

**INVESTIGATING THE USE OF DENSITY POLYETHYLENE IN MODIFYING BITUMEN
TO IMPROVE PERFORMANCE OF FLEXIBLE PAVEMENTS ALONG CLIMBING LANES**

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ABSTRACT

This research project investigates the use of linear low density polyethylene (LLDPE) as a modifier for bitumen in flexible pavements along climbing lanes. The LLDPE was incorporated into the bitumen in granular form at a mixing temperature of 150°C until achieving homogeneity. Key experiments conducted on the modified bitumen encompassed penetration, softening point, ductility tests, and the determination of temperature susceptibility via Penetration Index assessment. Upon modification with 2% LLDPE, the penetration value transitioned from 60/70 to 40/50. The softening point had a 7% rise, while ductility had a reduction of 30%. These results implied an improved stiffness in the bitumen. The Penetration Index demonstrated a substantial 60% decrease, indicating enhanced temperature stability of the bitumen. Subsequently, an asphalt mixture (asphalt cores) was prepared while utilizing the modified bitumen. Results indicated a 12% increase in air voids value, a 17% increase in stability, and a 5% reduction in flow. Additionally, there was a 1% rise in the TSR (Tensile Strength Ratio) value, signifying improved tensile strength characteristics. These findings suggest that incorporating LLDPE as a bitumen modifier yields positive alterations in the properties of asphalt mixtures, potentially enhancing their performance and durability of flexible pavements along climbing lanes.

DECLARATION

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

AINEBYONA MARVIN

Signature;.....

Date;.....

APPROVAL

This certifies that the work described in this report has been authorized for submission to Uganda Christian University's Department of Engineering and Environment, partially fulfilling the prerequisites for a Bachelor of Science in Civil and Environmental Engineering degree.

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Signature : Date :

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ABBREVIATIONS AND ACRONYMS

AC - Asphalt Concrete

ACV - Aggregate Crushing Value

AIV - Aggregate Impact Value

HDPE - High Density Polyethylene

HMA - Hot Mix Asphalt

ITSR - Indirect Tensile Strength Ratio

LAAB - Los Angeles Abrasion Value

LDPE - Low Density Polyethylene

PE - Polyethylene

PET - Polyethylene Terephthalate

PP - Polypropylene

TFV - Ten Percent Fines Value

VFB - Voids Filled with Bitumen

VIM - Voids in Mix

VMA - Voids in Mineral Aggregates

CHAPTER ONE: INTRODUCTION

1.1 Introduction

In Uganda, road transportation dominates the transportation landscape, carrying over 90% of all freight and passenger movements. About 5100 km of Uganda's total 144785 km of roads are paved, with the remaining portion being made of gravel or soil (Kagina, 2021). Nonetheless, the public's uproar over the quality of roads and their early deterioration before they reach their design life is ongoing (Ggoobi, 2020). Rutting, which results from plastic deformation and shows up as irregularities along the wheel path, is one of the main types of degradation (Lazar, 2017). This type of distress is the most typical on asphalt pavements and is more common along longitudinal slopes where there is slow moving traffic. This is associated with the decrease in average speed of vehicles while running up the slope thereby increasing the loading time on to the pavement (Chang, 2019).

The Uganda Meteorological Center has noted that pavement temperatures can reach as high as 59°C in Uganda. Thus, at these temperatures, the binder's viscosity and the particles' adhesion both drop, lessening the stiffness of the asphalt mixture (Rolt, 2022). The extended loading duration combined with the decreased stiffness under slow-moving heavy vehicle traffic results in a cumulative permanent deformation with each subsequent loading that leads to plastic deformation. Shear flow causes the aggregate particles to reorganize because the asphalt binder becomes too pliable to bear the shear stresses (Richard, 2009). The internal shearing mechanism in the middle layer of the asphalt pavement makes this situation more significant along longitudinal slopes.

Accurate prediction of permanent deformation depends on the degree of aggregate interlocking in asphalt concrete, which is a result of aggregate orientation and binder capability under compaction. It is crucial to strengthen the pavement's resistance to shear deformation at these areas, which may mean utilizing larger aggregates in the mix to promote aggregate interlocking through frictional resistance or strengthening the binder's stiffness to strengthen the pavement's resistance to shear flow. It should be highlighted, nonetheless, that utilizing larger aggregates contradicts with the requirements for durability because they increase the amount of voids in the mix, which raises the likelihood of aging. In order to improve bitumen's rheological and aggregate binding qualities and raise the stiffness of asphalt mixes used along longitudinal slopes, this study will concentrate on using linear low-density polyethylene.

1.2 Background to the Study

Rutting prediction models are used to forecast rutting depth, which is the basis for evaluating rutting performance. The internal shear stress distribution, which is the primary cause of shear deformation, particularly along longitudinal slopes, is not taken into consideration by the majority of prediction models, which employ vertical compressive stress as the essential parameter (Sun, 2021). The application of the Bailey Method of Gradation Selection has been utilized to enhance the asphalt mixture's compressive strength in situations involving extreme loading circumstances, such as slow-moving traffic on longitudinal slopes. By guaranteeing that there is adequate stone-to-stone contact between the greatest number of aggregate particles, maximum compressive strength is ensured (Rolt, 2022). This can help to improve the resistance

of the asphalt pavement to vertical compressive stress however; the issue of internal shear deformation, which is a major cause of rutting at longitudinal slope, is not accounted for.

Comprehending the parameters that impact shear stress during asphalt mix design processes can aid in improving comprehension of the rutting behavior along longitudinal slopes. However, internal distress variables that change asphalt's mechanical reaction when employed in the pavement layer are not taken into account by the current mix design processes, such as Marshal (Richard, 2009). I. In order to forecast the gradual deformation over time, the approach focuses on vertical compressive stress, which is commonly delivered to a cylindrical asphalt sample in a mold to replicate deformation that will occur under tire contact stresses in the field. In low stress conditions, such as flat portions, where there is little permanent strain or deformation in each load cycle and the compressive stress is proportionate to slow deformation over an extended period of time, this reaction might be appropriate. The link between stress and strain, however, will not result in the same gradual deformation at higher stresses (severe loading circumstances), such as slow moving traffic at longitudinal slopes (Sahoo, 2021). The asphalt will suffer a slow, heavy loading rate that causes shear displacement, which will cause rutting to occur earlier since the high temperature will alter the material qualities that determine stiffness.

1.3 Problem statement

Rutting is currently one of the most common distresses on flexible pavements. This issue is frequently observed in climbing lanes and crossroads where there is slow-moving traffic or static loading (Chilukwa, 2019). This is because when the pavement temperatures increase, the bituminous binder softens and loses its ability to withstand the shear stresses that arise within the asphalt pavement when it is loaded. Rutting is the result of fast shear displacement along the wheel path caused by a weakening of the adhesion between the aggregates and shear flow of the material. Rutting was noted in the segment of the Jinja Road climbing lane from Namanve to Bweyogerere (Kyamuwendo, 2021). Despite an Energo Project renovation of the road portion completed in 2022, which entailed covering the distorted surface with an asphalt overlay, the road has undergone early deformation. This study therefore focuses on the use of linear low-density polyethylene as a bitumen modifier, which will enhance the bitumen's rheological qualities and hence enhance the asphalt pavement's performance. By doing this, the pavement will be able to tolerate the shear deformation brought on by traffic along climbing lanes, which reduces the pavement's susceptibility to rutting.

1.4 Objectives of the Study

Main objective

To investigate the use of Linear Low Density Polyethylene as a bitumen modifier for flexible pavements along climbing lanes.

Specific objectives

- a) To characterize the mechanical properties of aggregates, and rheological properties of neat bitumen.
- b) To determine the optimum binder content to use in the asphalt mixture.
- c) To determine the rheological properties of the modified bitumen.
- d) To assess the performance properties of the modified asphalt mixture.

1.5 Research Questions to be Investigated

- a) What are the mechanical properties of the aggregates and the rheological properties of the neat bitumen?
- b) What is the optimum binder content to be modified and used in the asphalt mixture?
- c) What are the rheological properties of the modified bitumen?
- d) What are the performance properties of the modified asphalt mixture?

1.6 Scientific Justification of the study

The copolymer known as LLDPE is composed of ethylene, butane, and hexane. Its linear structure of short chains that branch enhances its surface area. It expands after absorbing the oily components of bitumen when introduced. When the swelled particles are combined with aggregates, the binding between the aggregate particles is strengthened. As a result, the adhesion and cohesiveness of the asphalt mixture are enhanced. An increase in adhesion within the binder stiffens it and reduces its tendency to flow and soften at high temperatures. This may improve the asphalt pavement's

stability and ability to withstand shear deformation. Because of the higher internal friction caused by the aggregates' greater cohesion, the pavement is more resilient to deformation under axle loads from driving.

1.7 Geographical scope

The research area, as seen in Figure 1, is located 150 meters from the Bweyogere intersection across from Harred Petro Station along the Kampala-Jinja Road's climbing lane from Namanve.



Figure 1 Namanve Bweyogere road

CHAPTER TWO: LITERATURE REVIEW

This chapter includes the theoretical framework for this research as well as an empirical analysis of prior studies that have examined the usage of plastic in the creation of bituminous mix. The review of empirical literature comes after the theoretical literature in its order of organization. A review of the current literature is also provided, along with an identification of the research need that justifies this study's addition to the body of knowledge.

2.1 Theoretical literature review

Bitumen, sometimes referred to as tar or asphalt, is a crystalline or viscous liquid that is soluble in trichloroethylene and is composed of hydrocarbons and their byproducts. It is a viscous, black, oily byproduct of petroleum refineries, but it can also be found in natural deposits as an organic byproduct of decaying vegetation that occurs naturally (Hirst, 2019). When bitumen is refined to fit paving criteria and other special purposes, it may be referred to in the US as asphalt or asphalt cement, rather than bitumen as used in Europe. The material will be referred to in this study as "bitumen," "asphalt cement," and "asphalt binder" interchangeably. The terms "asphalt," "asphalt mixture," "hot mix asphalt (HMA)," and "bituminous mixture" will also be used to refer to the combination of bitumen and aggregates (Hirst, 2019).

2.1.1 Asphalt mixtures

As seen in the diagram below, aggregates, filler, and binder are the components that make up asphalt mixtures. Various aggregate combinations can be used to create

different asphalt mixtures, each with unique properties appropriate for a particular design and intended usage based on the application. Aggregates and asphalt binder are combined to create mixtures, which cover the aggregates with the binder. The term "hot bituminous mixture" refers to the fact that the binder and aggregates are heated prior to mixing (Hirst, 2019).

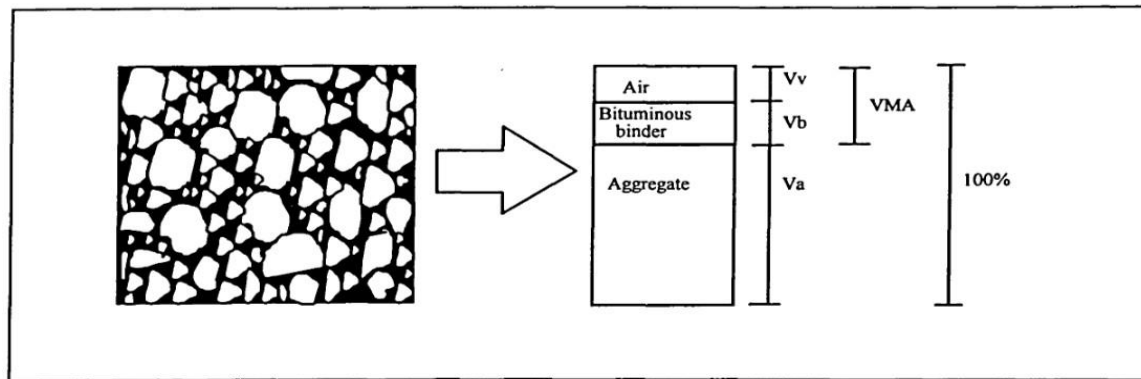


Figure 2 shows constituents of bituminous mixtures

2.1.1.1 Classification of asphalt mixes

Based on the aggregate gradation, and asphalt mix design, the asphalt mixes can be classified as;

- Dense-graded bituminous mix

Well-graded aggregates across the whole range of sieves in use make up a densely graded bituminous mixture. The distribution of stress within the pavement structure depends on both the coarse and fine particles since there are sufficient fine particles in this to effectively separate or fill the spaces between the coarse particles (Hirst, 2019). There are enough fines in the densely graded mixtures to fill in the gaps left by

the coarse particles since they comprise a variety of aggregate particles with varying sizes. For this, an asphalt binder content of 4.5% to 6%, a VMA of 11% to 17%, and air voids of around 4% are needed. These are appropriate for all pavement conditions requiring leveling, mending, structural stability, and friction resistance (Richard, 2009).

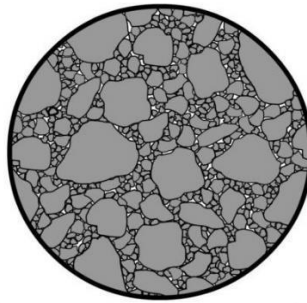


Figure 3 Dense graded asphalt HMA

- Gap-graded or Stone Matrix Asphalt (SMA)

In order to maximize resistance to rutting, gap-graded, or SMA, asphalt mixtures have a high coarse aggregate content. This is achieved by ensuring that there is an adequate amount of stone-to-stone contact within the asphalt mixture. This mix calls for higher bituminous mix content (usually greater than 6%), more durable aggregates, and a high filler content (about 10% by weight), which may call for a modified asphalt binder. With an asphalt binder percentage of 6%+ and a volume of voids near to 4%, the resulting mix has a VMA exceeding that of the densely graded material by more than 17% (Richard, 2009). However, because it requires more durability and enhanced rutting resistance to be put properly, this is more cost-effective in extreme loading situations, such as slow moving, heavily loaded traffic. There are less mid-sized particles in this mixture. This mix contains fewer mid-sized particles therefore the stress distribute with in mixture is achieved through frictional resistance of coarse particles hence more resistance to

deformation while the fine particles fill the spaces in between the coarse particles (Hirst, 2019).

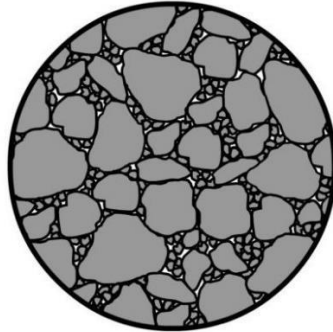


Figure 4 Gap graded HMA

- Open-graded bituminous mix mixes

The term "open-graded layer" refers to a bituminous mix combination that has a high percentage of air spaces (18 to 22 percent) in order to achieve water permeability, or the ability for water to easily pass through the pavement layer. Sand and crushed stone or gravel are needed for the Open-Graded combination (Richard, 2009). These mixtures could be created as

- i. Permeable pavement: In order to enable excellent drainage beneath a bituminous mix or Portland cement concrete pavement surface, open graded mix is utilized as a pavement layer.
- ii. Open graded friction course (OGFC): This is a densely graded asphalt surface with an impermeable surface course (approximately an inch thick) on top that allows water to percolate through to the underlying layer.

iii. Asphalt treated permeable bases (ATPB): This is similar to the OGFC but with less restricting specifications and can be used as a drainage layer for dense graded mixture, stone matrix asphalt or portland cement concrete.

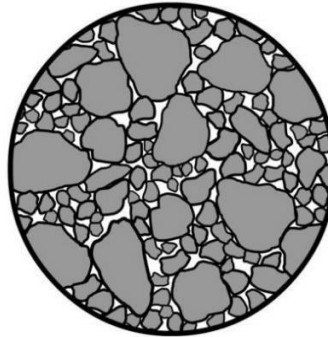


Figure 5 Open graded HMA

2.1.2 Performance of flexible pavements

Tensile and compressive strains brought on by heavy vehicle loads within bituminous (flexible) pavements decrease as depth increases. The gradation of materials is based on this occurrence, with the less expensive and less robust layers serving as the base and subbase and the comparatively strong and expensive asphalt layer serving as the surfacing. Because the induced stresses are distributed throughout the pavement layers as illustrated below, the induced stresses within the pavement layers decrease as the depth of the pavement structure increases (Rolt, 2022).

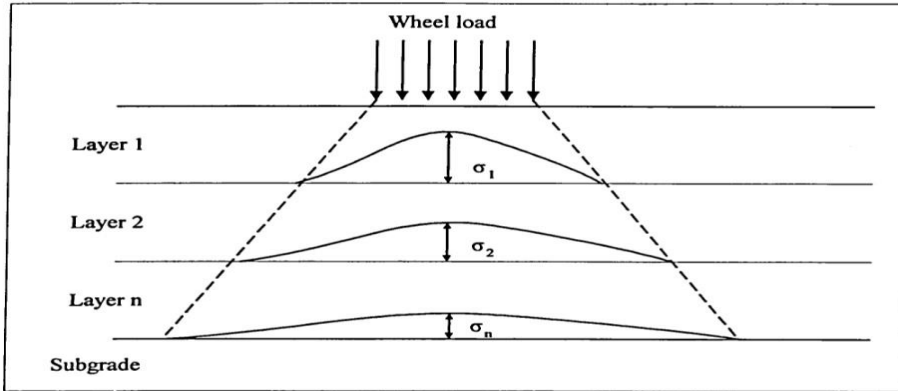


Figure 6 Distribution of traffic loads within the various layers of the flexible pavement

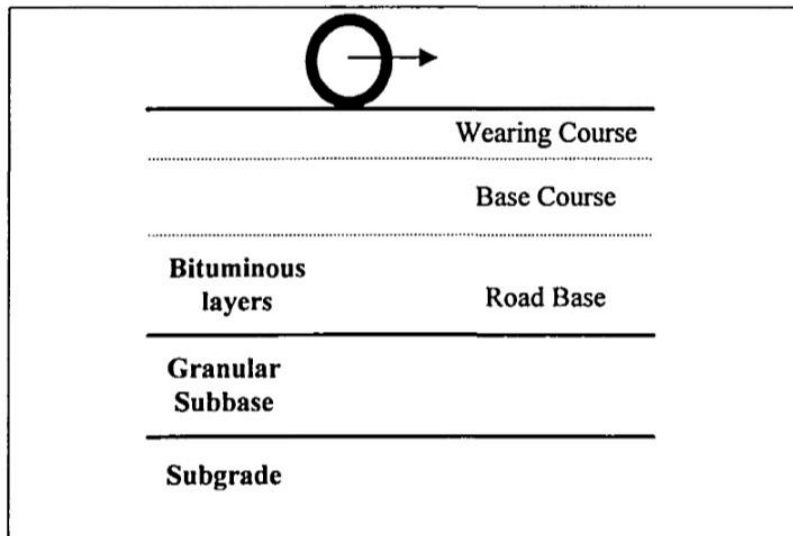


Figure 7 layers of a typical road pavement structure

2.1.3 Pavement design approaches

The goal of pavement design is to construct road pavements that are more cost-effective while still meeting structural and functional requirements for the duration of the pavement's design life. While the structural condition is focused on maintaining the structural integrity of the pavement layers, the functional conditions strive to improve serviceability in terms of road users' riding comfort (Singh, 2021). The following methods are employed in the design and analysis of bituminous pavements:

2.1.3 .1 Empirical approach

This bases on empirical equations of the measurable pavement characteristics obtained from constructed test sections to predict the response of pavement materials. The observations obtained are used to establish correlations between the pavement design and the pavement performance (Rolt, 2022). This approach does not address the exact cause and effect of the phenomenon and has no firm scientific basis. Henceforth, it can no longer accommodate the current changes and the development of new road materials and the increased demand in road traffic. This approach is however simple to apply and is based on actual data (Hirst, 2019).

2.1.3 .2 Analytical (mechanistic) approach

The analytical method evaluates a planned pavement structure by theoretically analyzing the mechanical characteristics of bituminous materials. The analytical method operates by restricting the vertical compressive strain at the top of the subgrade, which affects the pavement's response to permanent deformation, and the horizontal tensile strain created in the pavement layer, which defines the resistance to fatigue (Rolt, 2022).

2.1.3 .3 Mechanistic-empirical approach

The characteristics of the empirical and mechanistic approaches are combined in the mechanistic-empirical approach. The two primary components of this mechanistic-empirical approach are performance and response. Empirical distress models link pavement performance to pavement response, including stresses and strains from loads and environmental effects. One example is the use of linear elastic mechanistic models

to calculate the tensile strains in pavement caused by an applied load (Richard, 2009). The measured strain has an empirical relationship with the build-up of fatigue distresses in the pavement. By creating an empirical link between the reaction and the rate of deterioration, it is then possible to establish an approximate assessment of the pavement performance and determine the damage caused by various loading and environmental condition combinations (Rolt, 2022).

2.1.4 Pavement distresses

Pavement distress can be categorized into four major damage mechanisms: cracking, rutting, moisture damage, and age hardening. Identification of the distress that will occur is important for pavement design and maintenance. One important step in identifying pavement distress is studying the damage mechanisms that occur in bituminous pavements and the level of severity can be quantified then a measurement criterion developed (Lazar, 2017).

2.1.4 .1 Cracking

Cracking in bituminous pavements can be caused by thermal induced stresses under severe climatic conditions or by fatigue under repeated loading. Based on the causes of the cracking, it can be categorized as;

- i. ***Thermal cracking***; This is brought on by asphalt being subjected to a single thermal cycle during which the temperature drops to an extremely low level. When the bituminous binder can no longer flow quickly enough to relieve the

stress as it tries to accommodate the large tensile strains developed due to expansion and contraction caused by temperature variation, induced thermal volumetric stresses above the critical low temperature can also cause cracking (Wang, 2010). When the tensile strength is exceeded by thermally induced stresses, failure takes place. This type of mechanism is typically observed as;

- Transverse cracks: this manifest across the full width of bituminous pavements at regular intervals.
 - Longitudinal cracks: These occur parallel to the centerline of bituminous pavements.
 - Block cracks: These take place in the transverse and longitudinal direction of road pavement and are usually caused when the binder becoming too brittle due to high voids that allow oxidation of the bituminous surface.
- ii. ***Fatigue cracking***: The phenomena of fatigue cracking in bituminous pavements is brought on by tensile strains that are created in the pavement as a result of temperature changes, traffic loads, and building methods. The cracks may begin as one or more longitudinal parallel cracks and spread to the surface, but when repeated traffic loads cause the cracks to unite and take on the appearance of an alligator's skin, hence the phrase "alligator cracking." Alligator cracking only happens in places that frequently experience heavy traffic (Wang, 2010).
- iii. ***Reflective cracking***: This is one of the main causes of premature pavement deterioration occurs when a layer of bituminous material is placed on top of a discontinuous base. Reflection cracking is produced by either traffic or thermally

induced stresses, which may be initiated because of already existing cracks or joints in an underlying pavement (Wang, 2010).

2.1.4 .2 Moisture damage

This usually involves the segregation of the binder film from the aggregate surface in the presence of water causing loss of cohesion and adhesion failure between the binder and aggregates bond. This results in a reduction of the strength and stiffness of the mixture hence reducing the ability of the pavement to withstand traffic induced stresses and strains. Moisture damage can occur in two major ways as; stripping and raveling (Lazar,2017).

- i. Stripping: This results from the loss of adhesion between the aggregates and the binder and is brought on by the presence of moisture. According to (Scholz,1995), this often starts at the bottom of the bituminous layer and moves upward, creating bleeding, which reduces cohesiveness in the stripped layer and creates instability in the upper part of the layer due to too much bitumen.
- ii. Ravelling: This refers to the deterioration of the pavement surface brought on by a number of variables, such as inadequate compaction that can result in a high void content that speeds up age hardening, inadequate fine aggregate content that reduces adhesion between binder and aggregate, and inadequate binder content that causes poor coating in aggregates (Scholz, 1995).

2.1.4 .3 Permanent deformation.

Permanent deformation or rutting propagates as surface depressions generally in the wheel path as a result of traffic loading. The first stage of deformation is characterized by a small amount of deformation that occurs in bituminous surfaces due to densification under traffic hence referred to as secondary compaction. Permanent deformation becomes more significant as the cumulative number of traffic loading increases causing major structural failures (Prosper, 2019). There are three main types of permanent deformation namely;

- i. **Wear rutting:** This occurs in the wheel path, which is caused by, combined environmental and traffic conditions that lead to the progressive loss of coated aggregate particles from the pavement (Singh, 2021). This could be caused by;
 - poor mix properties such as; low bitumen content, less durable aggregates, inappropriate mixture design
 - inadequate compaction

This can be reduced by use of durable aggregates and good mixture design.

- ii. **Structural rutting:** This is caused by permanent deformation of pavement structure due to repeated traffic loading and is majorly associated to permanent deformation in the subgrade (Singh, 2021). Structural rutting can be caused by:
 - poor drainage
 - overstressing pavement layers due to excessive traffic loading
 - poor construction practices such as inadequate compaction

- contribution from other pavement distress like fatigue cracking, stripping

Structural rutting can be prevented by providing good drainage, adequate pavement design, construction quality control and selection of good quality materials.

iii. **Instability rutting or plastic deformation:** This occurs within the asphalt layer due to lateral (shear) displacement of a single bituminous layer along the wheel path (Singh, 2021). Instability rutting can be caused by:

- Adverse hot temperature
- Severe loading conditions e.g. heavy loading, increased tyre pressure, increased axle loading, slow speeding heavy traffic.
- Mix design and material properties e.g.; aggregate and binder characteristics, air void content in mixture, selection of a suitable mixture design.

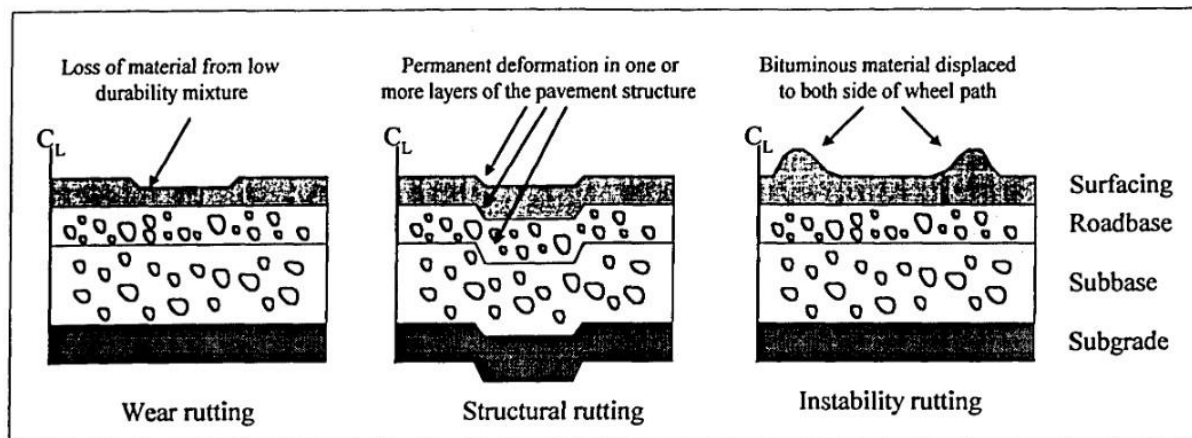


Figure 8 types of permanent deformation

One way to lessen unstable rutting is to employ binders with a high rigidity. This study focuses on plastic deformation (instability rutting) and aims to investigate how polymer-modified binder works to prevent plastic deformation caused by slow-moving traffic

that causes shear deformation along longitudinal slopes. Where applicable, structural rutting and wear will be taken into account.

2.1.5 Asphalt modification

The sharp rise in pavement distress brought to light the major issues with road paving technology, ranging from material design to associated application methods. The damage to asphalt pavements brought on by increased traffic loads has shortened the pavement's service life, which raises maintenance and repair expenses (Ggoobi, 2020). The characteristics of the aggregate and binder mortar provide asphalt mixtures with resistance to deformation. But because bitumen is a viscoelastic material, it will alter when unfavorable weather conditions like high temperatures and heavy loads occur (Locher, 2006). The usage of stiffer mixtures—such as 35 pen grade bitumen—that are characterized by high viscosity and limited penetration bitumen are prone to cracking because they become brittle at low temperatures. Conversely, soft bitumen is not as effective at withstanding high temperatures when big loads are applied, but it is good at preventing cracking (Nizamddin, 2022). Thus, in the event that an asphalt mix fails to satisfy the requirements for permanent deformation, bitumen modification may offer a different and more affordable course of action.

2.1.5.1 Reasons for modifying bituminous binders.

- i. To obtain softer mixtures to reduce cracking at low service temperatures and stiffer mixes to reduce permanent deformation at high temperatures.

- ii. To increase structural strength especially for bituminous mixtures where the strength of the mixtures relies on the stiffness of mortar binder thereby requiring polymer modification.
- iii. To improve workability and compaction in adverse weather conditions, such as strong winds and low temperatures, where road construction is a problem to extend the temperature range for mixing, laying, and compaction.
- iv. To allow for thicker binder films on aggregate to gain better workability and fatigue resistance while achieving sufficient stiffness to resist permanent deformation.
- v. To improve bonding and to reduce stripping of bitumen and aggregate that would cause loss of adhesion between binder and aggregates, especially in the presence of moisture by addition of polymers reduces moisture damage potential .
- vi. To reduce bleeding since increase in the stiffness at high temperatures, consequently reduces the bleeding potential
- vii. To improve resistance to ageing or oxidation by addition of antioxidants into the mixtures hence improving the durability of bituminous mixtures.
- viii. To reduce structural thickness of road pavement layers by addition of polymers to meet the same strength criteria as the road pavement structure without polymer modification.

2.1.5 .2 Properties of polymer modified binders

To achieve effectiveness in the use of modified bitumen (Iswandaru, 2008) suggested that following considerations be taken when choosing the modifier to use;

- i. The polymer to use should be readily available.
- ii. It should have good solubility when blending with bitumen to avoid phase separation.
- iii. Should resist degradation at asphalt mixing temperatures.
- iv. Should improve resistance to flow at high road temperatures affecting workability while laying or making it too stiff and brittle at low temperatures

Additionally, in order to optimize effectiveness, the modified binders should be used in combination with high quality aggregate especially in regions, where exceptional resistance to permanent deformation is needed. The use of mechanistic-empirical design approaches is more suitable for polymer-modified asphalt (Nizamddin, 2022).

2.1.5 .3 Classification on Polymer Modified Bituminous Binders

The Strategic Highway Research Program (SHRP) researchers (Kennedy, 2021) classified the modifier into six groups that are based on the mode of addition as;

- i. Mineral fillers (dust, lime, Portland cement, carbon black, Sulphur)
- ii. Elastomers (Styrene Butadiene Rubber (SBR))
- iii. Plastomers or thermoplastics (polyethylene, polypropylene, Ethylene Vinyl Acetate (EVA))

- iv. Oxidants (manganese and other metal salts)
- v. Antioxidants (lead compounds, carbon, calcium salts)
- vi. Hydrocarbons(aromatic oils)

This study will focus only on thermoplastics/plastomers/plastics. Thermoplastic polymers soften on heating and harden on cooling which is similar to bitumen. The commonly used thermoplastic polymers are polyethylene, polypropylene, polyvinyl chloride, polystyrene, and ethylene vinyl acetate because of their flexibility at low temperature, and hence they are not brittle.

2.1.5 .4 Polyethylene as a bitumen modifier

The polymerization of the ethylene monomer yields polyethylenes. Additionally, polyethylene is commonly accessible in both virgin and recycled forms (Svazic, 2006). When polyethylene is mixed with bitumen, the dispersed polyethylene particles take on the characteristics of a filler, increasing viscosity, which in turn causes shear deformation, at a temperature close to 50°C, when the bitumen matrix becomes soft and deformable. Three types of polyethylene are categorized: linear low density polyethylene (LLDPE), low density polyethylene (LDPE), and high density polyethylene (HDPE). These copolymers have a low glass transition temperature (around -120°C) and often melt between 100°C and 130°C (Bonicelli, 2017). This shows that the base bitumen's hardness and ductility can be enhanced by its high flexibility at low temperatures.

2.2 Empirical literature review

2.2.1 Material performance of polymer modified mixtures.

The main performance criteria for flexible pavements considers resistance to fatigue and to permanent deformation. However it should also be noted that modified asphalt mixtures should exhibit advantageous properties that do relate to the durability and deformation of the pavement (Nizamddin, 2022).

Therefore it is necessary for modified asphalt mixtures to satisfy the following properties;

- i. Good tolerance to adverse weather conditions
- ii. Good resistance to cracking
- iii. Good resistance to ageing
- iv. Good resistance to effects of water
- v. Good resistance to permanent deformation

2.2.2 Test methods used to measure permanent deformation

Some of the methods used to measure laboratory permanent deformation so as to predict the permanent deformation which will occur in the field include;

Wheel Tracking Test: This test is recommended for measuring the resistance to permanent deformation of polymer modified mixtures since it simulates traffic pressure on the actual pavement and is thought to be the best at forecasting pavement performance (Luo, 2023).

Triaxial test with repeated loads: This test has been suggested as the ideal substitute for the wheel tracking test since it may limit the sample, allowing the shear mechanism to occur rather than just compressive failure (Sun, 2021).

Dynamic Creep Test: For polymer-modified asphalt mixtures, dynamic creep data can be utilized to validate wheel tracking results (Sun, 2021). This test can also be used to forecast how modified asphalt mixtures would function in relation to the

Static Creep Test: The results of the static creep test do not correlate well with those of the wheel tracking test, dynamic creep test, or triaxial. Only conventional mixtures with a limited elastic recovery when the load is removed can be distinguished by the test. Moreover, it does not take into account repeated loading, and the other is stress confinement (Luo, 2023). As a result, it is preferable to avoid using this test to forecast pavement performance.

Marshall test: Since the Marshall test is an empirical method that does not measure any fundamental mechanical performance property, it should not be used to predict the resistance to permanent deformation. As a result, bituminous mixture performance cannot be accurately predicted using this method (Central Materials Laboratory, 2000).

Hveem stabilometer test: The Hveem test method is sensitive to bitumen content and gives similar ranking to that of the triaxial (confined) repeated load testing. However, this test cannot rank mixtures according to bitumen types hence it is unlikely to be applicable for modified mixtures (Luo, 2023).

2.2.3 Blending of polymer modified bitumen

Achieving a proper mix between bitumen and polymers is a challenging task, making it imperative to blend the two materials together. In order for the polymer to be correctly dispersed in bitumen to create swelling, the phase of dispersion is the primary parameter taken into consideration here (Iswandaru, 1998). In a 2013 study, the degree of swelling in several bitumens treated with SBS copolymer was examined (Brule, 2013). Over the 80-160°C temperature range, the swelling's extent was temperature-independent, but as the polymer content rose, the rate of swelling reduced. The Colloidal Instability (CI) index is the value of polymer content over which a polymer was no longer swelled.

Research by (Loeber, 2016) examined the effects of varying polymer concentrations on a variety of bitumens sourced from various regions. The findings indicated that a higher colloidal index was associated with a lower critical polymer concentration (CPC), a heterogeneous structure, low cohesion in tensile strength tests, and lower maximum phase angle values. On the other hand, a finely dispersed structure with a high CPC, high cohesion energy, and a high maximum phase angle is produced by a low colloidal index. The following figure demonstrates that the polymer modified binders exhibit optimal rheological performance at a minimum polymer concentration of 0.3 CI index, which corresponds to a polymer concentration ranging from 6 to 8%.

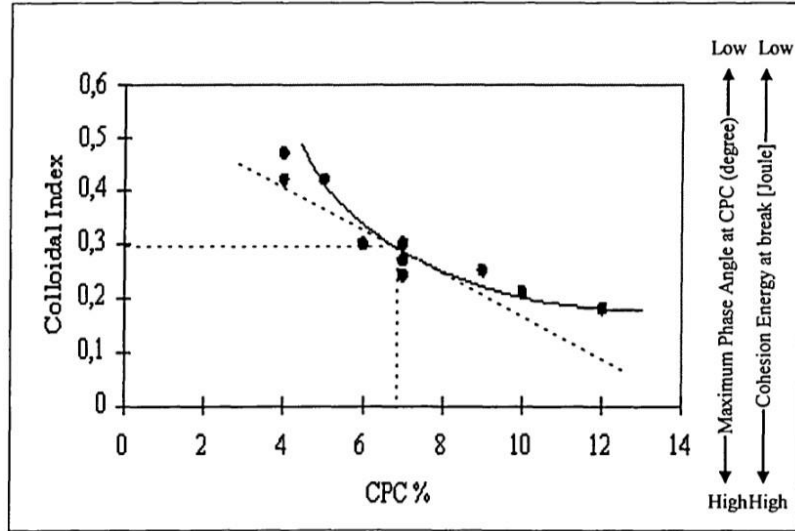


Figure 9 colloidal index against cpc

Figure 9 helps us analyze that blending of thermoplastics with bitumen can be done by varying the polymer concentration between 2% to 10% where the colloidal index remains constant.

2.2.4 Recent studies

Through physical, chemical, rheological, and thermal examination, a study by (Sabzoi,2020) examined basic bitumen and LLDPE modified bitumen blends to determine the suitability of LLDPE in the road sector. The viscosity and softening point were found to increase with the addition of high quantities of LLDPE, rising from 0.62 Pa s and 44.1oC to 5.75 Pa s and 122.3oC, respectively. Nonetheless, penetration values dropped from 59.3 to 14.3 (0.1mm). The modified bitumen had greater thermal stability and less evaporation than the base bitumen, according to the thermogravimetric analysis (TGA). The rheological analysis revealed that the bitumen's thermal susceptibility is greatly impacted by the addition of LLDPE, which also improves the

bitumen's resistance to permanent deformation at high temperatures and elastic recovery.

A study by (Adaluz, 2022) examined the mechanical properties of low-density polyethylene. In this work, the wet technique was used to modify an asphalt cement (AC) with low-density polyethylene (LDPE) residual concentrations of 5%, 7%, and 10% relative to the mass of the AC. It was discovered that the modified asphalt binder with 5% LDPE exhibited the best performance based on its physical-rheological characteristics. To determine if the modifications in the modified mixture's mechanical response compared to the control mixture are statistically significant, an ANOVA analysis of variance was conducted based on the findings. In summary, it has been claimed that LDPE blends might be utilized for thick layers in hot areas in order to

A study by (Harun, 1992) determined the impact of changing asphaltic concrete for usage along climbing lanes. The modified asphalt concrete was made using copolymers of ethylene vinyl acetate and ethylene methacrylate. The investigation came to the conclusion that bitumen modifiers are frequently beneficial in preventing premature deformation of asphalt concrete surfacing in severe areas. Depending on their structure and chemical makeup, polymers that are frequently employed as bitumen modifiers are classified as reactive, elastomers, or plastomers; nevertheless, each has a distinct effect when used in bituminous binders. While elastomers enhance the elastic characteristics of binder, which lessens effects, plastomers (plastic-elastomers) like polyethylene increase the stiffness and resistance of the asphalt to deformation when subjected to traffic stresses.

A study by (Nizamuddin, 2020), studied the potential of linear low-density polyethylene in modifying the properties of bitumen and concluded that the polymer showed significant improvements in the physical, chemical, rheological and thermal properties of bitumen with an increase in the viscosity, softening point whereas the bitumen penetration decreased. It is important to note that the rheological properties of bitumen are key in determining the resistance to shear deformation since they define the stiffness of the asphalt concrete

CHAPTER THREE: METHODOLOGY

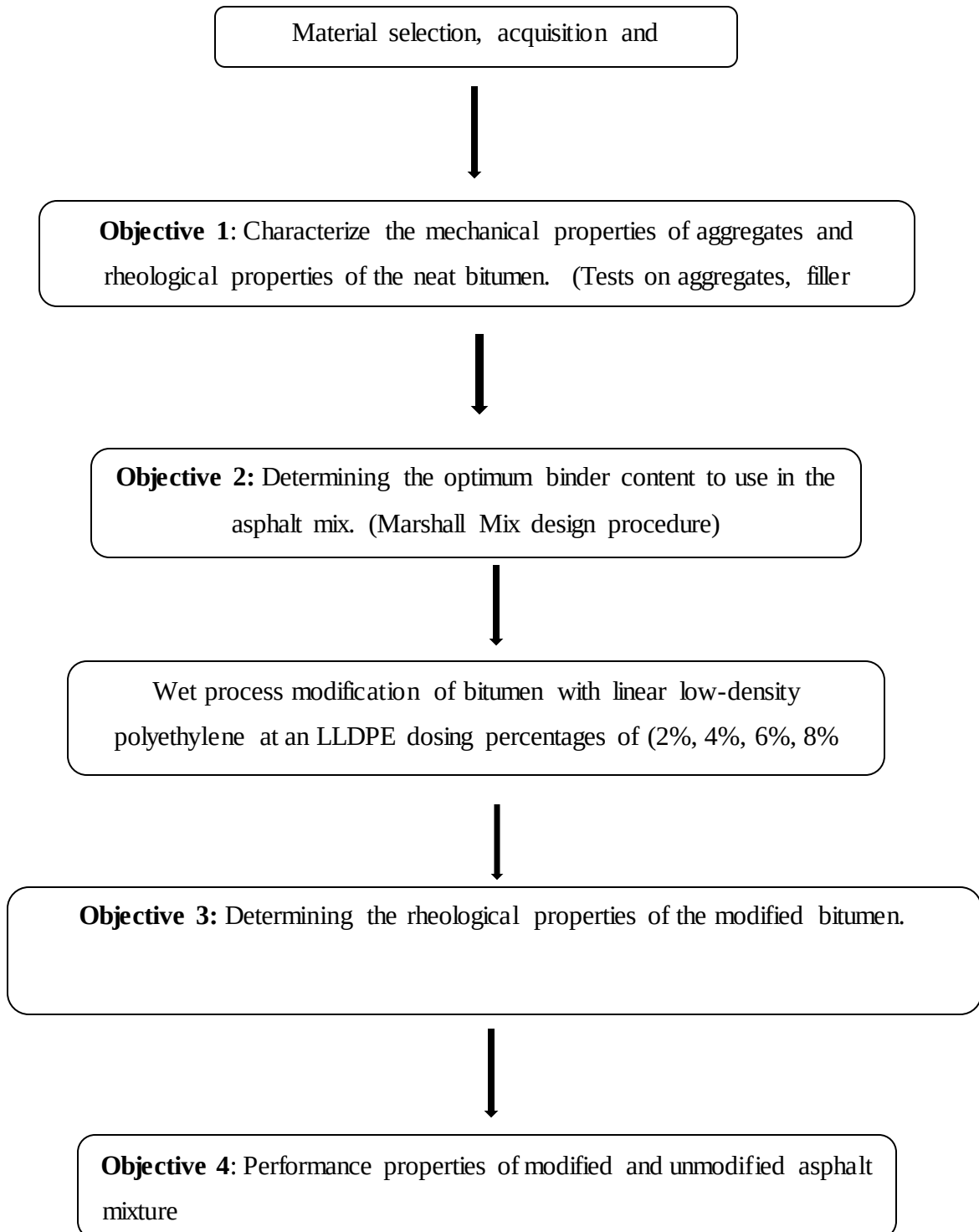


Figure 10 Methodology steps

3.1 Material selection and Preparation

3.1.1 Aggregate selection

The aggregates utilized were sourced from granite rock resources at the Wankoba quarry site in Kasenge parish, Nama subcounty, Mukono District. This quarry was managed by Stirling Engineering Company Limited. The aggregates were obtained after being crushed and graded in various hot bins with sieve sizes ranging from 0-6, 6-10, 10-14, and 14-20 millimeters. Granite aggregates were chosen for this study not only because the scope of study was built with granite aggregates, but also because of their good geological properties such as hardness and durability, roughness and angularity, and less hydrophobic nature, which make them suitable for use in road construction. Before use, the aggregates were tested to confirm that they fulfill the minimum standards for use in bituminous mixtures.

3.1.2 Bitumen selection

Penetration grade 60/70 bitumen is the suggested grade for this research. This is because of to the grade's thermoplastic qualities, which let it to harden at lower temperatures and soften at higher degrees, making it ideal to withstand deformation brought on by thermo-volumetric fluctuations, particularly in hot regions. The bitumen was obtained from the Mukono district's Nama subcounty laboratory of Stirling Civil Engineering Ltd.

3.2 Characterizing the Mechanical properties of aggregates and Rheological properties of Bitumen

3.2.1 Mechanical tests on aggregates

Table 1 Mechanical tests on aggregates

Material Property	Test method used
Aggregate strength	Aggregate Crushing Value
	Aggregate Impact Value
	Ten percent Fines Value
Abrasion resistance	Los Angeles Abrasion Value
Absorption of aggregates	Water absorption
Specific Gravity of aggregates	Specific gravity test
Gradation of aggregates	Particle size distribution test
Grading curve	Trial and error method

3.2.1.1 Aggregate Crushing Value (ACV)

To ascertain the aggregates' resistance to crushing under a progressively applied compressive load, the Aggregate Crushing Value test was used. This was accomplished by gradually applying a 400kN stress to the aggregates, and the ACV was calculated by measuring the material that passed through a 2.36mm sieve in compliance with BS

812: Part 110:1990.

Sample preparation

A riffled sample of 8 kg of aggregates with sizes ranging from 14 mm to 10 mm made up the test sample. The aggregate sample was separated into three roughly equal samples and set aside on different trays. Before testing, all the samples were cooled to room temperature after being heated to 105 ± 5 °C for approximately four hours, to ensure that all the moisture was removed.

Test Procedure

- i. The first sample of aggregates was poured in to a cylinder in 3 layers of equal approximate depth with each layer tamped with 25 blows by allowing the tamping rod to fall freely from a height of about 50 mm or more.
- ii. The excess material was removed and surface was carefully levelled using the straight edge of the tamping rod. The weight of the cylinder and aggregates were measured and recorded as the mass of the test specimen used.
- iii. The specimen was transferred into the test mold in the same manner as for the cylinder, the surface levelled and the plunger placed on top so that it rests horizontally on the surface.
- iv. This assembly was placed between the plates of the testing machine loaded at uniform rate so that the total load of 400kN was reached in 10 minutes.
- v. The load was then released and the crushed material poured on to a tray, weighed and its mass recorded as M_1 .
- vi. The material was sieved through a 2.36 mm sieve and the weight of the sample

passing (M2) through and that retained (M3) recorded.

- vii. This procedure was repeated for the second and third sample using the same op sample mass.

Recording of results

$$ACV = M2/M1 \times 100\% \dots \dots \dots \text{Equation (1)}$$

Where;

M2 - Mass of material passing through 2.36mm sieve

M1 - Mass of test specimen

3.2.1.2 Aggregate Impact Value (AIV) BS 812: Part 112:1990

The test was conducted for a proportion of aggregates passing a 14 mm screen and held on a 10 mm sieve in dry condition. The aggregate impact value was used to assess the resistance of the aggregates to abrupt shock or impact.

Sample preparation

A riffled sample of two kilograms of aggregates from the batch of 14 to 10 mm aggregates was utilized as the test sample. Three roughly equal samples of aggregates were taken from the sample. Before testing, all the samples were cooled to room temperature after being heated to 105 ± 5 °C for approximately four hours, to ensure that all the moisture was removed.

Test Procedure

- i. The first test sample was put in the cylindrical steel cup in three equal layers and tamping done (25 blows) for each layer evenly on the aggregate using a tamping rod falling freely from a height above 50 mm above the surface of the aggregate.
- ii. The surplus aggregates were removed by rolling the tamping rod across the top of the steel cup.
- iii. The net mass of the aggregate was measured and recorded (M1) and with the cylindrical cup of the impact machine fixed firmly in position on the base of the machine, the whole test specimen was placed in the cup.
- iv. The hammer was raised to the top of the hammer guide columns and allowed to fall freely on to the aggregate to give 15 such blows.
- v. The crushed specimen was removed from the cup, weighed and its mass recorded as M1.
- vi. The sample was then be sieved through a sieve of 2.36 mm, weight of sample that passing and that retained recorded as M2 and that retained as M3 respectively.
- vii. The same procedure was repeated for the other two samples for consistency.

The AIV was then determined for each sample using the Equation (1.1) and an average was calculated and taken as the required value.

$$AIV = \frac{M1-M2}{M1} \times 100\% \dots\dots\dots \text{Equation (1.1)}$$

3.2.1.3 Los Angeles Abrasion Test

The purpose of this test was to evaluate the aggregate's resistance to abrasion and

wear when utilized as a wearing course. The Los Angeles value is a measurement of the deterioration of mineral aggregates with standard grading caused by a combination of processes like grinding, impact, and abrasion in a steel drum that rotates and contains a given number of steel spheres that, when rotated for a predetermined number of revolutions, produce an abrasive action. The process was carried out in compliance with ASTM C131-89.

Equipment used

- i. Los Angeles Machine
- ii. Abrasive charge: 11 steel balls of approximately 48mm diameter and each weighing 390 to 445 g.
- iii. Test sieves: 1.70, 10, 12.5, 20 mm.
- iv. Weighing Balance and an oven

Sample preparation

Two sample sets, each weighing 5 kg and matching the grading B indicated in the table below, were obtained by sieving a sample of the aggregates through sieves 20, 12.5, and 10 mm.

The grading scheme was chosen so as to comply with AC 20, which was applied in this investigation. The sample specimen was allowed to cool to room temperature after being dried in an oven for four hours at 105° to 110°C.

Test procedure

- i. The sample was reduced to a required size by use of a riffle box. The weight of the samples was then recorded as W1.

- ii. The aggregates and abrasive charges were placed in the cylinder and the cover fixed.
- iii. The machine was started and rotated at a speed of 30 to 33 revolutions per minute for 500 revolutions.
- iv. The machine is stopped after the desired 500 revolutions and material was discharged to a tray and sieved through the 1.70 mm sieve.
- v. The material retained on the 1.7mm size was weighed and recorded.
- vi. The procedure was repeated for the other aggregate sample set to attain two sets of results to ensure consistency.

Computation of the results

The percentage of wear (abrasion value) was determined as an average of the percentage of wear for the two samples got using the formula;

Original weight of aggregate sample = W1 (5000g)

Weight of the sample specimen retained on 1.70 mm sieve = W2

Weight of the sample specimen that passed 1.7mm sieve = W1 - W2

Percentage of wear (Abrasion value) = $(W1 - W2) / W1 \times 100$Equation (1.2)

3.2.1.4 Ten Percent Fines Value(TFV)

This test was selected to determine the resistance of an aggregate to crushing under a gradually applied load. This was done both in the dry and soaked condition.

Main Principles

The load needed to crush aggregates with a typical size fraction of 14 mm to 10 mm and produce 10% material that passes through a 2.36 mm sieve after crushing was used to calculate the 10% Fines Value. The Aggregate Crushing Value (ACV) test, which necessitates applying a force of 400 kN to the test sample, is more similar to the TFCV test. With reference to BS 812: Part 111: 1990, this was completed.

Equipment used

- i. A Steel Cylinder of 150 mm diameter with Plunger and Baseplate
- ii. Test sieve of 2.36 mm.
- iii. Tamping rod
- iv. Compression Testing Machine
- v. Cylindrical Metal Measure of internal diameter 115 mm and depth 180 mm
- vi. Weighing balance
- vii. Metal tray of known mass

Sample preparation

For dry condition

The sample was cut down to create a test section with enough mass to create three test specimens with size fractions ranging from 14 mm to 10 mm.

Prior to testing, the test specimens were allowed to cool after being oven-dried for four hours at $105 \pm 5^{\circ}\text{C}$. Note the total mass of the materials that make up the test specimens.

For soaked condition

To ensure that the water level was at least 50 mm over the top of the wire baskets, each of the three test specimens was placed in its own basket and submerged in water. By raising the baskets 25 mm above the container's base and letting them drop 25 times, the trapped air was released. The aggregates were submerged to soak for a whole day. To get the water off the aggregates' surface, the specimen was taken out of the basket and towel-dried.

Test Procedure

- i. The cylinder was placed on the base plate the aggregates of the first test sample placed in three layers with each layer being compacted by 25 strokes using a tamping rod.
- ii. The surface of the aggregate was carefully levelled and the plunger inserted so that it rests horizontally on this surface.
- iii. The apparatus with the specimen and plunger in position were placed between the plates of the compression testing machine.
- iv. The machine was started and a force applied at a uniform rate to cause a total penetration of the plunger in 10 minutes $\pm$ 30 seconds.
- v. The maximum force (f) reached after the full penetration of the plunger within 10 minutes was recorded.
- vi. the force was released and the crushed material aggregate removed by holding the cylinder over a clean tray of known mass and hammering on the outside with the rubber mallet.
- vii. A wire brush was used to remove the fine particles adhering on to the inside.

- viii. The tray and aggregates were weighed and the mass of aggregate used (M1) was recorded.
- ix. The whole specimen was sieved on the 2.36 mm sieve until no further significant amount passed. The masses of the fraction passing and retained on the sieve were weighed and recorded as M2 and M3 respectively.

Computation of results

The percentage of the material (m) passing the sieve was calculated from Equation (1.3);

$$m = \frac{M2}{M1} \times 100 \dots \dots \dots \text{Equation (1.3)}$$

When this percentage did not fall within the range 7.5 % - 12.5 %, the test was repeated with the maximum target force adjusted using Equation (1.4) to bring the percentage of fines within the range.

The force F (in kN), required to produce 10 % fines for each test specimen was obtained from the equation:

$$F = \frac{14f}{m+4} \dots \dots \dots \text{Equation (1.4)}$$

Where; f is the maximum force (in kN), m is the percentage of material passing the 2.36 mm sieve at the maximum force.

The test procedure was repeated for the other two specimen of the same mass as the first specimen at the same force that gave a percentage fines value within the range 7.5 % - 12.5 %.

3.2.1.5 Relative density (specific gravity) And Water absorption of aggregates

This test was aimed at determining the relative densities of the aggregates for use in the asphalt mix design computations. The test was used to determine the;

- i. Relative density on oven dry basis which is mainly required in asphalt mix design.
- ii. Relative density on a saturated surface-dry basis mainly used in concrete mix design.
- iii. Apparent relative density, which may be used in production control to check if the density of the aggregate varies.
- iv. Water absorption of the aggregates.

This test was done in accordance to ASTM C127-88 and is suitable for aggregate sizes 5mm to 40 mm.

Equipment used

- i. An oven
- ii. Weighing balance capable of weighing the poke basket from below.
- iii. Wire mesh basket
- iv. Soft absorbent cloths
- v. Shallow tray
- vi. Water free of impurities (preferably distilled water)

Sample preparation

- i. Two aggregate test samples of about 2-2.5 kg each were used.

- ii. The samples were thoroughly washed through 10mm test sieve to remove finer particles e.g. clay, silt and dust while allowing it to drain.
- iii. The samples were placed in the wire basket and immersed in water for 24 hours
- iv. The entrapped air was removed by lifting the basket slightly up and down under water with gentle agitation to remove entrapped air.

Procedure

- i. The basket with the first sample was weighed in water and the mass recorded as mass C.
- ii. The aggregates were removed and placed on the dry cloth then gently surface-dried until all visible films of water were removed.
- iii. The aggregates were then weighed and the mass recorded (mass A).
- iv. The aggregates were placed on a tray and put in an oven to dry at $105 \pm 5^{\circ}\text{C}$ for 24 hours then left to cool.
- v. The sample mass was then weighed and recorded as (mass D)
- vi. The procedure was repeated for the second sample and the relative densities were calculated as an average of the two test results obtained from the equation below.

Computation of results

$$\text{Relative Density on an oven-dry basis} = \frac{D}{A-(B-C)} \dots\dots\dots \text{Equation (1.5)}$$

$$\text{Relative density on a saturated and surface-dry basis} = \frac{A}{A-(B-C)} \dots\dots\dots \text{Equation (1.6)}$$

$$\text{Apparent Relative Density} = \frac{D}{D-(B-C)} \dots\dots\dots \text{Equation (1.7)}$$

$$\text{Water absorption} = \frac{(B-A)}{A} 100 \dots \dots \dots \text{Equation (1.8)}$$

Where;

A is the mass of the saturated surface-dry aggregate in air (g)

B is the apparent mass in water of the basket + the sample of saturated aggregate (g)

C is the apparent mass in water of the empty basket (g)

D is the mass of the oven-dry aggregate in air (g)

3.2.1.6 Aggregate Gradation

This was carried out while following the BS (812-1985) standard. It presents the relative portions of different sizes of particles. From this, it is possible to determine whether the aggregates and filler consist of pre-dominantly gravel, sand, silt or clay sizes and to a limited extent, which of these size ranges is likely to control the mechanical properties of the aggregates. Gradation also affects many properties of an aggregate which include bulk density and permeability.

Required Equipment

- i. Test sieves with diameter 450 mm or 300 mm, 75 mm, 63 mm, 50 mm, 37.5 mm, 28 mm, 20 mm, 14 mm, 10 mm, 6.3 mm, 5 mm,
- ii. Test sieves with diameter 300 mm or 200 mm: 3.35 mm, 2.36 mm, 1.70 mm, 1.18 mm, 825 µm, 600 µm, 425 µm, 300 µm, 212 µm, 150 µm, 75 µm.
- iii. Lids and receivers
- iv. A balance readable and accurate to 0.5 g.
- v. Riffle boxes.

- vi. A drying oven capable of maintaining a temperature of $105\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$.
- vii. Metal containers.
- viii. Metal trays.
- ix. Mechanical sieve shaker (optional).

Sample Preparation

- i. The sample was reduced to produce a test portion which was appropriate to the maximum size of the material.
- ii. The test portion was dried by heating at a temperature of $105\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ for minimum 12 hours. It was then allowed to cool, was weighed and recorded.

Test procedure

- i. Appropriate sieves were assembled with a receiver at the bottom increasing aperture size from bottom to top. The oven-dried sample was placed on top of the coarsest sieve and covered with a lid.
- ii. The sieves were shaken for a sufficient time to separate the sample into the different size fractions.
- iii. Since sieving was done by hand alone, the coarsest sieve was started with and each sieve was shaken over a clean tray or receiver until no more material passed.
- iv. An intermediate sieve was introduced since the sieves were blinded by overloading.
- v. The material retained on each sieve was weighed, together with any material cleaned/picked from the mesh, on completion of sieving on that sieve.

Washing and sieving method

- i. Both sides of a 75 μ m test sieve were wetted, reserved for use in this type of test only, and fit with a guard sieve of 2.36 mm on top.
- ii. The weighed oven dried sample (M1) was placed in a container and sufficient water was added to half fill the container. The contents were agitated so that the fines were completely separated from coarser particles.
- iii. The suspension of fine solids was poured on to the guarded 75 μ m test sieve. The coarse residue was washed until the water was free from dirt.
- iv. All residues were washed from the container and sieved into the tray. Excess free water was removed by careful decantation through the 75 μ m sieve, and the total residue was dried in the oven 105 °C $\pm$ 5 °C for minimum 12 hours. It was then allowed to cool, weighed and recorded as M2.
- v. The mass of material passing the 75 μ m sieve was determined as: M1 -M2.

Reporting of results

Calculations

The mass retained on each sieve was calculated as a percentage of the original dry mass (M1). The mass of material passing the finest sieve was added to that passing during washing (M1-M2) found during the dry sieving.

The mass of the sample passing each sieve was calculated as a cumulative percentage, from Equation (1.9):

$$(\% \text{ passing this sieve}) = (\% \text{ passing previous sieve}) - (\% \text{ retained on this sieve})$$

.....Equation (1.9).

3.2.2 Tests on bitumen

3.2.2.1 Bitumen Penetration test

Under known loading, loading time, and temperature conditions, the penetration test was chosen to determine the relative measure of consistency of bituminous materials expressed as the distance in tenths of a millimeter that a standard needle vertically penetrates a sample of the material. This test helps classify the bitumen and is an indirect measure of viscosity of the bituminous material; a lower penetration indicates that the bitumen has a low viscosity and is therefore very hard. The test was conducted in accordance with ASTM D5-86.

Equipment used

- i. Standardized penetrometer
- ii. Set of standardizes penetration needles (2.5g)
- iii. Needle holder
- iv. Stop watch
- v. Penetration tins (cups) with 55mm diameter and 35mm depth
- vi. Calibrated thermometer
- vii. Water bathe with distilled water
- viii. Source of light (table lamp, flash light or similar)

Sample preparation

Using a gas stove, the bitumen sample in a metallic bucket was gradually heated until it became fluid. A part of the sample was collected using a metallic scoop, and it was then poured into each of the four clearly labeled penetration tins or cups to a depth greater than what the needle is supposed to penetrate. To keep out dust, the container was covered loosely and left to cool for an hour at room temperature. After the sample had cured, the test could begin. It was done by placing the container in a water bath kept at 25°C for an hour.

Test procedure

- i. The cup with the sample was placed in a glass beaker containing water maintained at 25°C which was placed at the base plate of the penetration apparatus.
- ii. The penetration needle load was adjusted with the specified load to just touch the surface of the sample.
- iii. While reading the dial gauge, the pointer was brought to zero and the needle loaded for 5 seconds to penetrate the bitumen sample.
- iv. The dial gauge was then adjusted to read the distance moved.
- v. The needle was then removed and switched to another position then then penetrated again and the penetration distance read and recorded on the dial gauge.
- vi. This was done the third time to obtain three penetration distance for the same sample.
- vii. An average of the three penetration distances in deci-millimeters was obtained and recorded as the penetration for the sample.

- viii. The test was repeated for the other three test samples to ensure consistency in results.
- ix. The penetration of the bitumen was recorded as the average of the penetration got from each of the four test samples in deci-millimeters.

3.2.2.2 Softening point (ASTMD36-95)

The test was used to ascertain the binder's softening point, which is a proxy for bituminous material viscosity. A material's softening point value reveals how sensitive it is to temperature changes. A high softening point shows decreased inclination to flow at high temperature while a low softening point shows increased tendency to flow.

Sample preparation

On a gas stove, the bitumen sample in a metallic bucket was gradually heated until it became fluid. The ring and ball apparatus's rings were well smeared with talcum powder and glycerol before being set on a well-smeared metal plate. After that, the bitumen was poured into both rings, and they were allowed to cool for an hour at room temperature.

Procedure

- i. A glass container containing the ring and ball apparatus and thermometer was filled with distilled water to a depth of 108 mm.
- ii. The balls were then placed onto the rings in the centering guide using forceps
- iii. The glass container was placed onto a heating unit.
- iv. Heat was applied to obtain a constant temperature raise of 5°C per minute.

- v. The temperature was recorded every 30 seconds.
- vi. The temperature reading when the sample of bitumen in each ball touched the base was recorded.
- vii. The average temperature of two recorded temperatures was reported as the softening point of that sample.
- viii. The test was repeated once again for the same sample of bitumen to obtain two sets of results.
- ix. The softening point of the bitumen was got as the average of the softening points of the two test results obtained.

3.2.2.3 Ductility test for bitumen

The purpose of this test was to ascertain bitumen's relative cohesive strength. The bitumen sample's ductility was measured by measuring how far it will stretch before breaking at a temperature below its softening point, while it is being stretched apart at a speed of 5 cm/min in a ductility testing machine. ASTM D113 was followed for conducting the test.

Equipment used

- i. Briquettes for ductility
- ii. Ductility testing machine with a water bath and thermometer
- iii. Brass plate

Test procedure

- i. The bitumen sample was heated to temperature above its softening point when the bitumen becomes completely liquid,

- ii. The molten bitumen was poured it into the set of briquette molds which were placed on a brass plate. coated with a mixture of glycerin to prevent sticking of bitumen.
- iii. The sample specimen was left to cool for one hour at room temperature.
- iv. After cooling, the briquette moved apart with the side and the plate removed.
- v. the mold assembly was the placed in the water bath for another one hour and attached to the mold clips of the machine carefully without applying any additional force to mold bitumen.
- vi. With the pointer of the machine calibrate to zero, the machine was started and the clips pulled horizontally at a constant speed of 50 millimeters per minute.
- vii. The ductility value was recorded as the distance at which the bitumen thread stretches and then ruptures.
- viii. The procedure was done for three mold samples and an average obtained as the ductility of the bitumen sample.

3.2.2.4 Determining Temperature Susceptibility

Temperature susceptibility refers to how the consistency of bitumen changes with variations in service temperatures. In simpler terms, it indicates how bitumen behaves in response to temperature fluctuations, especially regarding its viscosity and ability to maintain adequate pavement integrity. Temperature susceptibility can be quantified using Penetration Index. This parameter can be obtained from the penetration and softening point of bitumen as seen in Equation (2.0)

$$PI = \frac{1951.5 - 500 \log Pen - 20 \times \text{softening point}}{50 \log Pen - 52 - 120.1} \dots \dots \dots \text{Equation (2.0)}$$

This way it is possible to predict how the bitumen consistency will be affected by temperature rises hence causing rutting. Researcher done by (Fakhrur, 2013) recommends that the PI should be as close to 0 as possible to reduce the rutting susceptibility. This is because at this point, bitumen tends to equi-viscous state at which the viscosity will remain constant despite the changes in temperature. This study therefore intended to modify the bitumen used in the asphalt mixture to improve its pseudo rheological properties which will help reduce the pavement's susceptibility to rutting.

3.3 Determining the optimum binder content for the asphalt mixture.

This was achieved through following the Marshall mix design procedure from which graphs displaying the stability, flow, density, and voids against binder content were obtained and used to establish the ideal bitumen content using the Asphalt Institute approach.

3.3.1 Marshall mix design procedure

Three series of aggregate mixtures (for Gmm, Gmb, and Stability and flow) were made once the aggregate size gradation was predetermined as per the preceding technique. Each series consisted of two sample test specimens or duplicates (for consistency). To ensure consistency, this was carried out for every percentage of the binder to produce 15 sets of duplicate specimens. In order to coat the aggregates completely, modified bitumen was added to the mixtures of aggregates in different percentages and heated to between 145 and 160 °C while stirring. After being moved to a compaction mold, the mixture was compacted using 75 blows on each side of the sample. Instead of being

crushed, the Gmm test specimens were evenly spread out on a level surface and allowed to cool to ambient temperature before being put into different containers. Additionally, the compressed specimens were allowed to cure overnight at room temperature. In order to get them ready for the Marshall testing, they were subsequently cleaned with a wire brush to get rid of any loose material, as seen below;

3.3.1.1 Bulk specific gravity (Gmb) and Maximum specific gravity (Gmm) ASTM 155-89

The bulk specific gravity of the compacted mixture and maximum specific gravity of the mixture was determined as stated in ASTM 155-89. The specific gravities were used to calculate the bulk densities and air voids for each test specimen.

3.3.1.2 Voids in mineral aggregates analysis (VMA) (ASTM D6995-21)

The voids in mineral aggregates were obtained once the maximum specific gravity of asphalt mixture (G mm) and the bulk specific gravity had been determined. The percentage of voids in mineral aggregates was determined and a graph showing the voids in mineral aggregates against percentage of bitumen is plotted.

3.3.1.3 Stability and flow test (ASTM D6927)

For a duration of 25 to 30 minutes, the test specimen was submerged in a water bath maintained at 60 degrees Celsius. The Marshall test head was then used to hold the specimen, and the starting flow meter was set to zero. Applying the load progressively kept the rate of deformation constant. The maximum load prior to failure was

determined to be the Marshall Stability value, and the related flow value was determined to be the deformation. For every proportion of binder, graphs displaying the flow and stability against bitumen content were drawn.

3.3.1.4 Determine the bulk density of the compacted specimens (ASTM D2726)

The thickness of the specimens was measured at room temperature with a vernier caliper to the nearest 0.1 mm bulk densities of the asphalt samples determined as stated in Marshall mix design procedure. A graph showing the bulk density against bitumen content for each percentage was plotted. The Asphalt institute procedure was used to determine the optimum binder content from the four graphs plotted.

3.4 Wet process modification of bitumen

Since the goal of this study is to improve the binder qualities, a wet technique was used. In order to do this, the bitumen has to melt over its melting point. Next, five metallic trays were labeled 0%, 2%, 4%, 6%, and 8%, according to the percentages of LLDPE utilized in the alteration. The weighing scale was used to level off the tray, and bitumen was added based on the mass needed for each % change, as indicated in Table 2. To ensure that the bitumen was scattered evenly, the LLDPE of the necessary mass was also spread over it. After that, the mixture was placed on a heating gas stove, where it was heated for an hour to a uniform mixture while keeping the mixing temperature of 150°C. Following completion of this process for each sample, the bitumen underwent testing.

$$\text{Mass of LLDPE to add} = \% \text{LLDPE} \times \text{Mass of bitumen (1000) in g} \dots\dots\dots \text{Equation (2.1)}$$

Table 2: Showing the mass of bitumen and percentage of LLDPE mixed.

% LLDPE	Mass of bitumen alone (g)	Mass of LLDPE (g)	Bitumen & LLDPE mixture (g)
0	1000	0	1000
2	980	20	1000
4	960	40	1000
6	940	60	1000
8	920	80	1000

3.5 Determining the rheological properties of the modified bitumen.

Testing the rheological properties of bitumen after modifying it with Low-Density Polyethylene (LLDPE) is essential for comprehensive performance assessment and optimization in asphalt pavement applications. Rheological tests, such as Tests for penetration, ductility, and softening point offer valuable insights into the modified binder's viscoelastic behavior, temperature sensitivity, and compatibility. These tests enable engineers to evaluate the binder's ability to resist deformation, fatigue, and thermal cracking under various loading and environmental conditions. The test procedures followed in this objective are similar to the methodology study in section 3.2.2 above. Below are the different tests carried out and the purpose for each of the tests.

3.5.1 Penetration of the modified bitumen

A key function of the penetration test on bitumen modified with Low-Density Polyethylene (LLDPE) is to evaluate the hardness and consistency of the modified binder. The test gives information about the viscosity and stiffness of the modified binder by measuring the depth in tenths of a millimeter that a standard needle penetrates vertically into a bitumen sample under particular temperature, time, and loading conditions. The penetration test helps determine whether bitumen treated with LLDPE has produced the intended results, which include improved binder qualities like elasticity, deformation resistance, and thermal stability. When penetration levels are consistent amongst samples, it means that the change is uniform, guaranteeing that the binder satisfies performance standards for different asphalt applications. Furthermore, comparing the penetration values of modified and unmodified bitumen offers a quantitative indicator of how much the modification has changed the rheological characteristics of the binder, which helps with mix design optimization and quality assurance during the construction of asphalt pavement.

3.5.2 Softening point of modified bitumen

The Low-Density Polyethylene (LLDPE) modified bitumen softening point test is an essential measure of the modified binder's thermal properties and its appropriateness for different asphalt technology applications. The softening point test establishes the temperature at which the binder softens and flows under controlled circumstances by heating the modified bitumen. This test aids in evaluating the effect of polymer addition on the binder's temperature susceptibility and resistance to high-temperature

deformation for bitumen modified with LLDPE, two critical elements for pavement performance and durability. Pavement engineers and manufacturers can benefit greatly from the results of the softening point test by using the information to select suitable binder grades and optimize mix designs to guarantee the necessary performance characteristics, such as increased resistance to rutting. Furthermore, by confirming the consistency and uniformity of changed bitumen production processes, the test supports quality control and eventually contributes to the creation of asphalt pavements that are more durable and sustainable.

3.5.3 Determining Temperature susceptibility.

It is essential to ascertain the bitumen modified with Low-Density Polyethylene (LLDPE) temperature susceptibility in order to evaluate its performance in various climatic circumstances and guarantee the longevity and durability of asphalt pavements. Engineers can forecast the behavior of the modified binder during mixing, compaction, and service life by analyzing how its rheological characteristics vary with temperature. By comprehending temperature susceptibility, asphalt mix designs might be optimized to resist low-temperature cracking as well as high-temperature rutting, guaranteeing the pavement's resilience in a range of climatic circumstances. To further improve pavement performance and save maintenance costs during the pavement's lifespan, it makes it easier to choose the right modifiers and additives to modify the binder's qualities for certain applications.

3.5.4 Ductility of modified bitumen

The ductility test is a crucial assessment tool for bitumen modified with Low-Density Polyethylene (LLDPE) to determine the material's elongation and flexibility properties. These properties are essential to the material's performance in asphalt pavement applications. The ductility test evaluates the modified bitumen's resilience to cracking and deformation under traffic loads and temperature changes by putting it under controlled tensile stresses and measuring elongation before failure. In particular, the test aids in determining how well the polymer addition in LLDPE modification enhances the ductility and flexibility of the binder, which are critical elements in reducing fatigue and thermal cracking in asphalt pavements. Understanding the ductility properties of LLDPE-modified bitumen enables engineers to optimize mix designs and ensure the longevity and durability of asphalt pavements in diverse environmental and loading conditions.

3.6 Performance properties of the modified asphalt mixture.

For this objective, asphalt cores are made following the Marshall mix design procedure. The cores can then be tested to determine the indirect tensile strength, stability and flow, densities and the percentage refusal densities. This can be related to the control mixture, which is the unmodified asphalt mixture to check for the improvement in the asphalt properties against rutting.

3.6.1 Performance Test on Asphalt Concrete Marshall Test (ASTM D 1559-98) with Modified Bitumen

The Marshall Test is crucial for evaluating the physical properties of asphalt mixes, when modified with Linear Low-Density Polyethylene (LLDPE). By modifying bitumen with LLDPE at different percentages, that is to say 0%, 2%, and 4%, we aim to assess how these modifications affect the asphalt's behavior under applied loads. Understanding these effects is essential for optimizing asphalt mixtures for various applications, including road construction and pavement durability.

Equipment Required

The test requires various equipment, including specimen molds, a Marshall compaction apparatus, heating ovens, mixing equipment, a water bath with temperature control, and measurement tools like slide calipers. These tools ensure precise preparation and testing of asphalt specimens with modified bitumen.

Test Specimens Preparation

For each modification level (0%, 2%, and 4% of LLDPE), we prepare at least 3 test specimens (cores). Adjusting the mass ensures that each specimen achieves a consistent height of 63.5 ± 1.3 mm after compaction. Homogeneous mixing of aggregate and modified bitumen is crucial to ensure uniformity across specimens.

Test Procedure

After mixing the aggregate with modified bitumen containing varying percentages of LLDPE, we preheat specimen molds and the bituminous material to the required

temperatures. The mixture is then transferred into molds and compacted using a specified number of blows that is to say 75 blows. Specimens are measured, placed in a water bath for temperature equilibration, and then tested using the Marshall Test apparatus. Load is applied until maximum load is reached.

Reporting of Results

In the test report, we record detailed information such as mixing temperature, compacting temperature, number of blows during compaction, specimen height, temperature at testing, flow value, and maximum load value for each modification level (0%, 2%, and 4% of LLDPE). Additionally, we calculate Marshall stability corrected according to specimen height for each LLDPE percentage, providing insights into the performance of modified asphalt mixtures under load.

3.6.2 Test to Determine Durability of Asphalt Mixture (Indirect Tensile Strength ASTM D6931-17) with Modified Bitumen

The Indirect Tensile Strength test is essential for assessing the relative quality and durability of asphalt mixtures, particularly when modified with materials like LLDPE. By modifying bitumen with LLDPE at different percentages, we aim to understand how these modifications impact the asphalt's resistance to rutting, cracking, and moisture damage.

Equipment Required

Similar to the Marshall Test, this test requires specific equipment such as a testing machine (Marshall Type Test Apparatus), an indirect tensile stress loading frame, and

a water bath. These tools are crucial for accurately evaluating the durability of asphalt mixtures with modified bitumen.

Test Specimens Preparation

For each modification level (0%, 2%, and 4% of LLDPE), we prepare smooth, parallel surface specimens from modified asphalt mixtures. Precise measurements of height and diameter ensure consistency across specimens, facilitating accurate testing and analysis.

Test Procedure

After conditioning specimens in a water bath, we test them using the indirect tensile stress loading frame. The specimens are then dried, weighed, and analyzed to determine their indirect tensile strength and E-modulus. Testing within specific timeframes ensures reliable results for each modification level.

Reporting of Results

In the test report, we record maximum load values for asphalt mixtures modified with 0%, 2%, and 4% of LLDPE. Additionally, we calculate indirect tensile strength and E-modulus for each modification level, providing comprehensive insights into the durability of modified asphalt mixtures. Maximum load (N) is recorded.

$$S1 = (636.62 \times P_{max}) / (t \times D) \dots \text{Equation (2.2)}$$

Where:

S1 = indirect tensile strength (kPa)

P_{max} = maximum load at failure (N)

t = height of specimen (mm)

D = diameter of specimen (mm)

The material's E-modulus is calculated using the following equation:

$$E_{mod} = 6.1 \times S1 + 100 \text{ (MPa)} \dots \text{Equation (2.3)}$$

The specimen dry bulk density was calculated based on registered dry mass and height/diameter measurements (mass/volume).

CHAPTER FOUR : RESULTS AND DISCUSSIONS.

4.1 Characterizing the mechanical properties of aggregates and rheological properties of bitumen to use in the asphalt mixture.

Aggregate characterization typically involved testing parameters such as gradation, shape, surface texture, angularity, and particle density as shown in Table 3. These properties influence the aggregate's ability to interlock and provide stability within the asphalt mixture. The stiffness and temperature susceptibility of the binder were determined by the rheological properties of bitumen as shown in Table 4. These properties are vital for comprehending the bitumen's flow behavior, viscoelasticity, and temperature susceptibility.

4.1.1 Tests on aggregates

Table 3 tests on aggregates

Property	Test	Test standard	Unit	Average measured value $\pm$ SD	Specification
strength	ACV	BS 812: Part 110: 1990	%	16.7 $\pm$ 0.1	< 25
	AIV	BS 812: Part 112: 1990	%	15.2 $\pm$ 0.1	< 25
	TFV dry	BS812: Part 111:1990	kN	263.2 $\pm$ 0.2	> 160
	TFV wet	BS812: Part 111:1990	kN	296.3 $\pm$ 0.2	> 110
	LAA	ASTM C535-89	%	17.2 $\pm$ 0.1	< 30
particle shape	flakiness index	BS812:105.1:1989	%	19.3 $\pm$ 0.1	< 35
Combined specific gravity	Specific gravity	BS1377:Part 2:1990	g/cc	2.6 $\pm$ 0.05	2.0 - 3.0
Water absorption	Water absorption	BS812: Part 2:1975	%	$\pm$ 0.05	< 2%

1. Aggregate Crushing Value (ACV).

ACV measures the resistance of aggregate to crushing under a gradually applied compressive load. In asphalt pavements, aggregates serve as the skeleton, providing structural support. The ACV indicates the strength of the aggregates, influencing the durability and load-bearing capacity of the pavement. A low ACV (16.7%) indicates high resistance to crushing, which suggests that the aggregates used in the project are robust. This is crucial for maintaining pavement integrity under heavy traffic loads.

2. Aggregate Impact Value (AIV).

AIV measures the resistance of aggregate to sudden impact or shock. In climbing lanes where vehicles may accelerate or decelerate abruptly, aggregates with high AIV resistance are essential to prevent premature pavement deterioration. With an AIV of 15.2%, the aggregates exhibit excellent resistance to impact, which is favorable for ensuring the longevity of the pavement under dynamic loading conditions.

3. Toughness and Abrasion Resistance (TFV dry and TFV wet)

TFV evaluates the ability of aggregates to resist wear and degradation under abrasive conditions, both dry and wet. Climbing lanes often experience increased wear due to heavy vehicle usage. TFV results indicate the aggregate's ability to withstand this wear and maintain pavement integrity. The high TFV values (263.2 kN dry, 296.3 kN wet) indicate superior toughness and abrasion resistance, ensuring the durability of the asphalt pavement in climbing lanes.

4. Los Angeles Abrasion (LAA):

LAA test measures the resistance of aggregates to abrasion and degradation caused by traffic loads and environmental factors. LAA results are crucial for assessing the susceptibility of aggregates to wear and tear, which directly impacts pavement performance. The low LAA value (17.2%) signifies minimal aggregate degradation, supporting the pavement's ability to withstand the abrasive forces encountered in climbing lanes.

5. Particle Shape (Flakiness Index)

Flakiness index assesses the shape of aggregates, particularly their flatness and elongation. Proper particle shape enhances aggregate interlocking, improving pavement stability and resistance to rutting. The low flakiness index (19.3%) indicates a favorable particle shape, contributing to better asphalt mixture compaction and long-term pavement performance.

6. Combined Specific Gravity:

Combined specific gravity measures the density of aggregates relative to water. Proper aggregate density influences asphalt mixture compaction and ultimately, pavement durability. The specific gravity of 2.6 g/cc falls within the acceptable range, ensuring adequate aggregate packing and asphalt binder adhesion, critical for climbing lane pavement performance.

7. Water Absorption:

Water absorption indicates the susceptibility of aggregates to moisture damage. In climbing lanes exposed to varied weather conditions, low water absorption is essential to prevent pavement deterioration. The low water absorption value (0.3%) suggests minimal moisture susceptibility, enhancing the longevity and performance of the asphalt pavement in climbing lanes.

4.1.2 Combined grading of aggregates

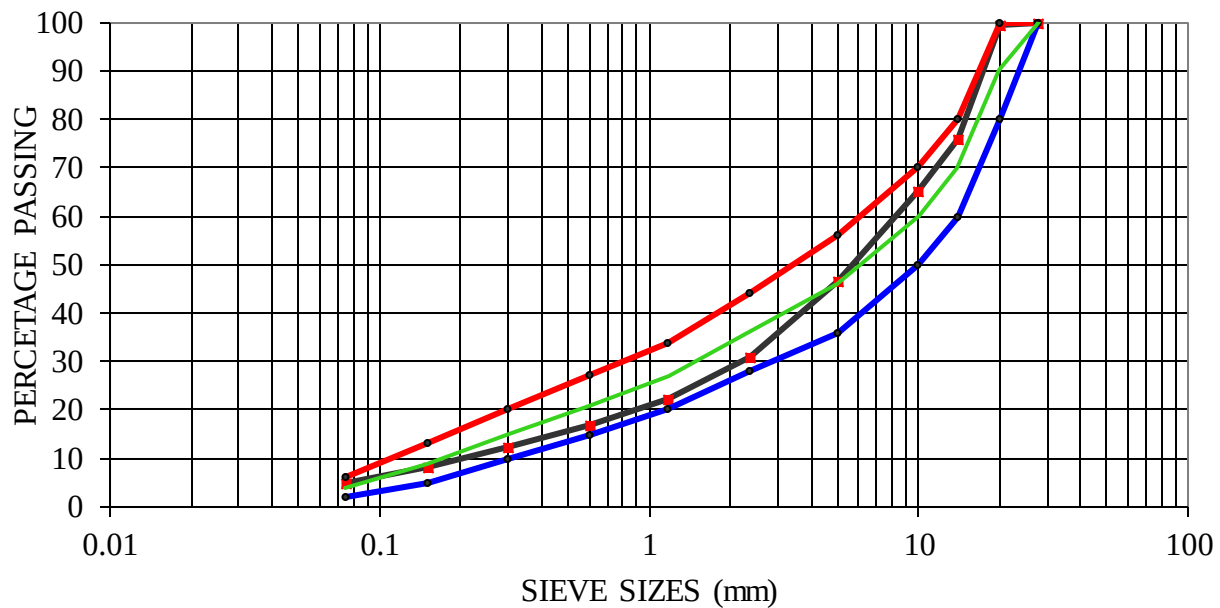


Figure 11 graph of combined grading of aggregates

Figure 10 shows the AC20 individual gradation and it also shows that the grading lies in the specified grading envelopes. This implies that the particle distribution of the aggregates achieved a proper mechanical interlock of aggregates which positively affects the durability of the mixture.

4.1.3 Tests on bitumen

Table 4 tests on bitumen

Property	Test	Test standard	unit	Average measured value $\pm$ SD	Specification
Penetration	Penetration	ASTM D-5	Deci mm	64 $\pm$ 0.5	60 - 70
Softening point	Softening point	ASTM D36	$^{\circ}\text{C}$	52 $\pm$ 0.5	49 - 56
Penetration Index	Annex A	-	-	-0.7	-1.5 to +0.7 (EN 12591)
viscosity	Viscosity	ASTM D4402-91	mm^2/s	340 $\pm$ 0.5	> 295
Specific gravity	Specific gravity	ASTM 1429	g/cc	1.027 $\pm$ 0.01	1.10 - 1.06
Ductility	Ductility	ASTM D113	Mm	1165 $\pm$ 0.5	> 1000

1. Penetration test

The penetration value obtained for neat bitumen indicates that the bitumen used was of penetration grade 60-70. Penetration relates with the stiffness of the bitumen. To resist permanent deformation, a highly stiff binder is required to increase the bond strength and stiffness in the asphalt mixture. However, highly stiff mixtures are less durable due to tendency to crack easily due to thermo-volumetric changes caused by temperature variations and higher loads beyond what the pavement can bear safely.

2. Softening point

The softening point is an empirical representation of the viscosity since it the temperature at which bitumen gradually changes from highly viscous (semi-solid) to low viscous fluid. Some researchers have stated that using binders with high softening point

can improve the resistance to permanent owing to the ability of the binder to soften at higher temperatures.

3. Temperature Susceptibility

Temperature susceptibility can be quantified using Penetration Index. A high penetration index indicates that the bitumen is softer and more susceptible to temperature induced changes hence more susceptible to rutting while a lower penetration index suggests that the bitumen is harder and less affected by temperature variations hence less susceptible to rutting. The pavement index was calculated using Equation (2) in section 3.2.2.4 and the value obtained was -0.7. However research done by (Fakhrur, 2013) recommends that the PI should be as close to 0 as possible to reduce the rutting susceptibility. This study therefore intended to modify the bitumen used in the asphalt mixture to improve its pseudo rheological properties at higher temperatures (up to 50°C) and increased loading time due to low vehicle speeds at the climbing lane section

4. Viscosity

Viscosity can be used to relate the measure of resistance of flow of the binder to permanent deformation. However, fluids that exhibit the Newtonian flow comply with the viscosity measurement. Bitumen exhibits such Newtonian fluids at temperatures above 60°C. This study therefore did not consider relating it with change in permanent deformation. However, the test was conducted to help in determining the mixing and compaction temperatures. The viscosity obtained was 340, which gives mixing, and compaction temperature of 146 °C, which lies within the range which is 145-160°C.

5. Ductility

The ductility of the modified bitumen (1165 ± 0.5 mm) exceeds the specified minimum requirement (> 1000 mm). This indicates that the addition of LLDPE has improved the bitumen's ability to stretch without breaking, which could enhance the flexibility and resistance to cracking of the asphalt pavement, particularly in climbing lanes subjected to frequent heavy loads and thermal cycling.

4.2 Determine the optimum binder content of the unmodified bitumen to use in the asphalt mix

In order to determine the optimum bitumen content, the Asphalt Institute Procedure was followed as shown in the graphs below plotted from the above table.

4.2.1 Air voids

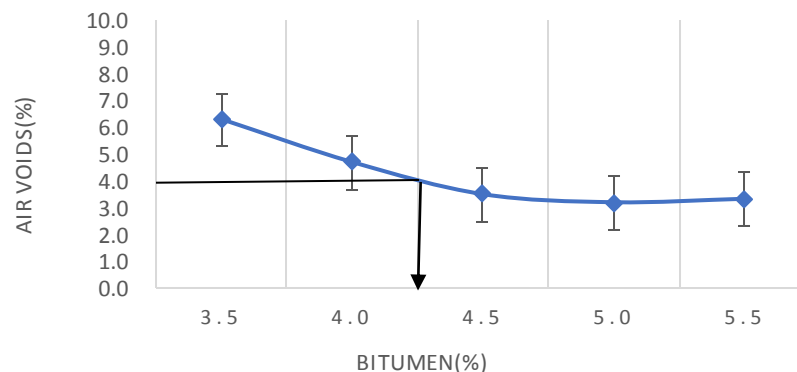


Figure 12 graph of air voids against bitumen content

The optimum bitumen content at air voids was obtained at 4% air voids which gave an optimum bitumen content of 4.3% as shown in Figure 11.

4.2.2 Stability

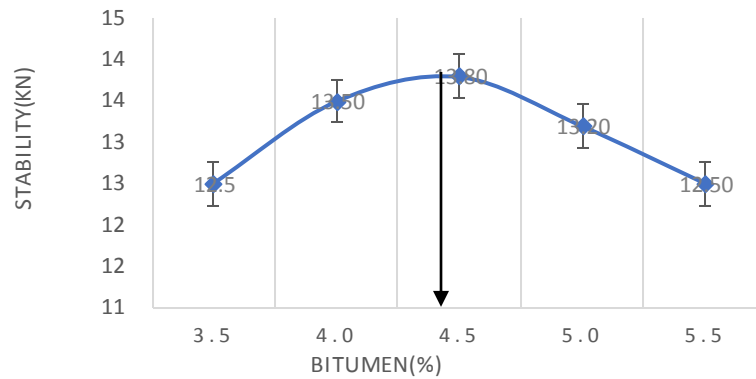


Figure 13 graph of stability against bitumen content

The optimum bitumen content at stability was obtained from the one that maximizes Marshall stability vs bitumen content graph which gave 4.4% as shown in Figure 12.

4.2.3 Unit Weight

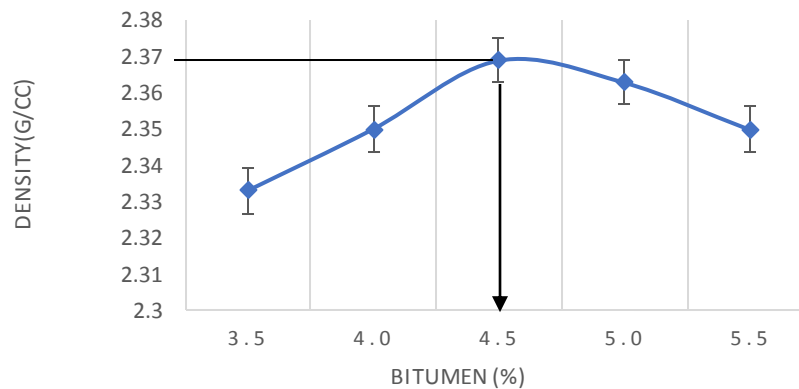


Figure 14 graph of unit weight against bitumen content

The optimum bitumen content at unit weight was obtained from the one that maximizes unit weight vs bitumen content graph which gave 4.6% as shown in Figure 13.

<i>Table 5 Average optimum bitumen content</i>	
Parameter	Optimum binder content (%)
AIR VOIDS	4.3
STABILITY	4.4
DENSITY	4.6
AVERAGE	4.4 ± 0.15

This average obtained in Table 5 is then checked to meet the criteria for flow as seen in the graph below (Figure 14);

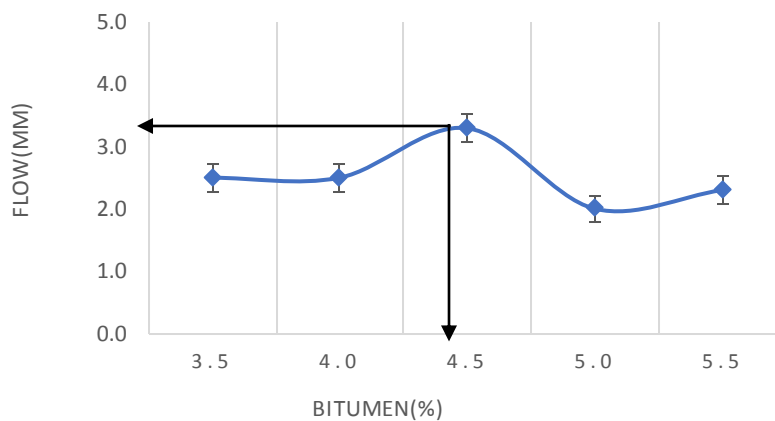


Figure 15 graph of flow against bitumen content

Since the flow value (3.3mm) obtained from the average optimum bitumen content (4.4%) is within the standard flow range of 2mm to 4mm, then the optimum bitumen content is 4.4%.

4.3 Determining the rheological properties of the modified bitumen.

Having followed procedures in methodology Section 3.4 and Section 3.5, the results of bitumen tests helped ascertain the modified bitumen's index qualities. The average values and standard deviations of these tests were computed after they were conducted in duplicate and triple. By applying the penetration index, an asphalt mechanistic model used in IS EN 12591, was utilized to relate the index features to temperature susceptibility of the bitumen. The results were analyzed and discussed further to determine the effect of the LLDPE on the rheological properties of the bitumen and ascertain the favorable dosage to use in the asphalt mixture.

4.3.1 Bitumen softening point.

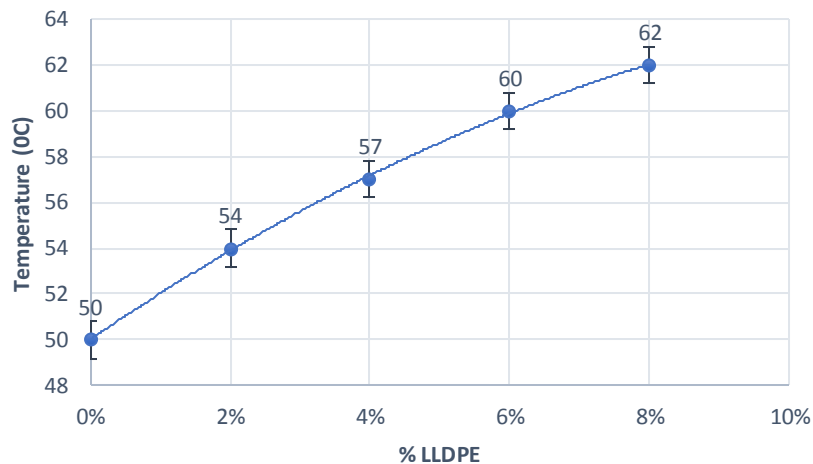


Figure 16 Temperature against % of LLDPE

Figure 15 shows that the bitumen's softening point is trending upward. Any additional LLDPE addition above 6% went beyond the 49-56 °C standard range set by MoWT and EN 12591. However, it should be highlighted that determining the high temperature performance or temperature susceptibility in paving application cannot be done solely

based on compliance of the softening point values derived to the specification. This indicates that this parameter is purely empirical and cannot be supported as a guarantee that it will lessen the asphalt's ability to rut.

4.3.2 Bitumen Penetration

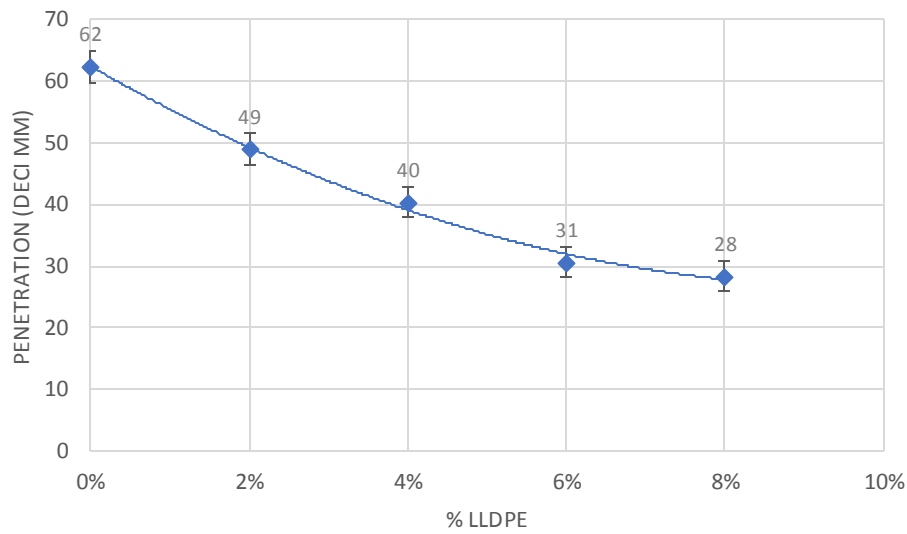


Figure 17 Penetration against % of LLDPE

Figure 16 shows that when the amount of LLDPE was raised, the data revealed a trend of reduced bitumen penetration, indicating a rise in stiffness. When applying bitumen for paving, 40-50 and 50/70 penetration grades are advised. The bitumen penetration to pen 40-50 was enhanced by the addition of 2% and 4%, which should ideally result in an increase in stiffness and the capacity to withstand rutting because of increased shear strength. Harder bitumen with penetration falling between pen grades 20 and 30 was developed by adding more LLDPE up to 6% and 8%. Pen grades 20-30 bitumen are regarded as hard and should not be used for paving (Robert, 2015). While the bitumen's hardness was raised by 2% and 4% LLDPE modification, this does not prove that the bitumen has the ability to withstand rutting because penetration is a one-point

temperature test and cannot be used to determine the bitumen's consistency in stiffness at different temperatures.

4.3.3 Determining temperature susceptibility using penetration index (PI)

Using Equation (2) in section 3.2.2.4, the Penetration index was calculated as seen in Table (7) as seen below;

Table 6 Penetration Index values

% LLDPE	Penetration (deci mm)	± SD	Softening point SD (°C)	± Penetration Index
0%	62		50	-0.67
2%	49		54	-0.29
4%	40		57	-0.09
6%	31		60	-0.08
8%	28		62	0.13

The penetration index represents the change in penetration of bitumen with temperature variations, providing insights into its thermal behavior and potential for rutting or softening under different climatic conditions. With increased addition LLDPE, the PI reduces to zero which indicates reduced susceptibility to softening at high temperatures, which is particularly important for asphalt pavements along climbing lanes where elevated temperatures due to heavy traffic and friction can lead to pavement deformation and rut formation. Addition of LLDPE will therefore help to reduce on the pavement's susceptibility to rutting

4.3.4 Bitumen Ductility

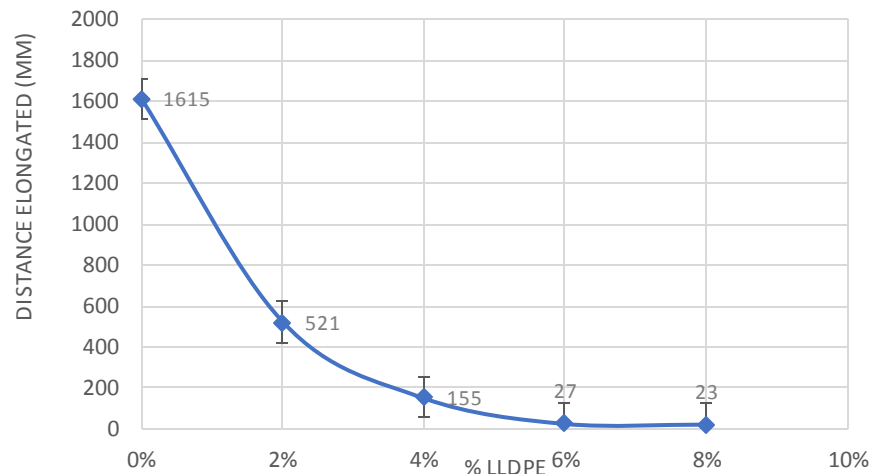


Figure 18 Distance elongated against % of LLDPE

In order to make sure the binder can tolerate high strain and is sufficiently flexible to prevent cracking, ductility test was carried out. According to the MoWT, the minimum ductility for bitumen modified with SBR and SBS polymers should be 500 mm, while the minimum ductility for EVA—a plastomer similar to LLDPE—should be 300 mm. The recommended dosage going forward is only 2% LLDPE because of these specifications. But adding more polymer to the bitumen results in a larger percentage of the polymeric phase in the bitumen, which strengthens the binder and increases its resistance to deformation. As a result, this study looked at 2% and 4% as the ideal LLDPE dosages in the asphalt mixture and evaluated their performance characteristics. These dosage percentages were used to prepare the modified bitumen, which was mixed with the aggregates to prepare asphalt specimen that were subjected to Marshall Stability and flow, indirect tensile strength and percentage refusal density tests to analyze their performance against rutting as shown below

4.4 Performance properties of asphalt mix

4.4.1. Air Voids

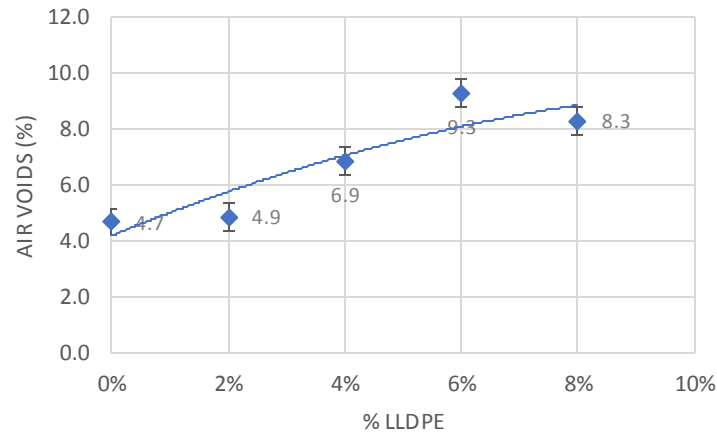


Figure 19 Air voids against % of LLDPE

Figure 18 illustrates an increasing trend in air spaces as the bitumen's proportion of LLDPE rose. This has a close relationship to the rise in bitumen stiffness depicted in the previous graph. According to a research study by (Guangji,2019), the phenomenon results in a more porous asphalt mixture with a larger void content as bitumen stiffens because the flow reduces through aggregate voids. In order to provide stability and durability overall, the specifications suggest a minimum and maximum air void content of 3% to 5%, respectively. According to research, pore pressure increase and binder bleeding at high temperatures can cause asphalt mixtures with air voids less than 2% to become unstable under loading, which can result in permanent deformation (Efraem, 2014). Furthermore, the study indicates that because voids are interconnected and allow oxidants and moisture to enter the asphalt layer, there is a risk of durability loss if vacancies surpass 6%. Thus, merely 2% LLDPE satisfies the requirement for enough air

spaces to increase the mixture's stability against permanent deformation without compromising its durability.

4.4.2 Stability

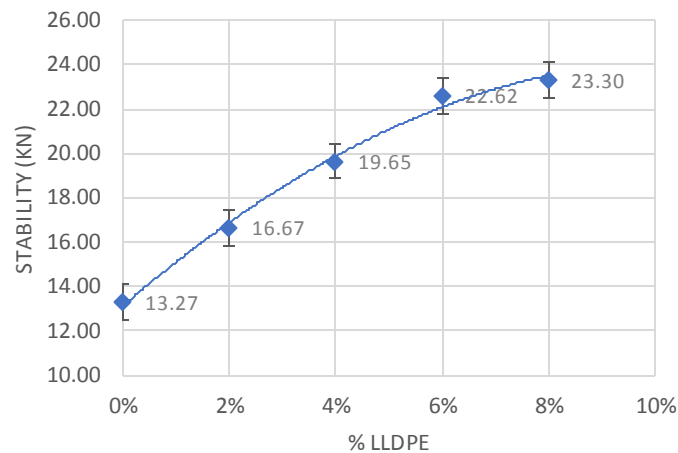


Figure 20 Stability against LLDPE

As the amount of LLDPE was increased, Figure 19 demonstrates an increasing trend in the stability of the asphalt mixture. Given that the Marshall Stability test was conducted at a high temperature (60°C), this may be connected to the binder's increased stiffness modulus and improved temperature performance (low temperature susceptibility demonstrated by an improved penetration index) as a result of the addition of LLDPE. According to a study by (Efraem, 2014), binders that are more stiff and perform better at high temperatures are more stable and show superior resistance to rutting in asphalt pavements. Higher stability values, on the other hand, indicate an excessively stiff combination, which reduces flexibility and leads to reflective, thermal, and fatigue cracking. According to (Nejad, 2018) this reduces the pavement's longevity. The minimum and maximum requirements for Marshall stability of asphalt specimen is 9kN

and 18kN respectively. This indicates that only 2% LLDPE meets the required specifications.

4.4.3 Flow

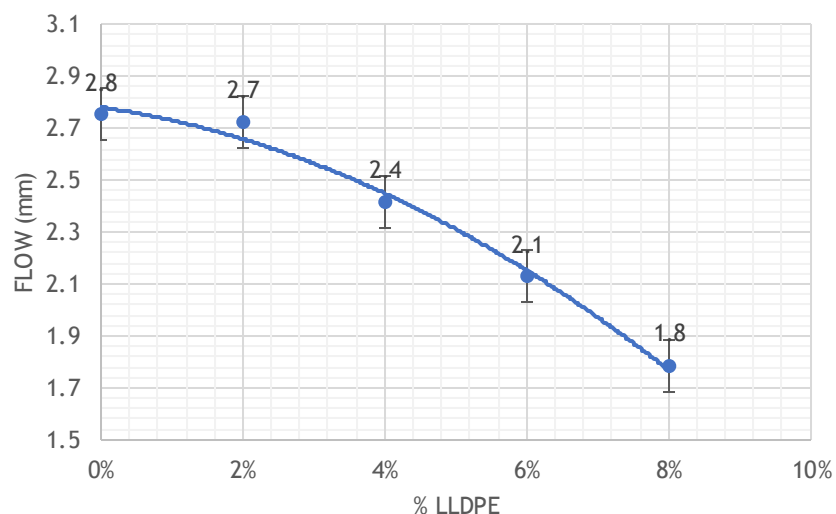


Figure 21 Flow against % of LLDPE

Figure 20 shows that the addition of LLDPE reduces flow, which implies that the asphalt mixture's capacity to flow and deform under high temperatures and loads is diminished. When exposed to high temperatures and traffic loads, binders with higher flow values typically show greater sensitivity to rutting. The bitumen's low temperature susceptibility and enhanced stiffness to support large loads are linked to the decline in flow value. This indicates that at high loads and temperatures, the asphalt mixture's resistance to rutting could be strengthened by the LLDPE. Nevertheless, additional modification up to 8% LLDPE results in extremely low flow values that are less than the 2 mm minimum required by the (Asphalt Institute, 1979). In other words, the excessive stiffness of the asphalt binder resulted in a reduction in flexibility, which raised the asphalt pavement's vulnerability to cracking and limited its longevity.

From the above Marshall test analysis, the addition of LLDPE to the bitumen increased the asphalt mixture's stiffness and decreased its temperature susceptibility, which speaks to the asphalt mixture's capacity to maintain consistency at high temperatures, as demonstrated by the above Marshall tests. Nevertheless, additional alteration resulted in an excessively rigid asphalt mixture, hence compromising the asphalt pavement's longevity. An asphalt mixture with only 2% LLDPE was able to increase its resistance to permanent deformation without sacrificing its durability.

4.4.4 Indirect Tensile Strength

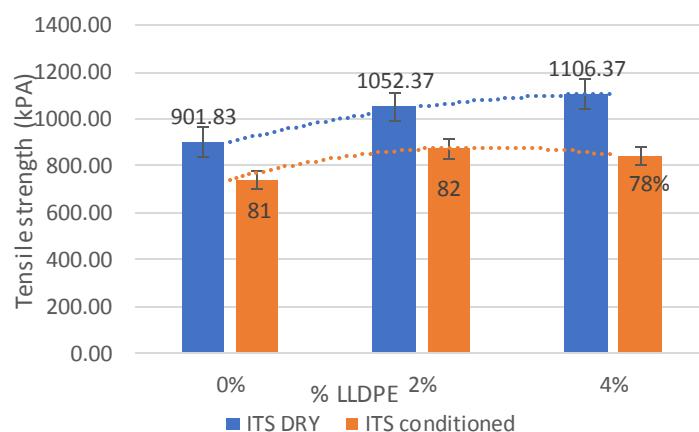


Figure 22 Tensile strength against % of LLDPE

Research indicates that an asphalt mixture that is resistant to moisture damage should have a minimum TSR value of 0.80 (80%), according to (Asphalt Institute, 2014). According to the MoWT (Ministry of Works and Transport, 2005) specification, the ITS achieved for the conditioned specimen must be at least 80% that of the unconditioned (dry) specimen. This specification applies to that form Asphalt institution. The 1% rise in the TSR value suggests that the 2% LLDPE modified sample specimen is safe against moisture damage, with a modest increase in resistance to moisture damage when

compared to the unmodified sample. As for the concern that a mixture might not have enough tensile strength to withstand deformation under load, the Asphalt Institute (Asphalt Institute, 1979) further suggests that agencies set a minimum indirect tensile strength to account for. The MoWT specification (Ministry of Works and Transport, 2005) specifies a minimum tensile strength value of 800kPa for the unconditioned state. The results obtained, as shown in Figure 21, indicated that the modified asphalt mixture had adequate tensile strength with an approximate 16% increase in tensile strength when compared to the tensile strength obtained for the unmodified specimen.

4.5 Research design

Table 7 Research Design

Aggregate sizes	percentage of Agg sizes	Unmodified asphalt (%)	Modified asphalt mix with 2% LLDPE (%)	Mass in total mix (g)	Mass in total mix Gmm (g)
20/14	25	25	25	286.8	598
14/10	12	12	12	137.7	286.8
10/6	8	8	8	91.8	191.2
3/6	53	53	53	608.0	1266.7
Filler	2.0	2.0	2.0	22.9	47.8
Total Agg	100	100	100	1147.2	2390
Bitumen	-	4.4	4.4	52.8	110
Total mix	100			1200.0	2500

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. The mechanical properties of the aggregates were within the required specifications meaning that the aggregates used have the ability to withstand heavy traffic loads hence improving the pavement's stability, and resistance to rutting. This research identified that the bitumen was susceptible to temperature fluctuations hence causing softening and weakening of the asphalt mixture hence leading to shear flow that manifests as rutting in flexible pavements. This initiated the rationale of this study creating the need to modify the bitumen and improve the rheological properties of the binder.
2. The optimum bitumen content was the obtained as 4.4% through following the Marshall mix procedure in accordance to the Asphalt Institute procedure. This was used to prepare the asphalt mixtures and it's from this that partial replacement with LLDPE was done at different percentages.
3. The study showed that when the bitumen is modified with LLDPE, the temperature susceptibility of the bitumen was lowered and the stiffness of the asphalt mixture was improved. This meant that the binder was capable of resisting softening at high service temperatures while maintaining consistency and high stiffness. This would therefore reduce on the pavement's susceptibility to rutting.
4. The Marshall test findings showed an increase in voids with only a 2% alteration, keeping the voids within the specification's required range of 3% to 6%. When the asphalt mixture is modified with 2% LLDPE, the sample produced a stability value

within the specified range, while the remaining percentages produced values that were higher than the recommended standards. Additionally, the flow values showed a decrease in deformation, which suggests a reduced vulnerability to permanent deformation. Only 2% LLDPE was shown to be able to improve pavement temperature susceptibility and improve resistance to higher loads without compromising the asphalt mixture's longevity. To assess the modified asphalt mixture's resistance to moisture-induced damage, an indirect tensile strength test was conducted using 2% LLDPE. According to the study, the Tensile Strength Ratio was 1% better than the neat asphalt mixture and was within the minimum of 80% stipulated by the (Asphalt Institute, 2014). Consequently, this study concludes that 2% alteration of asphalt mixtures can enhance their performance along heavily trafficked areas, such climbing lanes.

5.2 Recommendations

- i. Further research needs to be conducted to evaluate the effect of aging on PE-modified asphalt binders and the effect of PE on the fatigue behavior of the asphalt binder.
- ii. Studies need to be carried out on the effect of the different types of plastic for example Polyethylene Terephthalate(PET), (Polyvinyl Chloride(PVC), Polypropylene(PP) and High Density Polyethylene(HDPE)
- iii. For this study, the aggregates used was granite therefore, studies with the use of other types of aggregates such as sandstone, basalt and quartz should be experimented

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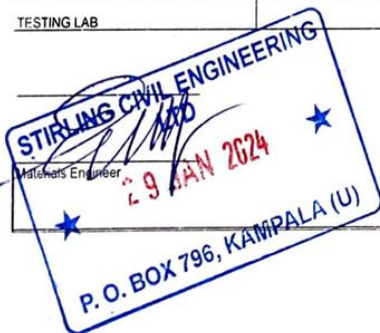
APPENDICES

Appendix A : Results for Study.

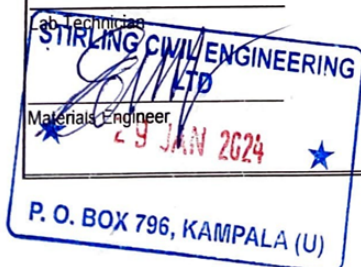
INSTITUTION	STUDENTS	CONTRACTOR
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)	Stirling
PROJECT	INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES	
<u>FLAKINESS INDEX OF AGGREGATES (BS 812 PART 105.2 1990)</u>		
Location:	STIRLING LAB	Operator:
Material:	COMBINED AGGREGATES FOR AC 20 ASPHALT	Date: 1/20/2024
		weight of sample (gms) 2107.4
BS sieve Size	Weight Retained (gm) (from grading sheet)	% Retained
28mm	0	0.0
20mm	0	0.0
14mm	87.0	4.1
10mm	141.0	6.7
is less than 5% that size is not tested for flakiness		
BS sieve size(mm)		
Weight retained gm (A)		
Weight retained gm (B)		
Correction factor a/b (C)		
Wt. Passing sieve gm (D)		
Wt. Retained on sieve gm (E)		
Corrected Wt. Passing (dxc) (F)		
	28.0	20.0
	14.0	10.0
		Total
		228
		255.2
		0.3
		33.0
		54.0
		11.3
		32.7
		43.9
Flakiness Index $\frac{\text{TOTAL F}}{\text{TOTAL A}} \times 100 = 19.3$		
FOR STUDENTS Lab Technician Materials Engineer		

INSTITUTION  UGANDA CHRISTIAN UNIVERSITY A University of the Future for Africa	NAMES AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)	TESTING LAB Stirling	
PROJECT: INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES			
DETERMINATION OF AGGREGATE'S 10% FINES VALUE DRY AND SOAKED (BS 812PART 111:112:1990)			
LOCATION:	Lab	OPERATOR	
		DATE SAMPLED 15 January 2024	
MATERIAL DESCRIPTION:	AGGREGATES FOR ASPHALT	DATE TESTED 16 January 2024	
10% FINE VALUE DRY			
TEST NO	1	2	3
CRUSHING FORCE (KN)	263	263	263
WT. OF AGGREG (gm) after crushing (M1)	2832.9	2868.7	2896.3
WT. OF AGGREG. RETAINED ON SIEVE 2.36 mm (M3)	2570.1	2610.7	2641.2
WT. AGGREG. (gm) PASSING SIEVE 2.36 mm (M2)	262.8	258.0	255.1
TEN % FINE VALUE (M=M2/M1*100)	9.3	9.0	8.8
AVERAGE RESULTS % (M)	9.0		
AVERAGE CRUSHING FORCE (F)	263.2		
$F = \frac{14}{11} \times \frac{F}{4} = \frac{14}{11} \times \frac{282.8}{4} = 282.8 \text{ DRY } 282.8 \text{ KN}$			
10% FINE VALUE SOAKED			
TEST NO	1	2	3
CRUSHING FORCE (KN)	263	263	263
WT. OF AGGREG (gm) after crushing (M1)	2863.0	2864.0	2851.8
WT. OF AGGREG. RETAINED ON SIEVE 2.36 mm (M3)	2621.3	2625.3	2608.5
WT. AGGREG. (gm) PASSING SIEVE 2.36 mm (M2)	241.7	238.7	243.3
TEN % FINE VALUE (M=M2/M1*100)	8.4	8.3	8.5
AVERAGE RESULTS % (M)	8.4		
AVERAGE CRUSHING FORCE (F)	263.2		
$F = \frac{14}{11} \times \frac{F}{4} = \frac{14}{11} \times \frac{296.3}{4} = 296.3 \text{ SOAKED } \text{WET/DRY(\%)} = 135$ 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 <0> discard)			

TESTING LAB



INSTITUTION	CLIENT	TESTING LAB	
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S10B12/620)	Stirling	
PROJECT:	INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE		
A.C.V. LABORATORY TEST RESULT FORM (BS 812PART 110:1990)			
LOCATION:	MUKONO SITE	Operator	15/Jan/24
MATERIAL DESCRIPTION:	AGGREGATES FOR ASPHALT	Date	16/Jan/24
A.C.V			
(A) WT BEFORE CRUSHING (gm)	2860.5	2826.2	2799.6
(B) WT AFTER CRUSHING (gm)	2859.5	2825.8	2799.1
(C) WT RETAINED AFTER CRUSHING (gm)	2371.8	2363.5	2335.7
(D) WT PASSING SIEVE 2.36 mm	488.7	462.7	463.9
A.C.V.(%) (D/B)*100	17.1	16.4	16.6
AVERAGE RESULTS %	16.7		
NB more than B by 10gms repeat the test			
A.I.V			
(A) WT BEFORE TEST (gm)	356.2	358.1	367.5
(B) WT AFTER TEST (gm)	355.5	357.9	367.5
(C) WT RETAINED AFTER TEST (gm)	300.5	305.9	311.1
(D) WT PASSING SIEVE 2.36 mm	55.7	52.2	56.4
A.I.V.(%) (D/B)*100	15.7	14.6	15.3
AVERAGE RESULTS %	15.2		
NB If c+d is more than B by 1gms repeat the test			
SPECIFIED LIMITS IN ACCORDANCE WITH TYPE OF MATERIAL			
FOR TESTING LAB			



INSTITUTION  UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		CLIENT AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)		TESTING LAB Stirling	
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES			
RESISTANCE TO DEGRADATION BY ABRASION AND IMPACT TO LOS ANGELES MACHINE (AASHTO T96 - 99)					
JOB:	MUKONO SITE	OPERATOR			
LOCATION :	MUKONO CRUSHER	TOTAL BY DRY WT. OF THE SAMPLE:1		5,000.0	
SUPPLIER:	STIRLING	TOTAL BY DRY WT. OF THE SAMPLE:2		5,000.0	
MATERIAL:	AGGREGATES FOR ASPHALT	DATE SAMPLED:		15/Jan/2024	
SPECIFICATION...		DATE TESTED:		16/Jan/2024	
Test 1 Grading of Test Samples					
SIEVE SIZE		Mass of indicated Sizes,g			
		Grading			
Passing	Retained on	A 12 balls	B 11balls	C 8 balls	D 6balls
mm 20	10				
37.5 (1 1/2in)	25.0 (1 in)	1250 ± 25	.....	.....	.....
25.0 (1 in)	19.0 (3/4 in)	1250 ± 25	.....	.....	.....
19.0 (3/4 in)	12.5 (1/2 in)	1250 ± 10	2500 ± 10	.....	.....
12.5 (1/2 in)	9.5 (3/8 in)	1250 ± 10	2500 ± 10	.....	.....
9.5 (3/8 in)	6.3 (3/4 in)	.....	.....	2500 ± 10	.....
6.3 (3/4 in)	4.75 (No. 4)	.....	.....	2501 ± 10	.....
4.75 (No. 4)	2.36 (No. 8)	.....	.....	.....	5000 ± 10
TOTAL:.....		5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10
Speed of Rotation: 33Rev/min. Max. 500 Rev.					
Max.Duration 15 min				Wt after crushing: :	4,972.3
GRADING USED FOR TEST:		SAMPLE: 1	SAMPLE: 2	Wt after crushing: :	4,982.5
Wt of Mat. Retained on 1.7mm sieve :		4,144.5	4,132.0		
Wt of fine material _		855.5	868.0	Average: %	17.2
Percentage of wear _ %		17.1	17.4	Spec Req	40%
FOR TESTING LAB					
STIRLING CIVIL ENGINEERING LAB TECHNICIAN LTD  MATERIALS ENGINEER P. O. BOX 793, KAMPALA. (U) 19 JAN 2024					

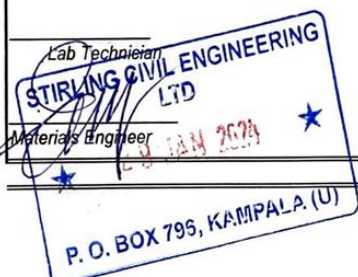
INSTITUTION	STUDENTS	TESTING LAB	
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)	Stirling	
PROJECT	INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES		
<u>SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES</u> (AASHTO ; T85—91) ASTM DESIGNATION ; C127—88			
LOCATION: Mukono Quarry	OPERATOR:		
SAMPLE No	SAMPLE DATE: 1/15/2024		
TYPE: 14-20 mm	TESTING DATE: 1/17/2024		
TEST NO	A	B	C
[A] wt. of oven dry sample in air (gm)	2427.1		2184.8
[B] wt. of saturated surface dry sample in air (gm)	2431.0		2188.5
[C] wt of saturated sample in water (gm)	1506.9		1354.6
Bulk Specific Gravity on oven dry basis	A (B-C)		2.620
Bulk Specific Gravity on saturated surface dry basis	B B-C		2.624
Apparent Specific Gravity	A A-C		2.632
Water Absorption(%)=	100(B-A) A		0.2
AVERAGE RESULTS			
BULK SPECIFIC GRAVITY		2.623	
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS		2.628	
APPARENT SPECIFIC GRAVITY		2.635	
WATER ABSORPTION		0.2	
FOR TESTING LAB			


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

INSTITUTION  UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	STUDENTS AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)	TESTING LAB Stirling	
PROJECT	INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES		
<u>SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES</u> (AASHTO : T85—91) ASTM DESIGNATION ; C127—88			
LOCATION: Mukono Quarry		OPERATOR:	
SAMPLE No		SAMPLE DATE: 1/15/2024	
TYPE: 14-10 mm		TESTING DATE: 1/17/2024	
TEST NO		A	B
[A] wt. of oven dry sample in air (gm)		2021.4	2014.0
[B] wt. of saturated surface dry sample in air (gm)		2026.6	2019.7
[C] wt of saturated sample in water (gm)		1254.6	1250.3
Bulk Specific Gravity on oven dry basis		A	
		(B-C)	
		2.618	2.618
Bulk Specific Gravity on saturated surface dry basis		B	
		B-C	
		2.625	2.625
Apparent Specific Gravity		A	
		A-C	
		2.636	2.637
Water Absorption(%)=		100(B-A)	
		A	
		0.3	0.3
AVERAGE RESULTS			
BULK SPECIFIC GRAVITY		2.618	
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS		2.625	
APPARENT SPECIFIC GRAVITY		2.637	
WATER ABSORPTION		0.3	
FOR TESTING LAB			
STIRLING CIVIL ENGINEERING LTD Lab Technician  Materials Engineer P.O. BOX 795, KAMPALA (U)			

INSTITUTION	STUDENTS	TESTING LAB
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)	Stirling
PROJECT	INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES	
<u>SPECIFIC GRAVITY & WATER ABSORPTION COARSE AGGREGATES</u> (AASHTO : T85—91) ASTM DESIGNATION ; C127—88		
LOCATION: Mukono Quarry	OPERATOR:	
SAMPLE No	SAMPLE DATE: 1/15/2024	
TYPE: 10 - 6 mm	TESTING DATE: 1/17/2024	
TEST NO	A	B C
[A] wt. of oven dry sample in air (gm)	2088.4	2033.8
[B] wt. of saturated surface dry sample in air (gm)	2094.2	2041.8
[C] wt of saturated sample in water (gm)	1296.1	1262.8
Bulk Specific Gravity on oven dry basis	A (B-C) 2.617	2.611
Bulk Specific Gravity on saturated surface dry basis	B B-C 2.624	2.621
Apparent Specific Gravity	A A-C 2.636	2.638
Water Absorption(%)= $\frac{100(B-A)}{A}$	0.3	0.4
AVERAGE RESULTS		
BULK SPECIFIC GRAVITY	2.614	
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS	2.623	
APPARENT SPECIFIC GRAVITY	2.637	
WATER ABSORPTION	0.3	

FOR TESTING LAB



INSTITUTION	STUDENTS	TESTING LAB
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)	Stirling
PROJECT	INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES	
SPECIFIC GRAVITY & WATER ABSORPTION FINE AGGREGATES (AASHTO : T84—00) ASTM DESIGNATION : C128—97		
LOCATION:	OPERATOR:	
SAMPLE No	SAMPLE DATE: 1/15/2024	
TYPE: QUARRY DUST (0/6 mm)	TESTING DATE: 1/17/2024	
TEST NO	1	K
[A] wt. of oven dry sample in air (gm)	567.54	547.12
[B] wt. of pycnometer filled with water (gm)	1805.71	1771.19
[C] wt. of pycnometer with specimen and water (gm)	2157.22	2110.82
[S] wt of saturated surface dry sample (gm)	569.44	549.28
Bulk Specific Gravity on oven dry basis $\frac{(B-C)}{(B+S-C)}$	2.604	2.610
Bulk Specific Gravity on saturated surface dry basis $\frac{S}{(B+S-C)}$	2.613	2.620
Apparent Specific Gravity $\frac{A}{(C-B) - A(C-B)}$	2.627	2.637
Water Absorption(%)= $\left(\frac{S-A}{A}\right)100$	0.3	0.4
BULK SPECIFIC GRAVITY		2.607
BULK SPECIFIC GRAVITY ON SATURATED SURFACE DRY BASIS		2.616
APPARENT SPECIFIC GRAVITY		2.632
WATER ABSORPTION		0.4

FOR TESTING LAB

Lab Technician

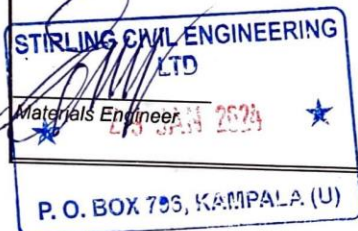
 Materials Engineer

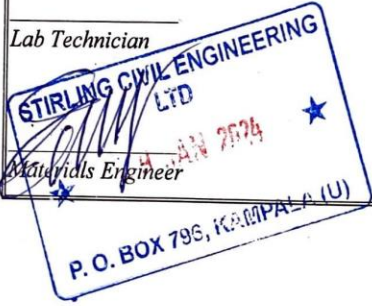
STIRLING CIVIL ENGINEERING LTD
 24 JAN 2024
 P. O. BOX 795, KAMPALA. (U)

INSTITUTION	STUDENTS	TESTING LAB
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)	Stirling
PROJECT: INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES		
SPECIFIC GRAVITY FILLER (AASHTO T100-95 (1995))		
LOCATION: Mukono Lab		OPERATOR:
SAMPLE No		SAMPLE DATE: 1/15/2024
TYPE: Filler		TESTING DATE: 1/17/2024
	Beaker K	Beaker 1
[A] Wt. OVEN dry sample (gm)	490.43	483.28
[B] Wt. of Pycnometer containing water alone (gm)	1805.95	1768.7
[C] Wt of Pycnometer containing Sample and water (gm)	2109.49	2069.36
SPECIFIC GRAVITY OF FILLER $\frac{A}{A + (B - C)}$	2.624	2.646
AVERAGE	2.635	

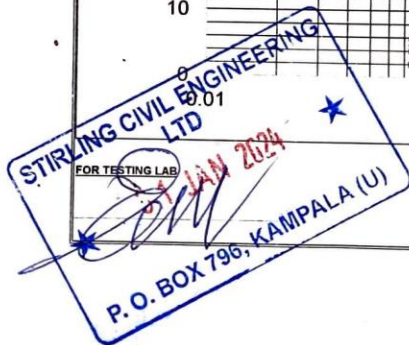
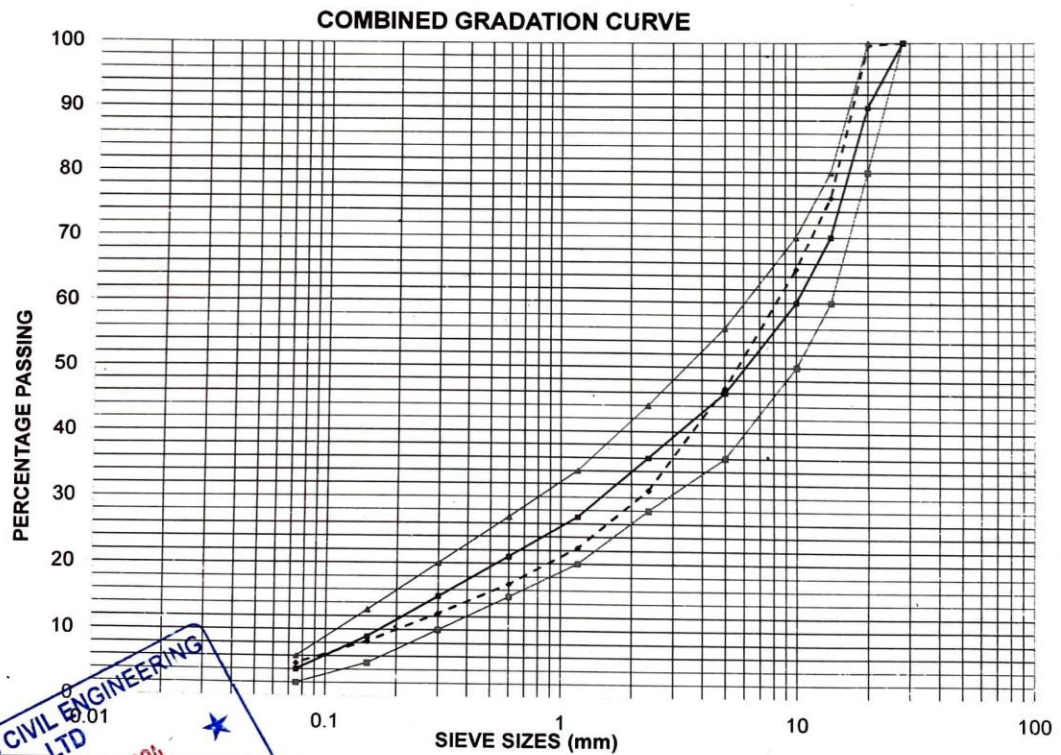
FOR TESTING LAB

Lab Technician



INSTITUTION		CLIENT		TESTING LAB		
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)		Stirling		
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES				
TEST		SPECIFIC GRAVITY				
TEST METHOD		ASTM:C128-97				
Sample Ref:		AC 14 MM		Technician :		
SOURCE:		Mukono Stirling quarry		Sampling date:		
Aggregate size :		COMBINED		Testing date:		
Description of aggregates:		HOT BINS				
Aggregate size :		20-14	14-10	10-6.0	6.0-0	FILLER
GS bulk :		2.623	2.618	2.614	2.607	2.635
PROPORTIONS:		5	7	18	66	4
COMBINED SG :		2.611				
WATER ABSOPTION		0.2	0.3	0.3	0.4	
COMBINED WATER ABSOPTION		0.3				
REMARKS						
FOR TESTING LAB						
Lab Technician 						

INSTITUTION  UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		STUDENTS AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)	TESTING LAB Stirling					
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES						
JOB ASPHALT MIX DESIGN								
LOCATION MUKONO LAB		18-Jan-24						
SUPPLIER HOTBIN No1								
SAMPLE No								
MATERIAL AC 20 INDIVIDUAL GRADATION								
	14/20MM	10/14MM	6/10MM	0/6MM	FILLER	actual	TARGET GRADING	SPEC
	25.0	12.0	8.0	53.0	2.0	100.0	100	100
28	100.0	100.0	100.0	100.0	100.0	100	100	100
20	98.6	99.4	100.0	100.0	100.0	100	90	80—100
14	18.7	70.3	99.4	100.0	100.0	76	70	60—80
10	1.6	18.7	93.9	100.0	100.0	65	60	50—70
5	0.4	1.3	6.6	83.0	100.0	47	46	36—56
2.36	0.4	0.9	5.1	0.4	28.5	31	36	28—44
1.18	0.4	0.8	4.3	0.3	19.8	22	27	20—34
0.6	0.4	0.7	3.6	0.3	14.4	17	21	15—27
0.3	0.4	0.6	3.0	0.2	19.1	12	15	10—20
0.15	0.4	0.5	2.5	0.2	12.0	8	9	5—13
0.075	0.4	0.4	2.2	0.2	6.5	5	4	2—6

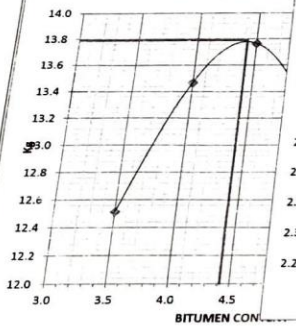


FOR STUDENTS

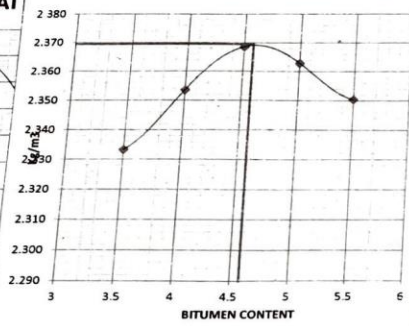
20 JOB MIX DESIGN

DATE: 1/20/2024

STABILITY AT



DENSITY AT MAXIMUM

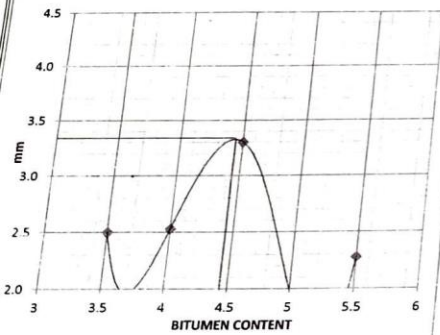


MIX PROPORTION

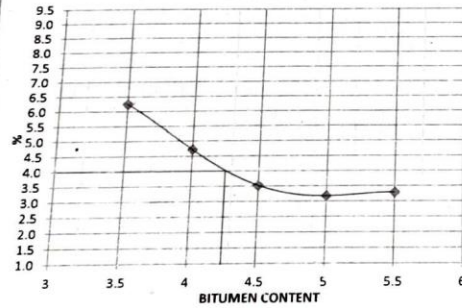
Stability	4.4	%	FILLER	2	%
Density	4.6	%	Q / Dust	53	%
Flow	4.4	%	10mm	8	%
Voids	4.3	%	14mm	12	%
Average	4.4		20mm	25	%
TOTAL				100	

3

FLOW



VOIDS

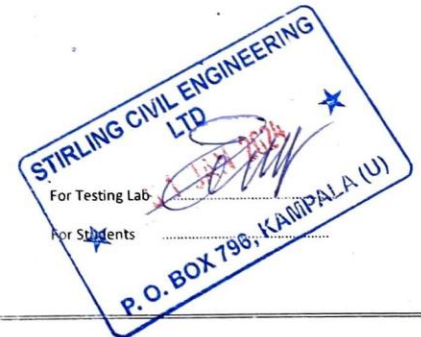


BITUMEN %	3.5	4	4.5	5	5.5
DENSITY	2.333	2.354	2.369	2.363	2.350
STABILITY	12.5	13.5	13.8	13.2	12.5
FLOW	2.5	2.5	3.3	2.0	2.3
VOIDS	6.3	4.7	3.5	3.2	3.3

Signatures:

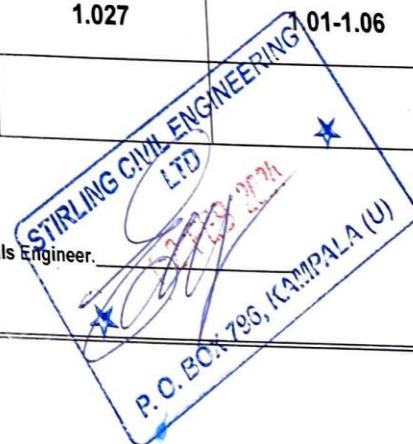
For Testing Lab

For Students



INSTITUTION		STUDENT'S NAME						TESTING LAB	
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)						Stirling	
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES							
LOCATION		BITUMEN TESTS						OPERATOR Lab team	
SUPPLIER								CONTAINER/DELIVERY NO	
NEAT BITUMEN								DESTINATION	
12-Jan-24									
MATERIAL TYPE 60/70									
TEST NO	IFF	3	L	D	S2	R	AVERAGE	REMARKS	
PENETRATION 5 sec 25 C 100gr	62 65 63	65 67 64	62 63 63	65 62 65	60 62 61	65 64 65	64	60-70	
SOFTENING POINT (°C)	52	51					52	(49-56)°C	
BITUMEN AFFINITY								>95	
SPECIFIC GRAVITY	1.029	1.028	1.024	1.028	1.028	1.028	1.027	1.01-1.06	

Materials Engineer.



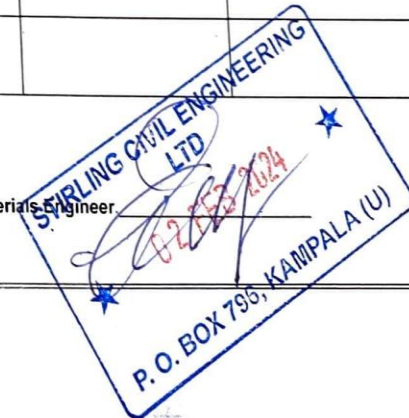
INSTITUTION		STUDENT'S NAME						TESTING LAB			
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)						Stirling			
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES									
MODIFIED WITH 2% PLASTIC											
LOCATION		BITUMEN TESTS						OPERATOR Lab team			
SUPPLIER								CONTAINER/DELIVERY NO			
16-Jan-24								DESTINATION			
MATERIAL TYPE 60/70											
TEST NO		2B		CM		RL		RS		AVERAGE	REMARKS
PENETRATION 100gr 5 sec 25 C		50 46 45		47 45 45		47 45 44		47 45 45		46	60-70
SOFTENING POINT (°C)			52		52.5					52	(49-56)°C
BITUMEN AFFINITY											>95
SPECIFIC GRAVITY		1.018		1.019		1.019		1.016		1.018	1.01-1.06

Materials Engineer.



INSTITUTION		STUDENT'S NAME				TESTING LAB				
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)				Stirling				
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES								
MODIFIED WITH 4% PLASTIC										
LOCATION		BITUMEN TESTS						OPERATOR		Lab team
SUPPLIER								CONTAINER/DELIVERY NO		
16-Jan-24								DESTINATION		
MATERIAL TYPE 60/70										
TEST NO	NG		4I		RM		IFF		AVERAGE	REMARKS
PENETRATION 5 sec 25 C	100gr	45		43		47		45	45	60-70
		45		44		42		45		
		45		45		46		46		
SOFTENING POINT (°C)			53		53.5				53	(49-56)°C
BITUMEN AFFINITY										>95
SPECIFIC GRAVITY		1.008		1.010		1.010		1.007	1.009	1.01-1.06

Materials Engineer



INSTITUTION	STUDENT'S NAME	TESTING LAB
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)	Stirling

PROJECT INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES

MODIFIED WITH 6% PLASTIC									
LOCATION	BITUMEN TESTS							OPERATOR	Lab team
SUPPLIER								CONTAINER/DELIVERY NO	
16-Jan-24								DESTINATION	
MATERIAL TYPE 60/70									

TEST NO	O8	I	4B	D	AVERAGE	REMARKS
PENETRATION 100gr 5 sec 25 C	27	30	25	30	29	60-70
	30	30	27	31		
	30	28	25	33		
SOFTENING POINT (°C)	55	55			55	(49-56)°C
BITUMEN AFFINITY						>95
SPECIFIC GRAVITY	1.010	1.000	1.009	1.008	1.006	1.01-1.06

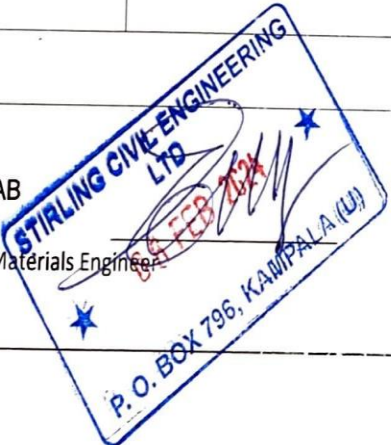
Materials Engineer.



INSTITUTION		STUDENT'S NAME						TESTING LAB		
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)						Stirling		
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES								
MODIFIED WITH 8% PLASTIC										
LOCATION		BITUMEN TESTS						OPERATOR Lab team		
SUPPLIER								CONTAINER/DELIVERY NO		
16-Jan-24								DESTINATION		
MATERIAL TYPE 60/70										
TEST NO	6		S2		K		2'		AVERAGE	REMARKS
PENETRATION 100gr 5 sec 25 C	30		28		32		33		32	60-70
	34		28		32		34			
	34		31		30		33			
SOFTENING POINT (°C)		57		58					58	(49-56)°C
BITUMEN AFFINITY										>95
SPECIFIC GRAVITY	0.995		0.997		1.001		0.999		0.998	1.01-1.06

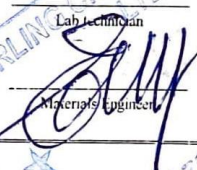
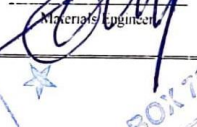
Materials Engineer.

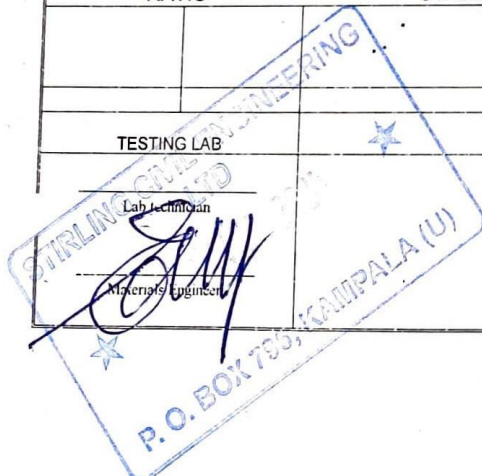
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INSTITUTION		STUDENTS			TESTING LAB	
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)			Stirling	
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES				
PROPERTY TESTS FOR BITUMEN						
Testing method	EN 12596		VISCOCITY TEST			Operator : Lab Team
Date sampled:	16-Jan-24					
Date tested:	16-Jan-24					
Material Type	60/70					
Test No	1		2	3	AVERAGE	REMARKS
Viscosity at 135°C (mm ² /Sec)	340		340	341	340	Min 295
Remarks:						
FOR TESTING LAB ab Technician 						

INSTITUTION		STUDENT'S NAME			TESTING LAB	
 UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)			 CML CENTRAL MATERIALS LABORATORY	
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES				
LOCATION		DUCTILITY BITUMEN TEST			OPERATOR Lab team	
MATERIAL TYPE BITUMEN					DESTINATION	
TEST NO		0% LLDPE			AVERAGE 1615	REMARKS (mm) >1000
Mould No.						
Time poured		1	2	3		
Time place in water bath		12:10pm	12:10pm	12:10pm		
Distance elongated (mm)		1:10pm	1:10pm	1:10pm		
		1610	1610	1625		ASTM D113
TEST NO		2% LLDPE			AVERAGE 521	REMARKS (mm) >500
Mould No.						
Time poured						
Time place in water bath		9:15am	9:15am	9:15am		
Distance elongated (mm)		10:15am	10:15am	10:15am		
		494	548	522		DIN 52013 (For modified bitumen)
TEST NO		4% LLDPE			AVERAGE 155	REMARKS (mm) >500
Mould No.						
Time poured						
Time place in water bath		12:20pm	12:20pm	12:20pm		
Distance elongated (mm)		1:20pm	1:20pm	1:20pm		
		180	158	126		DIN 52013 For modified bitumen)
TEST NO		6% LLDPE			AVERAGE 27	REMARKS (mm) >500
Mould No.						
Time poured						
Time place in water bath		10:02am	10:02am	10:02am		
Distance elongated (mm)		11:02am	11:02am	11:02am		
		30	25	25		DIN 5201 For modified bitumen)
TEST NO		8% LLDPE			AVERAGE 23	REMARKS (mm) >500
Mould No.						
Time poured						
Time place in water bath		1:03pm	1:03pm	1:03pm		
Distance elongated (mm)		2:05pm	2:05pm	2:05pm		
		25	22	23		DIN 520 For modified bitumen)

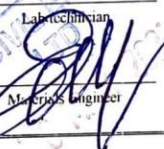
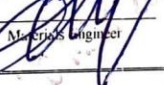


INSTITUTION		STUDENTS		TESTING LAB	
UGANDA CHRISTIAN UNIVERSITY		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)		Stirling	
PROJECT :		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES			
NEAT ASPHALT					
SUMMARY OF A/C 20TEST RESULTS					
		BITUMEN CONTENT		4.9	
MARSHALL MIX TEST RESULTS AFTER MIX				ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW				2.8	2—4
MARSHALL STABILITY 75BLOWS				13.9	9-18
MARSHALL AIR VOIDS 75BLOWS				4.7	3—5
VOIDS IN MINERAL AGGREGATES				15.2	>14%
VOIDS FILLED WITH BINDER				68.9	65—75%
INDIRECT TENSILE STRENGTH @ 25C				743	>800kpa
INDIRECT TENSILE WET STRENGTH				82	>80% of dry
RATIO		STABILITY/FLOW		4.8	>2.5
TESTING LAB					
 Lab Technician  Materials Engineer					



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INSTITUTION				STUDENTS						TESTING LAB							
UGANDA CHRISTIAN UNIVERSITY				AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)						Stirling							
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES															
INDIRECT TENSILE STRENGTH																	
BITUMINOUS MIXTURE SAMPLED ON				2/2/2024		102 GMM		2.456		Bit content, %		4.5		NO OF BLOWS		54	
Compacted material parameters																	
SAMPLE NO.	THICKNESS				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		
	HEIGHT 1 (mm)	HEIGHT 2 (mm)	HEIGHT 3 (mm)	Av. Thickness (mm)													
MIX																	
NEAT ASPHALT																	
WET																	
1	65.1	65.4	65.2	65.2	1184.2	680.5	1192.3	511.8	2.291	2.456	34.390	1204.5	20.300	59.028	6.7		
4	66.0	66.3	66.4	66.2	1189.5	677.0	1193.5	516.5	2.280	2.456	36.954	1208.0	18.500	50.063	7.2		
3	67.2	66.8	67.0	67.0	1199.7	681.2	1202.6	521.4	2.278	2.456	37.741	1216.5	16.800	44.513	7.2		
DRY																	
2	66.8	66.5	67.0	66.8	1178.4	675.8	1186.4	510.6	2.285	2.456	35.529				7.0		
5	66.5	66.9	66.7	66.7	1185.1	675.1	1188.4	513.3	2.286	2.456	35.527				6.9		
6	67.2	67.0	66.8	67.0	1183.5	673.4	1187.4	514.0	2.280	2.456	36.872				7.2		
INDIRECT TENSILE STRENGTH																	
DRY						WET						$S_t = \frac{2P}{\pi t D}$ where P = maximum load (N) t = specimen thickness (mm) D = specimen diameter (mm)	WET/DRY				
SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD, P	SINGLE TENSILE STRENGTH, S _t	AVERAGE TENSILE STRENGTH, S _t	SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD, P	SINGLE TENSILE STRENGTH, S _t	AVERAGE TENSILE STRENGTH, S _t		spec 80%				
	div	kn/div	kn	spec min 800 kPa			div	kn/div	kn	kPa	kPa						
2	44	0.213	9.4	896.3	901.8	1	35	0.213	7.5	713.0	743						
5	48	0.213	10.2	956.3		4	37	0.213	7.9	742.4							
6	43	0.213	9.2	852.9		3	39	0.213	8.3	773.5							
FOR TESTING LAB																	
Lab Technician																	
Materials Engineer																	

INSTITUTION		STUDENTS		TESTING LAB	
UGANDA CHRISTIAN UNIVERSITY		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)		Stirling	
PROJECT :		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES			
2% LLDPE					
SUMMARY OF A/C 20 TEST RESULTS					
		BITUMEN CONTENT			4.9
MARSHALL MIX TEST RESULTS AFTER MIX				ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW				2.7	2—4
MARSHALL STABILITY 75BLOWS				18.1	9-18
MARSHALL AIR VOIDS 75BLOWS				4.9	3—5
VOIDS IN MINERAL AGGREGATES				15.6	>14%
VOIDS FILLED WITH BINDER				68.4	65—75%
INDIRECT TENSILE STRENGTH @ 25C				872	>800kpa
INDIRECT TENSILE WET STRENGTH				83	>80% of dry
RATIO		STABILITY/FLOW		6.1	>2.5
TESTING LAB					
 Lab technician  Materials Engineer					



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INSTITUTION					STUDENTS					TESTING LAB								
UGANDA CHRISTIAN UNIVERSITY					AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)					Stirling								
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES																
INDIRECT TENSILE STRENGTH																		
BITUMINOUS MIXTURE SAMPLED ON 2/2/2024					102		GMM		2.456		Bit content, %		4.5		NO OF BLOWS		54	
Compacted material parameters																		
SAMPLE NO.	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	VMA, AIR VOIDS (%) =100*(F-E)/F spec min 1.0% G			
MIX	2% LLDPE																	
WET																		
1	62.7	62.6	63.3	62.9	1192.5	665.00	1196.50	531.5	2.221	2.391	37.742	1204.5	12.000	31.795	7.1			
4	64.1	62.5	63.0	63.2	1187.0	664.00	1193.00	529.0	2.221	2.391	37.519	1208.0	21.000	55.971	7.1			
3	63.0	62.9	62.5	62.8	1194.0	670.50	1199.00	528.5	2.237	2.391	34.121	1216.5	22.500	65.942	6.5			
DRY																		
2	66.0	65.9	66.2	66.0	1190.0	665.9	1196.0	530.1	2.222	2.391	37.377				7.1			
5	66.1	66.9	65.8	66.3	1185.2	660.2	1186.8	526.6	2.228	2.391	35.865				6.8			
6	65.2	65.2	65.4	65.3	1192.5	665.4	1196.3	530.9	2.224	2.391	37.142				7.0			
INDIRECT TENSILE STRENGTH																		
DRY						WET						S _t =2P/πtD where P= maximum load(N) t=specimen thickness(mm) D=specimen		WET/DRY spec 80% 83				
SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD, P	SINGLE TENSILE STRENGTH, S _t	AVERAGE TENSILE STRENGTH, S _t	SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD, P	SINGLE TENSILE STRENGTH, S _t	AVERAGE TENSILE STRENGTH, S _t							
	div	kn/div	kn	spec min 800 kPa			div	kn/div	kn	kPa	kPa							
2	49	0.213	10.4	1,035.8	1,052.3	1	41	0.213	8.7	866.7	872							
5	54	0.213	11.5	1,082.9		4	43	0.213	9.2	904.1								
6	51	0.213	10.9	1,038.4		3	40	0.213	8.5	846.4								
FOR TESTING LAB																		
Lab Technician																		
Materials Engineer																		

INSTITUTION		STUDENTS		TESTING LAB	
UGANDA CHRISTIAN UNIVERSITY		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)		Stirling	
PROJECT :		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES			
4% LLDPE					
SUMMARY OF A/C 20 TEST RESULTS					
		BITUMEN CONTENT			4.9
MARSHALL MIX TEST RESULTS AFTER MIX				ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW				2.4	2—4
MARSHALL STABILITY 75BLOWS				21.0	9-18
MARSHALL AIR VOIDS 75BLOWS				6.9	3—5
VOIDS IN MINERAL AGGREGATES				18.7	>14%
VOIDS FILLED WITH BINDER				63.4	65—75%
INDIRECT TENSILE STRENGTH @ 25C				677	>800kpa
INDIRECT TENSILE WET STRENGTH				74	>80% of dry
RATIO		STABILITY/FLOW		8.2	>2.5
TESTING LAB					
Lab technician  Materials Engineer					



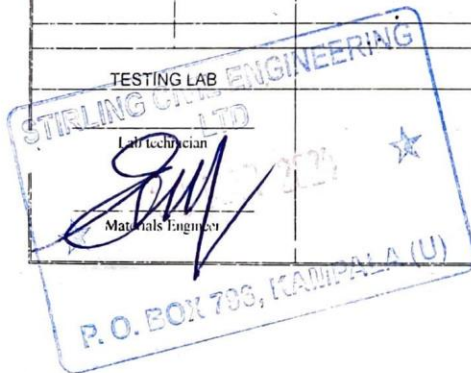
INSTITUTION				STUDENTS				TESTING LAB											
UGANDA CHRISTIAN UNIVERSITY				AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)				Stirling											
PROJECT				INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES															
Field Ref. No:		Lab. no.		MIX		4% LLDPE		Sampling date		02-Feb-24									
Sample grade: AC 20		Compaction: 75 blows						Testing date		03-Feb-24									
Sample Description:				AC 20															
ASTM D2726 - Standard Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures.										ASTM D6927 Standard 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)		Flow (mm)	Ratio (Stab./Flow)		
1	1209.5	675.20	1215.60	2.238	2.227	6.5	18.5	64.6	67.2	66.5	66.4	66.7	0.93	20.5	19.09	2.34	8.159		
2	1203.2	669.50	1209.60	2.228	2.217	7.0	18.8	63.0	65.6	66.2	66.2	66.0	0.94	22.5	21.15	2.66	7.951		
3	1210.9	669.90	1215.90	2.218	2.207	7.4	19.2	61.5	67.1	66.5	66.4	66.7	0.93	21.6	20.04	2.55	7.859		
4	1215.1	677.20	1220.00	2.239	2.228	6.5	18.4	64.6	66.2	65.9	65.8	66.0	0.94	19.5	18.33	2.12	8.646		
Average Sample 1				2.231	2.220	6.9	18.7	63.4	Average Sample 1			66.3	0.94	21.0	19.65	2.4	8.2		
Average Sample 2																			
Average Sample 1 & 2				2.231	2.220	6.9	18.7	63.4											
ASTM D2041- Standard Test Method for Theoretical Maximum Specific gravity and Density of Bituminous Mixtures										EXTRACTED BITUMEN CONTENT									
										4.5									
SAMPLE 1					SAMPLE 2														
(Pycnometer with Water)					(Pycnometer with Water)														
Temperature of water (°C) 25°C					Temperature of water (°C) 25°C														
in pycnometer		in water bath			in pycnometer		in water bath												
Test No-		1 2			Test No-		1 2												
Asphalt		2603.5			Asphalt		2611 -												
Pycn. - Water		18531			Pycn. - Water		18531 -												
Pycnometer - Asph. + Water		20045			Pycnometer - Asph. + Water		20043.5 -												
Volume of asphalt		1089.5			Volume of asphalt		1098.5 -												
G _{mb}		2.390			G _{mb}		2.377 -												
Av. G _{mb}		2.390			Av. G _{mb}		2.377												
Av. G _{mb} (Kg/m3) Sample 1 & 2		2.383																	
Comment:																			
FOR TESTING LAB																			
Materials Engineer																			

INSTITUTION					STUDENTS					TESTING LAB						
UGANDA CHRISTIAN UNIVERSITY					AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)					Stirling						
PROJECT		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES														
BITUMINOUS MIXTURE SAMPLED ON					INDIRECT TENSILE STRENGTH											
2/2/2024					102 GMM		2.456		Bit. content, %		4.4		NO OF BLOWS		54	
SAMPLE NO.	THICKNESS				Compacted material parameters											
	HEIGHT 1 (mm)	HEIGHT 2 (mm)	HEIGHT 3 (mm)	Av. Thickness (mm)	Weight of Core in Air (g) A	Weight of Core in Water (g) B	Weight of Core in SSD condition (g) C	Volume of Core (cc) D=(C-B)	Bulk Density (g/cm ³) E=(A/D)	GMM (maximum theoretical density) (g/cm ³) F	VOLUME OF AIR	SATURATED SPECIMEN	VOLUME OF WATER	DEGREE OF SATURATION	VIM, AIR VOIDS (%) =100*(F-E)/F spec min 2.0% G	
MIX																
4% LLDPE																
WET																
1	66.6	65.5	66.1	66.1	1195.0	667.50	1205.80	538.3	2.198	2.383	41.846	1204.5	9.500	22.702	7.8	
4	66.6	67.0	66.9	66.8	1190.5	665.00	1202.00	537.0	2.195	2.383	42.415	1208.0	17.500	41.259	7.9	
3	65.5	65.6	64.9	65.3	1193.5	665.00	1206.30	541.3	2.183	2.383	45.469	1216.5	23.000	50.584	8.4	
DRY																
2	67.3	67.7	67.1	67.4	1188.5	664.00	1199.00	535.0	2.199	2.383	41.246				7.7	
5	66.6	66.8	66.5	66.6	1179.5	653.50	1186.50	533.0	2.191	2.383	42.985				8.1	
6	66.8	66.0	67.3	66.7	1188.0	659.50	1196.30	536.8	2.191	2.383	43.254				8.1	
INDIRECT TENSILE STRENGTH																
DRY						WET						$S_t = \frac{2P}{\pi tD}$ where P= maximum load(N) t=specimen thickness(mm) D=specimen diameter	WET/DRY			
SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD, P	SINGLE TENSILE STRENGTH, S _t	AVERAGE TENSILE STRENGTH, S _t	SPECIMEN No.	GAUGE READING	LOAD RING FACTOR	MAXIMUM LOAD, P	SINGLE TENSILE STRENGTH, S _t	AVERAGE TENSILE STRENGTH, S _t					
	div	kn/div	kn	spec min 800 kPa			div	kn/div	kn	kPa	kPa					
2	48	0.213	10.2	965.5	913.2	1	36	0.213	7.7	724.1	677	74				
5	48	0.213	10.2	957.3		4	31	0.213	6.6	616.4						
6	41	0.213	8.7	816.9		3	34	0.213	7.2	691.6						
FOR TESTING LAB																
Lab Technician Materials Engineer 																

INSTITUTION		STUDENTS		TESTING LAB	
UGANDA CHRISTIAN UNIVERSITY		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)		Stirling	
PROJECT :		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES			
6% LLDPE					
SUMMARY OF A/C 20 TEST RESULTS					
		BITUMEN CONTENT			4.9
MARSHALL MIX TEST RESULTS AFTER MIX			ACHIEVED PLANT PRODUCTION	SPECIFIED	
MARSHALL FLOW			2.1	2—4	
MARSHALL STABILITY 75BLOWS			23.9	9-18	
MARSHALL AIR VOIDS 75BLOWS			9.3	3—5	
VOIDS IN MINERAL AGGREGATES			18.5	>14%	
VOIDS FILLED WITH BINDER			49.7	65—75%	
RATIO		STABILITY/FLOW	10.7	>2.5	
TESTING LAB					
 Lab technician					



INSTITUTION		STUDENTS		TESTING LAB	
UGANDA CHRISTIAN UNIVERSITY		AINEBYONA MARVIN (S20B32/017) & ADRIKO DERRICK (S19B32/629)		Stirling	
PROJECT :		INVESTIGATING THE USE OF LINEAR DENSITY POLYETHYLENE IN BITUMEN TO IMPROVE THE PERFORMANCE OF ASPHALT PAVEMENTS ALONG LONGITUDINAL SLOPES			
8% LLDPE					
SUMMARY OF A/C 20 TEST RESULTS					
		BITUMEN CONTENT			4.9
MARSHALL MIX TEST RESULTS AFTER MIX				ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW				1.8	2—4
MARSHALL STABILITY 75BLOWS				25.5	9-18
MARSHALL AIR VOIDS 75BLOWS				8.3	3—5
VOIDS IN MINERAL AGGREGATES				18.4	>14%
VOIDS FILLED WITH BINDER				54.7	65—75%
RATIO		STABILITY/FLOW		13.5	>2.5



Appendix B : Pictorial for Laboratory Work



Figure 23 LLDPE Granules



Figure 24 Sample collection for bitumen



Figure 25 Adding LLDPE to bitumen



Figure 26 Mixing LLDPE with bitumen



Figure 27 Modified asphalt mixture



Figure 28 Marshal compaction



Figure 29 Modified asphalt cores



Figure 30 Marshal Stability and Flow test



Figure 31 ITS Dry



Figure 32 ITS Wet