Water (g) B	Weight of Core in SSD condition (g) C	Volume of Core (cc) D=(C-B)	Bulk Density (g/cm³) E=(A/D)	GMM (maximum theoretical density) (g/cm³) F	VOLUME OF AIR	SATURATED SPECIMEN	VOLUME OF WATER	DEGREE OF SATURATION	VIM, AIR VOIDS (%) =100*(F-E)/F spec min 3.0% G
MIX	5% POLYPROPYLENE FIBER														
WET															
1	64.1	63.7	64.1	64.0	1195.0	680.0	1197.5	517.5	2.286	2.452	34.969	1217.3	22.300	63.770	6.8
2	63.5	63.8	63.7	63.7	1201.1	688.0	1202.5	514.5	2.311	2.452	29.506	1217.9	16.800	56.937	5.7
DRY															
3	64.2	64.0	64.2	64.1	1189.0	678.0	1195.0	517.0	2.277	2.452	36.892				7.1
4	63.7	63.1	6300.0	2142.3	1179.5	672.0	1184.0	512.0	2.281	2.452	35.728				7.0

INDIRECT TENSILE STRENGTH

DRY: SPECIMEN No.	GAUGE READING (div)	LOAD RING FACTOR (kn/div)	MAXIMUM LOAD,P (kn)	SINGLE TENSILE STRENGTH,S_t (spec min 800 kPa)	AVERAGE TENSILE STRENGTH,S_t	WET: SPECIMEN No.	GAUGE READING (div)	LOAD RING FACTOR (kn/div)	MAXIMUM LOAD,P (kn)	SINGLE TENSILE STRENGTH,S_t (kPa)	AVERAGE TENSILE STRENGTH,S_t (kPa)	S_t =2P/∏tD where P= maximum load(N) t=specimen thickness(mm) D=specim	WET/DRY (spec 80%)
3	72	0.2052	14.8	1,441.0	743.8	1	70	0.2052	14.4	1,401.0	1,555		209
4	78	0.2052	16.0	46.6		2	85	0.2052	17.4	1,709.2			

FOR TESTING LAB

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT :	INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

7.5% POLYPROPYLENE FIBER

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	3.7	2—4
MARSHALL STABILITY 75BLOWS	25.0	9-18
MARSHALL AIR VOIDS 75BLOWS	4.5	3—5
VOIDS IN MINERAL AGGREGATES	14.8	>15%
VOIDS FILLED WITH BINDER	69.7	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,725	>800kpa
INDIRECT TENSILE WET STRENGTH	111	>80% of dry
BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
RATIO STABILITY/FLOW	6.9	>2.5

TESTING LAB

Lab technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT

INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

Field Ref. No.:		Lab. no.	MIX	7.5% POLYPROPYLENE FIBER	Sampling date:	21-Jan-24	Test Type	Done by	Test Type	Done by
Sample grade: AC 14	Compaction:	75 blows			Testing date:	22-Jan-24	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	1204.9	695.30	1205.50	2.362	2.350	4.1	14.4	71.6
2	1208.5	698.80	1208.90	2.369	2.358	3.8	14.1	73.2
3	1200.8	693.50	1201.50	2.364	2.352	4.0	14.3	72.0
4	1205.2	685.60	1207.30	2.310	2.299	6.2	16.3	62.0
Average Sample 1				2.351	2.340	4.5	14.8	69.7
-				-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2				2.351	2.340	4.5	14.8	69.7

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)
63.0	63.0	62.8	62.9	1.02	28.7	29.30	3.75	7.814
62.3	62.5	62.5	62.4	1.03	26.7	27.48	4.26	6.450
62.6	62.7	63.0	62.8	1.02	25.0	25.54	3.91	6.531
64.7	64.5	64.8	64.7	0.97	19.5	18.91	2.70	7.003
Average Sample 1			63.2	1.0	25.0	25.3	3.7	6.9
-	-	-	-	-	-	-	-	-
Average Sample 2								
Average Sample 1 & 2								

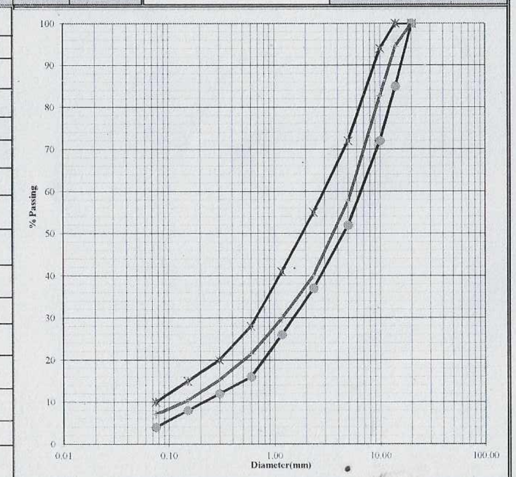
ASTM D 2172- Standard Test Method for Quantitative Extraction of Bitumen from Asphalt Mixtures

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 (Pycnometer with Water)			SAMPLE 2 (Pycnometer with Water)		
Temperature of water (^{O}c)	25^{O}C		Temperature of water (^{O}c)	25^{O}C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1200.6		Asphalt	1198.5	-
Pycn. + Water	8553.5		Pycn. + Water	8553.5	-
Pycnometer + Asph. + Water	9264		Pycnometer + Asph. + Water	9263.1	-
Volume of asphalt	490.1	-	Volume of asphalt	488.9	-
G_{mm}	2.450	-	G_{mm}	2.451	-
Av. G_{mm}	[illegible]		Av. G_{mm}	2.451	
Av. Gmm (Kg/m3) Sample 1 & 2	2.451				

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:

FOR TESTING LAB

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT: INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

INDIRECT TENSILE STRENGTH

BITUMINOUS MIXTURE SAMPLED ON 1/21/2024 | 102 | GMM 2.451 | Bit.content,% 4.9 | NO.OF BLOWS 54

SAMPLE NO.	THICKNESS: HEIGHT 1 (mm)	HEIGHT 2 (mm)	HEIGHT 3 (mm)	Av. Thickness (mm)	Compacted material parameters: Weight of Core in Air (g) A	Weight of Core in Water (g) B	Weight of Core in SSD condition (g) C	Volume of Core (cc) D=(C-B)	Bulk Density (g/cm³) E=(A/D)	GMM (maximum theoretical density) (g/cm³) F	VOLUME OF AIR	SATURATED SPECIMEN	VOLUME OF WATER	DEGREE OF SATURATION	VIM, AIR VOIDS (%) =100*(F-E)/F spec min 3.0% G
MIX	7.5% POLYPROPYLENE FIBER														
WET															
1	63.3	63.7	63.8	63.6	1194.0	686.9	1196.0	509.1	2.322	2.451	26.737	1207.7	13.700	51.239	5.3
2	64.0	64.0	64.2	64.1	1198.5	687.9	1203.6	515.7	2.301	2.451	31.519	1203.6	5.100	16.181	6.1
DRY															
3	63.5	63.9	63.8	63.7	1206.0	691.2	1207.1	515.9	2.314	2.451	28.689				5.6
4	65.2	64.8	64.9	65.0	1200.8	677.9	1205.1	527.2	2.255	2.451	42.090				8.0

INDIRECT TENSILE STRENGTH

DRY: SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD,P	SINGLE TENSILE STRENGTH,S_t	AVERAGE TENSILE STRENGTH,S_t	WET: SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD,P	SINGLE TENSILE STRENGTH,S_t	AVERAGE TENSILE STRENGTH,S_t		WET/DRY
	div	kn/div	kn	spec min 800 kPa			div	kn/div	kn	kPa	kPa		spec 80%
3	84	0.2052	17.2	1,690.8	1,554.8	1	90	0.2052	18.5	1,811.6	1,725	S_t =2P/∏tD where P= maximum load(N) t=specimen thickness(mm) D=specim	111
4	72	0.2052	14.8	1,418.8		2	82	0.2052	16.8	1,638.6			

FOR TESTING LAB

Lab Technician

Materials Engineer

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

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT : INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

10% POLYPROPYLENE FIBER

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	3.8	2—4
MARSHALL STABILITY 75BLOWS	30.3	9-18
MARSHALL AIR VOIDS 75BLOWS	4.5	3—5
VOIDS IN MINERAL AGGREGATES	14.9	>15%
VOIDS FILLED WITH BINDER	69.8	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,842	>800kpa
INDIRECT TENSILE WET STRENGTH	102	>80% of dry
BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
RATIO STABILITY/FLOW	8.1	>2.5

TESTING LAB

Lab technician

Materials Engineer

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

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UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT

INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

Field Ref. No.:	Lab. no.	MIX	10% POLYPROPYLENE FIBER	Sampling date:	21-Jan-24	
Sample grade: AC 14	Compaction: 75 blows			Testing date:	22-Jan-24	
Sample Description:	AC 14					

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

ASTM D2726 - Standard Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures. / ASTM D6927Standard Method for Marshall Stability and Flow

Marshall specim.	Mass in air	Mass in Water	Saturated surface Dry in air	Bulk S.G (G_{mb})	Unit Wt. (Kg/m^3)	% Air Voids	% VMA	% VFB	Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Stability (KN) Adjusted	Flow (mm)	Ratio (Stab./Flow)
1	1205.9	694.00	1206.70	2.352	2.341	4.3	14.7	70.7	63.2	62.8	63.2	63.1	1.01	31.2	31.50	3.42	9.211
2	1208.3	695.20	1209.70	2.348	2.337	4.5	14.9	70.0	64.0	63.7	63.8	63.8	0.99	32.4	32.10	3.94	8.147
3	1198.7	685.40	1200.80	2.326	2.315	5.4	15.7	65.7	63.7	63.4	63.8	63.6	1.00	25.0	25.03	3.96	6.322
4	1209.7	698.30	1210.50	2.362	2.350	3.9	14.4	72.8	63.5	63.4	63.3	63.4	1.00	32.4	32.42	3.75	8.646
Average Sample 1				2.347	2.336	4.5	14.9	69.8	Average Sample 1			63.5	1.0	30.3	30.3	3.8	8.1
-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average Sample 2									Average Sample 2								
Average Sample 1 & 2				2.347	2.336	4.5	14.9	69.8	Average Sample 1 & 2								

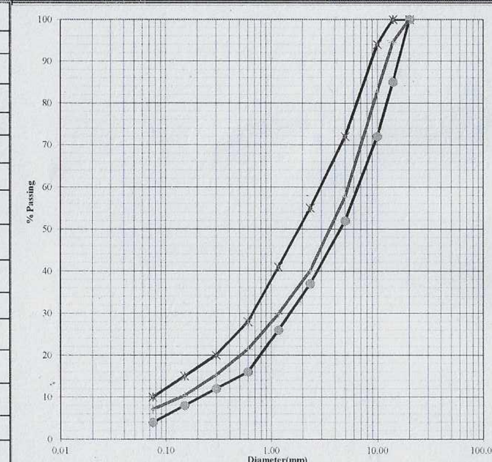
ASTM D 2172- Standard Test Method for Quantitative Extraction of Bitumen from Asphalt Mixtures

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 (^{O}c)	25°C		Temperature of water (^{O}c)	25°C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1162.1		Asphalt	1110.1	-
Pycn. + Water	8553.5		Pycn. + Water	8553.5	-
Pycnometer + Asph. + Water	9240.5		Pycnometer + Asph. + Water	9209.9	-
Volume of asphalt	475.1	-	Volume of asphalt	453.7	-
G_{mm}	2.446	-	G_{mm}	2.447	-
Av. G_{mm}	2.446		Av. G_{mm}	2.447	
Av. Gmm (Kg/m3) Sample 1 & 2			2.446		

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



Comments:

FOR TESTING LAB

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
02 FEB 2024
P.O. BOX 706, KAMPALA (U)

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	WASSWA MARVIN DEO (S20B32/016) & KAINERUGABA ROBERT (S19B32/907)	Stirling

PROJECT: INVESTIGATING THE USE OF POLYPROPYLENE FIBER IN HOT MIX ASPHALT ON THE DURABILITY OF FLEXIBLE PAVEMENT

INDIRECT TENSILE STRENGTH

BITUMINOUS MIXTURE SAMPLED ON 1/21/2024 102 GMM 2.446 Bit.content,% 4.9 NO.OF BLOWS 54

SAMPLE NO.	THICKNESS: HEIGHT 1 (mm)	HEIGHT 2 (mm)	HEIGHT 3 (mm)	Av. Thickness (mm)	Compacted material parameters: Weight of Core in Air (g) A	Weight of Core in Water (g) B	Weight of Core in SSD condition (g) C	Volume of Core (cc) D=(C-B)	Bulk Density (g/cm^3) E=(A/D)	GMM (maximum theoretical density) (g/cm^3) F	VOLUME OF AIR	SATURATED SPECIMEN	VOLUME OF WATER	DEGREE OF SATURATION	VIM, AIR VOIDS (%) =100*(F-E)/F spec min 3.0% G
MIX	10% POLYPROPYLENE FIBER														
WET															
1	63.7	64.0	63.9	63.9	1201.2	685.0	1203.4	518.4	2.294	2.446	32.301	1220.7	19.500	60.369	6.2
2	64.2	63.8	64.0	64.0	1210.2	695.5	1211.4	515.9	2.322	2.446	26.159	1223.0	12.800	48.931	5.1
DRY															
3	63.2	63.1	63.7	63.3	1194.2	682.0	1196.6	514.6	2.297	2.446	31.334				6.1
4	62.7	63.1	62.8	62.9	1193.6	683.0	1195.9	512.9	2.304	2.446	29.877				5.8

INDIRECT TENSILE STRENGTH

DRY: SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD,P	SINGLE TENSILE STRENGTH,S_t	AVERAGE TENSILE STRENGTH,S_t	WET: SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD,P	SINGLE TENSILE STRENGTH,S_t	AVERAGE TENSILE STRENGTH,S_t		WET/DRY
	div	kn/div	kn	spec min 800 kPa			div	kn/div	kn	kPa	kPa		spec 80%
3	92	0.2052	18.9	1,844.1	1,807.9	1	90	0.2052	18.5	1,804.1	1,842	S_t =2P/∏tD where P= maximum load(N) t=specimen thickness(mm) D=specim	102
4	87	0.2052	17.9	1,771.7		2	94	0.2052	19.3	1,880.3			

FOR TESTING LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
P. O. BOX 98, KAMPALA (U)
FEB 2024