EVALUATING THE RUTTING RESISTANCE OF ASPHALT CONCRETE MODIFIED WITH ORGANO-PHILIC MONTIMORILLONITE NANO CLAY (OMMT)

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ABSTRACT

Asphalt pavements are required to have long-term performance and durability to keep highway traffic safe and protected from damage from serious failures such as rutting which is described as the permanent deformation of the pavement surface in the area of the wheel path (Huang, 2012).This was the primary reason this research was conducted based on the idea that OMMT could potentially be used to increase the mechanical and volumetric properties and, therefore, the rutting resistance of the asphalt mixture. Unlike previous studies that concentrated on using montmorillonite in its untreated form, this research investigated the use of surface-modified OMMT to improve OMMT compatibility with the bituminous binder. Results from the laboratory indicated that adding 1% OMMT by weight of aggregate achieved significant improvements in the asphalt mixture's Marshall Stability (17.2 kN) and Flow Value (3.6 mm) as well as the Air Voids Content (4.2%), Voids in Mineral Aggregate Value (15.3%), Voids Filled with Bitumen Value (72.4%), and Bulk Density Value (3.352).

A comprehensive literature review identified the mechanisms that cause rutting in pavements and evaluated the structural response of pavements to loading, and indicated that the physical and performance-related characteristics of the asphalt mixtures tested were adequate to meet asphalt pavement performance requirements and supported an increase in their deformation resistance. Additionally, the standard mechanical tests indicated that adding OMMT to the asphalt mixture hindered rutting and created a more uniform distribution of applied loads. These results suggest that the use of Binders that use Nanotechnology such as OMMT is a more efficient method to increase the load-carrying ability of Ugandan Highways, allowing them to last longer and reduce maintenance expenses.

APPROVAL

This is to certify that my Project Proposal Report entitled "Evaluating the Rutting Resistance of Asphalt Concrete Modified with Organo-philic Montmorillonite Nano clay" is submitted as Partial Fulfillment of the Degree of Bachelor of Science In Civil & Environmental Engineering Program at Uganda Christian University.

Signature:……………………………….

Date: ……………………………………….

ENG. DR. MORRIS OLENG

ACADEMIC SUPERVISOR

DECLARATION

The Report represents my Original research, work and findings under the direction of My Academic Supervisor. The report has never been submitted to another institution or university for any reason. All sources and references that were used to develop this report have been credited in full detail.

Signature: ……………………………….

Date: ……………………………………….

GAMUKAMA MICHAEL

DEDICATION

I would like to dedicate this report to my parents, teachers and mentors for their continued support, patience and guidance throughout my academic career. The encouragement I received from you, along with the confidence you had in me, has been a major motivating factor in my studies. I consider this accomplishment to be a reflection not only of the hard work I have put forth, but also of all the part you have played in supporting me. Thank you for everything

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ABBREVIATIONS AND ACRONYMS

AC - ASPHALT CONCRETE

ACV - AGGREGATE CRUSHING VALUE

AIV - AGGREGATE IMPACT VALUE

HMA - HOT MIX ASPHALT

ITSR - INDIRECT TENSILE STRENGTH RATIO

LAAV - LOS ANGELES ABRASION VALUE

TFV - TEN PERCENT FINES VALUE

VFB - VOIDS FILLED WITH BITUMEN

VIB - VOIDS IN BITUMEN

VMA - VOIDS IN MINERAL AGGREGATES

MMT - MONTMORILLONITE NANO CLAY

OMMT - ORGANOPHILIC MONTMORILLONITE NANO CLAY

UNRA - UGANDA NATIONAL ROADS AUTHORITY

XRD - X-RAY DIFFRACTION

CHAPTER ONE: INTRODUCTION AND BACKGROUND

Road infrastructure is vital to national economic growth as well as to the social development of any country including Uganda. Through its ability to enable trade and mobility and access to essential services through its road network system, Uganda is able to grow its economy. In Uganda, the road network consists mostly of flexible pavements made of conventional bitumen (UNRA, 2023), and serves as the backbone of the country's transport sector. Unfortunately, premature failure of flexible pavements from the effects of environmental conditions such as cracking, rutting and potholes continues to be a problem causing increased costs for maintenance, safety concerns, and decreased economic activity (Mugo et al., 2021).

The mechanical properties of asphalt concrete constitute a significant portion of the performance of flexible pavements. Heavy traffic on flexible pavements exerts repeated axial loadings and therefore flexible pavements must be able to withstand the effects of these loads. The bitumen component of a flexible pavement must retain enough strength and elasticity to resist both permanent deformation and crack fatigue. However, most standard bitumen and its related composites typically do not have adequate mechanical strength to withstand the stresses associated with heavy vehicle loads,which leads to pavement detoriation. Additionally, bitumen is susceptible to thermal and water damage, which further reduces the load response capability of the pavement and enables more frequent repair and maintenance of flexible pavements (Apeagyei et al., 2018; Kisaaka et al., 2022).

Recent advancements in nano technology of clay have shown montmorillonite (MMT) is a viable addition (or modifier) to asphalt. The 2:1 silicate structure of MMT combined with its vast surface area allows MMT to be dispersed within the binder (asphalts) and to interact with the binder at a much greater rate than previously available MMT to create a matrix of intercalated nanoparticulates. Intercalated nanoparticulates prevent freedom of movement of the asphalt-bound molcules; therefore, increasing the stiffness and shear strength of the asphalt-bound products and improving thermodynamic (or thermal) stability compared to non-treated MMT forms of montomorillonite.

Historically, researchers have studied montmorillonite using untreated montmorillonite products – typically exhibiting limited compatibility with hydrophobic materials such as asphalt. Furthermore, this investigation involved using organo-philic montmorillonite having the organo-philic grade of MMT treated with organic cation surface modifiers to create organo-philic montmorillonite products with improved dispersion qualities when incorporated into a hydrophobic binder such as asphalt and providing an improved binder performance when subject to changes in load and thermocycle stresses during use under heavy loads.

This research evaluated the additive of OMMT Nano clay, on flexible pavement and increased the structural integrity, stiffness and shear strength of the asphalt products. As a result of incorporating OMMT Nano clay, asphalt products have enhanced resistance to deterioration from repetitive loading or repeated axial stresses imposed by the weight of heavy commercial vehicle traffic.

1.1PROBLEM STATEMENT

The deteriorating of asphalt pavements in Uganda at a rapid rate is because the asphalt cannot support the heavy axle loadings being put on it causing rutting, fatigue cracking and the destruction of the asphalt due to moisture ingress. The creation of ruts is of particular concern because not only does it reduce the longevity of the pavement's service use, but also creates a hazardous situation for vehicles operating on the pavement with the potential to create an accident. The concentrated stress created by axle loadings directly affects the asphalt pavement the weight of the axle acts as a point source of stress on the pavement leading to continual deformations occurring throughout the different layers of the asphalt pavement. With repeated axle loadings, there will be an accumulation of the deformations resulting in an increase of plastic strains developing within the asphalt pavement weakening the overall structural integrity of the asphalt pavement. The result of this is the creation of ruts throughout the wheel path of the asphalt pavement severely reducing the evenness of the pavement surface and increasing the hazard to vehicles operating on said pavement (Zhao, Z et al., 2020). With heavier axle load requirements for heavier trucks on the market today, rutting has become the number one reason for asphalt pavement failure. This has led to the need for the development of new and innovative procedures for managing and maintaining asphalt pavements.

Routine maintenance strategies used along the Mukono-Mbalala section of the Kampala-Jinja Highway have failed to decrease the amount of rutting that continues to occur within the pavement. This section of roadway carries very high volumes of heavy commercial vehicles causing the pavement to be subjected to extremely high axle loadings and causing the development of permanent deformations at the wheel path within the pavement. Due to the amount of overloaded vehicles operating on the Mukono-Mbalala section of the Kampala-Jinja Highway, the rate of accumulation of plastic strains in the asphalt layers has significantly increased; thus causing the rate of rut formation to increase. (Kaloush, Rada, and Youcef, 2001)

This study aims to evaluate the rutting resistance of asphalt concrete modified with organophilic Montmorillonite Nanoclay, with a focus on its performance under heavy axle loading. By investigating the effects of nanoclay modification on the rheological properties and rutting resistance of asphalt mixtures.

1.2MAIN OBJECTIVE

To evaluate the rutting resistance of asphalt concrete modified with organophilic montmorillonite Nano clay

1.2.1SPECIFIC OBJECTIVES

1. To characterize the properties of oganophilic Montimorillonite Nano clay, bitumen and aggregates.
2. To determine the optimum OMMT Nano clay content to be used in the mix
3. To determine the mechanical properties and rutting resistance of organophlic Montmorillonite nanoclay-modified bitumen

1.2.2RESERCH QUESTIONS

1. What are the properties of organophlic Montimorillonite Nano clay, bitumen and aggregates.
2. What is the optimum OMMT Nano clay content to be used in the mix
3. What are the mechanical properties and rutting resistance of organophilic Montmorillonite nanoclay-modified bitumen

1.3SCIENTIFIC JUSTIFICATION

Repeated axle loading causes a permanent deformation of asphalt pavements, resulting in a shorter operational life of the pavement (AASHTO 2017). The usage organo-montmorillonite (OMMT) nanoclay to improve the mechanical properties of asphalt mixtures will increase their resistance to rutting (You et al. 2011). Montmorillonite is a type of clay mineral that has a plate-like structure composed of silicate polymers and when dispersed within the bitumen forms either an intercalated or exfoliated nanostructure (Jahromi & Khodaii 2009). The nanostructure that is formed restricts the movement of molecules thus increasing the stiffness of the binder resulting in less deformation under heavy loading giving an increase in resistance to rutting (Khattak et al 2013).

In many studies, raw montmorillonite nanoclay exhibits promising physical properties that will enhance the ability of the asphalt mixture to withstand high axle loads thus considerably reducing the depth of rutting and increasing the performance of the pavement under repeated loading (Liu et al 2018). The increased mechanical properties of asphalt mixtures modified with nanoclay can also be attributed to improved adhesion of aggregates to the bitumen and their improved stiffness and deformation resistance (Wu et al. 2020).

Overall, the addition of montmorillonite nanoclay into asphalt mixtures can be an effective way to improve the ability of the asphalt mixture to withstand rutting caused by axle loading therefore extending the lifespan of the pavement and reducing maintenance costs.

1.4GEOGRAPHICAL SCOPE

The scope of this study was along the Mukono-Mbalala stretch along the Kampala-Jinja highway

CHAPTER TWO: LITERATURE REVIEW.

2.1ROAD PAVEMENTS

A road pavement is a complex structure that consists of several overlapping layers of engineered materials that are deposited over the underlying natural soil. According to their statement, its primary role as presented by Tom and Rao (2007) is to transfer the vehicle loads that are exerted on the surface to bottom sub-grade in a regulated way. In the field of Highway engineering, there are two common types of road pavements: flexible pavement and rigid pavement. Flexible pavements are made of bituminous binders (that are usually referred to as asphalt cement in North America) mixed with aggregates (Ridmika, 2019). Rigid pavements, on the contrary, use Portland Cement Concrete as a major building material.

2.1.1FLEXIBLE PAVEMENTS: CONSTRUCTION AND BEHAVIOUR.

In flexible pavements, they are meant to take these stresses that occur due to loading of traffic through a stratified interior structure. The sequence normally includes a surface course, base course, a sub-base and sub-grade with each layer having a specific dissipation of load. The bituminous surface layer also has a smooth, stable riding surface and the layers beneath the surface give resistance to the deformation by interlocking together and also by the inherent stiffness of the granular material (Zhang et al., 2023). The combination of the low flexural strength of these constructions allows them to creep under load and, consequently, relieve the peaks of stresses; they regain their elasticity when the load is eliminated, which is explained by the viscoelastic characteristics of bitumen (Khan et al., 2022). Therefore, pavements of this nature need to be resistant to change of climatic conditions, temperature changes, and intrusion of moisture that are some of the factors that hasten their degradation. Material choice, therefore, does not only rely on the functional classification and the intensity of traffic, but depends on the climatic aspect as well (Al-Qadi and Wang, 2021). Sturdiness and maintenance in good time are essential in increasing service life and achieving stability in performance.

2.1.2BITUMEN: CHARACTERISTICS, COMPOUNDS AND APPLICATIONS.

Asphalt, also known as bitumen in American colloquialism, is a petroleum by-product or natural mineral, a visco-elastic hydrocarbon (Read and Whiteoak, 2003). Its behaviour under mechanical loading varies with temperature: at low temperatures of loading and high frequency loading it acts like an elastic solid, and at high temperatures and low loading rates like a viscous liquid (Anderson et al., 2021). This duality demands the emergence of performance enhancing technology. Low-temperature cracking and high-temperature rutting mitigation are of special concern in the tropical climate, like in Uganda, where bitumen is used as the base material in asphalt concrete (Obaid and Al-Mansob, 2022).

2.1.3CHEMICAL AND RHEOLOGICAL CHARACTERISTICS.

Bitumen is a complicated structure of hydrocarbons in the form of aliphatic, alicyclic, and polyaromatic compounds, supplemented by heteroatoms (O, N, S) and traces of metals (vanadium, nickel, and iron) (Lesueur, 2022). According to the Nellensteyn model, this is a structure that is filled with asphaltene particles dispersing in a resin-stabilised maltene (saturates and aromatics) matrix (Petersen, 2009). Important rheological characteristics such as viscosity, penetration, softening point, and ductility have a direct effect on mixing, compaction, and adhesion of aggregates (Airey, 2023). Lack of control in the viscosity may affect aggregate coating, and a dynamic shear rheometer (DSR) test measures the visco-elastic reaction to applied simulated traffic conditions (Bahia et al., 2021).

2.2CHALLENGES AND INNOVATIONS

The world pavement industry is faced with the rising distresses of rutting and cracking, partly due to the increased load on the traffic and extreme climatic conditions (Zaumanis et al., 2023). The developing nations are often characterised by poor maintenance regimes and thus enhance wear and tear faster resulting in the need to use high-performance bitumen. Other advanced methods of analysis, such as Fourier Transform Infrared Spectroscopy (FTIR) and Gel Permeation Chromatography (GPC), can give information about ageing processes and chemical structure (Yin et al., 2021), whereas polymer modifiers, such as styrenebutadienestyrene (SBS) and crumb-rubber, can play an important role in maximising elasticity and rut resistance (Polacco et al., 2022).

2.2.1TERMINOLOGY AND STANDARDS

According to the American Society of testing and materials (ASTM) D8, bitumen is a carbon disulfide-soluble, hydrocarbon-based cementitious substance (ASTM, 2021). In Uganda, the nomenclature is that bitumen (the binder) is differentiated with asphalt, which is a composite product of bitumen and aggregates (UNRA, 2022).

2.2.2RUTTING OF ASPHALT PAVEMENTS: CAUSES, MECHANISM, AND RISKS.

Rutting should be regarded as a severe distress of pavements that are flexible as it causes the decline in performance and poses a threat to the safety. The high truck traffic, tyres pressure, and the growth of traffic quantities contribute to the permanent deformation of asphalt layers in the form of longitudinal depressions along the tracks of the wheels (Wang et al., 2023). Repeated loading of structures with irreversible strain does not only undermine structural integrity but also encourages pooling of water following which activities such as hydroplaning and loss of traction become probable (Almeida et al., 2022).

2.2.2.1TYPES OF RUTTING

Rutting generally breaks off into two major types:

1. Subgrade Rutting - occurs when the underlying layers (sub -grade or foundations) degenerate excessively, which is normally caused by inadequate pavement depth or structural support. The form is more common in thin pavements that have higher loads with the stresses induced by the load exceeding the bearing capacity of the sub-grade (Zhou et al., 2021).

2. Hot Mix Asphalt (HMA) Rutting: This phenomenon develops as a result of plastic deformation of asphalt layer itself, and this may be due to poor mix design, break even due to improper compaction or high-temperature susceptibility. It is in contrast to subgrade rutting where HMA rutting may take place even with constant underlying layers (Khan et al., 2023).

The current research focuses on the rutting of HMA, which is basically caused by recurrent heavy axle weights, excessive pavement temperatures (lowening the asphalt stiffness) and inadequate quality of binder or aggregates that causes poor shear resistance. Highly developed tests of materials and refined mix designs, including polymer-modified binders and high-performance aggregates, have been found to be effective in rutting mitigation of HMA (Ghabchi et al., 2022).

2.2.2.2ASPHALT MIXTURES TESTING PROCEDURES: RUTTING.

Rutting resistance forms a crucial performance indicator of pavements made of asphalt. To test this property, a number of standardised laboratory tests are used. The most common methods are the following:

1. Asphalt Mixture Performance Tester (AMPT)

This apparatus measures rutting susceptibility in terms of flow number, which represents the onset of the tertiary flow or permanent shear deformation and in turn, the dynamic modulus; which is critical for mechanistic-empirical pavement design (NCHRP, 2021). Request testing is done at repeated compressive loads controlled at different temperatures.

2. For example: Scotland Burger Wheel Tracking Machine (HWTD).

By rolling a steel wheel over a specimen of asphalt submerged in water and water, this device simulates the loading of traffic, so it evaluates the level of resistance of moisture damage and rutting. Accelerated deformation in such a setup is an indication of stripping susceptibility (AASHTO T 324, 2021). The device provides a way to track the progression of depth of rut over thousands of cycles.

3. An initial step in prosecuting these firms was completed when the Asphalt Pavement Analyzer (APA) discovered numerous plants applied a component containing elevated tetane levels.<|human|>Asphalt Pavement Analyzer (APA) was one of the first steps taken in piling up charges on these firms when the Asphalt Pavement Analyzer (APA) test found more than a dozen of plants used a compound with higher levels of tetane.

Utilising a loaded aluminium wheel during pressurised hose operation, the APA simulates the traffic condition and determines the rut depth after a predetermined number of cycles and thereby, provides a comparative assessment of the mix's stability (West et al., 2022).

2.3NANOCLAYS: MATERIALS, PREPARATION AND USES.

Nanoclays are a class of nanomaterials of layered mineral silicates, with dimensions capable of being less than 100 nm for each. Their exceptional structures and physicochemical characteristics have received huge interests as useful additives in polymer composites, green remedial efforts, biomedical engineering, and energy storage (Giannakas et al., 2021). The high surface area, exceptional aspect ratio, and tunable surface chemistry of them make them very effective for improving the mechanical strength, thermal stability and barrier properties of composite materials (Kausar, 2022).

2.3.1STRUCTURE AND COMPOSITION

Nanoclays consist of stacked layered units, which mostly consist of:

Tetrahexahedron shapes In this case, each tetrahedron uses 3 oxygen atoms that have an oxygen atom with its neighbors, creating a two dimensional sheet.

Octahedral sheets (aluminium/magnesium- oxygen-hydroxyl = Al/MgO6) - these sheets are covalently attached to tetrahedral layers hence forming a lamellar structure (Bergaya & Lagaly, 2023).

This arrangement of these sheets defines the type of nanoclay (e.g., montmorillonite, kaolinite or halloysite), which in turn affects the properties such as cation exchange capacity and swelling behaviour (Zhou et al.,oda, 2021).

These materials have been integrated to polymer nanocomposites where they are used to enhance tensile strength, flame retardant and gas barrier properties (Kotal & Bhowmick, 2021); used for environmental remediation due to their effectiveness in adsorbing heavy metals and organic pollutants (Unuabonah & Taubert, 2022) in wastewater; and have medical engineering applications such as drug delivery, wound dressing and tissue scaffolds due to their biocompatibility (Gaharwar et al 2023).

2.3.2NANOCLAYS: TYPES, PROPERTIES AND CLASSIFICATION.

Nanoclays are classified into classes according to their electrochemical charge property as anionic, neutral, and cationic, and are classified as follows because they have different structural and functional properties: each class has unique characteristics for a specific use.

A unique feature of anionic nanoclays, in particular of layered double hydroxides (LDHs), is the presence of positively charged octahedral sheets containing divalent (Mg, Zn) and trivalent (Al, Fe) metal cations with charge balancing anions (CO3^2-, NO3-, Cl-) located in the interlayer space (Wang et al., 2021). These nanoclays have excellent anion exchange capacity that make them valuable for environmental remediation particularly for the removal of pollutants like phosphate and arsenic from wastewater. The advantages of them are their thermal stability and pH-responsiveness according to flame-retard polymer uses and controlled drug delivery (Cao et al., 2022; Rives et al., 2023).

Kaolinites and talc are neutral nanoclays that are associated with either 1:1 or 2: 1 layer structures and weakly electrochemical charges. In the 1:1 configuration, one tetrahedral (SiO4) sheet is bonded with a single octahedral (AlO6) sheet. 2:1 configuration is composed of two tetrahedral sheets sandwiching an octahedral (MgO6) sheet (Murray, 2021). Owing to their low surface charge and low swelling capacity, these nanoclays are chemically inert and hence employed in the production of ceramics, paper coatings, as well as reinforcing fillers in polymers composites where there is need for electrical neutrality (Bergaya et al., 2022).

Cationic nanoclays, as montmorillonite and vermiculite, for example, have a 2:1 layered structure with a permanent negative charge (0.2-2 per unit cell) due to isomorphous substitutions in the tetrahedral sheets or in the octahedral sheets (e.g. Al3+ for Si4+). This imbalance of charges is replaced by exchangeable cations (Na+, Ca++, K+) in the interlayer space and gives these materials a high cation exchange capacity. Such attributes make cationic nanoclays especially useful for heavy metal adsorption in water treatment, as rheology modifiers in drilling fluids and reinforcing agents in polymer nanocomposites to improve their barrier properties in food packaging applications (Unuabonah et al., 2021; Giannakas et al., 2022).

The unique properties of these nanoclay types ranging from anion exchange capacity provided by LDHs up to the cation exchange capacity of smectites and chemical inertness of kaolinites enable their use in various fields of applications from environmental engineering through to materials science and biomedical applications.

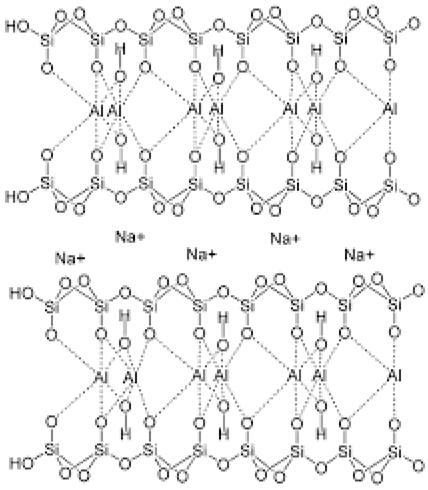


Figure 1TETRAHEDRAL-OCTAHEDRAL SHEETS OF MONTMORILLONITE

2.3.3MONTMORILLONITE

In Montmorillonite, the chemical composition divides nanoclay minerals (Smectite Group) into two different categories based on their structure. The formula is Na, Ca) 0.33 (Al, Mg) 2 (Si 4 O 10) (OH) 2.nH 2 O.Montmorillonite has a unique combination of uses and properties due to its ability to hold cations, swell when wet, and adsorb gases and pa flammables like mercury (Bergaya and Lagaly, 2013). The montmorillonite mineral found in bentonite deposits is derived from the weathering of volcanic ash and can be used as an additive in polymer composites as a replacement for fiberglass to improve the strength of the products and decrease the overall weight of these reinforced plastics. Because of its ability to release water when heated, montmorillonite provides a flame-retardant feature in plastics or coatings that would otherwise burn easily (Kotal and Bhowmick, 2015; Leszczyńska et al., 2021).

Due to its significantly high surface area and Cation Exchange capacity (CEC), montmorillonite can efficiently remove heavy metals and harmful organic pollutants in the environment by sorbing them. Examples of how montmorillonite can be used in agriculture include soil amendment and enhancing soil's ability to retain moisture (Uddin, 2017). Additionally, montmorillonite can act as a catalyst because of its unique ability to support other materials through ion exchange and sol-gel preparation (Zango et al., 2022). Recent work has shown that montmorillonite can enhance the performance of polymer nanocomposites by improving their thermal stability, barrier properties and biodegradation characteristics (Mallakpour et al., 2023), whilst Saba et al. (2021) have shown that montmorillonite can also provide substantial benefits in the automotive and aerospace sectors through the reduction in vehicle weight and improvement in mechanical properties. The unique capabilities of montmorillonite make it a revolutionary material in various construction, packaging and chemical industries, with many ongoing research projects that are developing further applications for montmorillonite using advanced modification techniques (Hussain et al., 2022).

Figure 2 organophilic montmorillonite nanoclay

CHAPTER THREE: METHODOLOGY

3.1MATERIAL SELECTION AND PREPARATION

3.1.1BITUMEN

The grade of bitumen that was used in this study was 60/70 due to its thermoplastic property which causes the material to soften at high temperatures and harden at lower temperatures and used in hot climates because due to its durability against heavy traffic loads.

3.1.2AGGREGATES

Aggregates selected were the ones in the asphaltic concrete wearing course (AC 14). Indicating that the nominal size of aggregates is 14mm. Grading tests on aggregates to ensure that the nominal size of aggregates is 14 mm with reference to HMA 007-02. AC 14 was chosen to be used in asphalt because of its ability to carry loads of up to 10,000 kgs, making it ideal for larger projects where durability and strength are a priority. AC 14 has an excellent skid resistance. The combination of the components in AC 14 creates a surface that is flexible enough to allow for temperature fluctuations without cracking.

3.1.3ORGANOPHILIC MONTMORILLONITE

The OMMT was obtained in its readily modified form from the raw MMT into the fine nano size OMMT from a certified supplier.

3.2To characterize the properties of organophilic Montimorillonite Nano Clay, Bitumen, and Aggregate

3.2.1TEST ON ORGANOPHILIC MONTIMORILLONITE NANO CLAY

The OMMT clay was characterized for its hydrophilic surface properties, ability to absorb and exchange cationic ions, and its reactivity to heat. In order to establish the characteristics of organophilic Montimorillonite Nano clay, X-ray diffraction (XRD) was conducted. This method is an analytical method that does not change the surface of the material being investigated, and is used primarily to determine the atomic and molecular structure of substances that are crystalline in form (Cullity and Stock, 2001; Patterson et al., 2017).

The procedure followed to conduct X-ray Diffraction (XRD) analysis on Organophilic Montmorillonite (MMT) Nano Clay;

1. A nanoclay sample for XRD analysis was prepared by heating the nanoclay sample into a fine powder, which will provide a random orientation of the crystallites (Patterson et al., 2017) and prepared for inclusion in the sample holder.

2. Once placed into the sample holder, the sample holder was mounted to a goniometer stage that was a part of the XRD instrument.

3. Once the sample holder was mounted to the goniometer stage, the XRD instrument consisted of an X-ray source, a sample holder, and a detector.

4. The X-ray source emitted X-rays that passed through the sample holder, which in turn created a series of diffraction patterns that were captured by a detector (Cullity and Stock, 2001). The sample was exposed to X-rays for a specified length of time as described by the capabilities of the XRD instrument.

In order to characterize the nanoclay's crystalline structure and phase composition, diffracted X-rays were recorded and plotted as a function of the angle (2θ) between the incident beam and the detector site. The resulting plot, intensity versus 2θ, contains valuable information about the nanoclay's configuration, as reported in Bergaya and Lagaly (2013). Subsequently, the intensity versus 2θ plots were analysed using software programs, including either DIFFRAC.SUITE or HighScore Plus (Bruker, 2021). At the conclusion of IDF and XRD analyses of the sample nanoclay, the analyst can derive an estimate of the sample's crystallite sizes and lattice parameters, as well as assess whether the sample contains any impurities.

3.2.2CHARACTERISATION OF BITUMEN

The properties of bitumen were obtained through, the penetration test (ASTM D5-86), softening point (ASTM D36-70), viscosity (ASTM D2170).

3.2.2.1THE PENETRATION TEST ASTM D5-86.

The Penetration Test consists of a standardized experiment to determine how deep a weighted (50 g) tapered needle, placed vertically above the sample in a temperature-controlled environment at 25°C, will penetrate into the sample during five seconds of exposure to the temperature. A high penetration rate indicates that the sample is soft; conversely, a low penetration rate indicates that the sample is relatively hardness.

3.2.2.2SOFTENING POINT TEST. ASTM D 36

Softening point is the temperature at which bitumen attains a particular degree of softening under specified conditions of the test. This helps in classifying bitumen, evaluating tendency of the material to flow at elevated temperatures encountered in service.

3.2.2.3SPECIFIC GRAVITY OF BITUMEN. ASTM D-70.

The specific gravity is integral in determining the appropriate bitumen grade for asphalt mix designs, influencing the selection of penetration or viscosity grades and also plays a crucial role in calculating volume-correction factors, ensuring accurate volume measurements in mix designs. The specific gravity establishes compatibility between bitumen and aggregates, influencing coating, adhesion, and overall performance of the asphalt mixture.

3.2.3TESTING ON AGGREGATES

Aggregates were evaluated using the following techniques: BS 812-P103-1 (Sieve), BS 812-112 (Impact), and BS 812-113 (Abrasion).

3.2.3.1SIEVE AND GRADING TESTS, BS 812-P103-1:

Sieve and grading tests are used to classify different types of aggregates based on particle size. From this information, the predominant aggregate will be determined, i.e. gravel, sand, silt, clay; the degree to which each of the four groups contributes to the aggregate's mechanical properties can be estimated.

3.2.3.2AGGREGATE CRUSHING VALUE BS 812: PART 110: 1990:

The strength of aggregates can be determined by performing the Aggregate Crushing Value (ACV) test. An aggregate's ACV indicates how resistant it will be to crushing under an increasing load; the ACV is determined by taking a sample from the crushed material and passing it through a specified size sieve with 400 kN.

3.2.3.3LOS ANGELES ABRASION TEST - ASTM C 131-89:

Repeated loading on pavement by vehicles exhibits a wear effect on stones on the pavement surface. Hence the most important physical property to consider is the resistance to wear, (sometimes referred to as hardness), of the aggregate when used in the wear course of asphalt pavements. Performance of this test allows for the evaluation of mineral aggregate degradation due to combined actions of abrasion.

3.2.3.4SPECIFIC GRAVITY OF AGGREGATES ACCORDING TO BS812 PART 2: 1975

This test used to calculate the volumetric properties of an asphalt mix. This includes air voids, VMA (voids in mineral aggregate) and VFA (voids filled with asphalt).

3.2.3.5THE AGGREGATE IMPACT VALUE, AS DESCRIBED IN BS812 PART 112: 1990.

This test is an indicator of how resistant aggregate is to sudden shock or impact. Road-building aggregates must have sufficient strength to support the loads placed on them by the wheels of vehicles travelling over them.

3.3To determine the optimum organophilic MMT Nano clay content to be used in the mix

To identify how much organophilic MMT nano clay to use in a mix the following tests were conducted. Samples of asphalt with different amounts of bitumen were made and compacted. Each of these asphalt mixes were tested for ; stability (ASTM D6927), flow (ASTM D6927), Bulk density (ASTM D2726), air voids, and VMA (ASTM D2041) per sample. The bitumen content yielding the best combination of performance were taken as the optimum bitumen content used in that particular sample.

A systematic testing procedure was used to determine the maximum percentage of organophilic montmorillonite nano clay to add to asphalt mixes. The aim is to determine the percentage of OMMT nano clay that enhances the performance of the bitumen.

Preparation of Samples

- Sample asphalt mixtures containing various percentages of OMMT Nanoclay 0%, 0.5%, 1% and 1.5% by weight of of the total mix.

- . For each OMMT percentage, 392 g of 60/70 penetration grade bitumen which is 4.9% of the total 8,000g mix was heated to between 150˚C and 160˚C and rotation of 3000rpm for 20-30 minutes to enable adequate mixing.

- Asphalt samples were then compacted using marshall compactors; (ASTM-D 6926).

2. Key Tests Used to Evaluate Performance

The additional tests that were performed on each compacted asphalt sample, were used to determine the optimum level of OMMT Nanoclay content;

3.3.1MARSHALL STABILITY AND FLOW TEST (ASTM-D 6927)

The Marshall Stability and Flow Test measured the compressive strength of an asphalt mixture and represented its resistance to deformation under load. In the Marshall Stability Test, 60 degrees celcius is applied as the temperature under simulated high temperature pavement conditions, and a consistent loading rate of 50.8 mm/min up to failure is used to perform the Marshall Stability Test. The test yielded two parameters, the Marshall Stability (in Kilo-Newtons) as well as the Marshall Flow (in mm). The higher the representative Marshall Stability is, the more rut resistant the asphalt is expected to be. The representative flow should ideally be between 2-4 mm, which indicates a balance between Stiffness and Flexibility, to avoid excessive brittleness or deformation of the product.

3.3.2BULK SPECIFIC GRAVITY & DENSITY (ASTM D2726)

The test conducted under ASTM D2726 proves the existence of a compatibility and voids within an asphalt mixture. The process of weighing a sample in both air and in water under saturated surface-dry provides the bulk specific gravity of the asphalt concrete or Gmb. A higher value of Gmb signifies that there is greater compaction and less voids filled with air, which also promotes higher durability and provides greater resistance to moisture entering the material. Proper compaction allows for the mix to be able to withstand the stresses of traffic without experiencing excessive deformation.

3.3.3AIR VOIDS (AV) & VOIDS IN MINERAL AGGREGATE (VMA) (ASTM D3203 / D2041)

The voids within an asphalt mixture are a vital part of the overall durability and resistance to moisture damage. The Void in Mineral Aggregate test and Air Voids test are performed per ASTM D3203 and ASTM D2041 respectively. The Air Voids (AV) are the percentage difference between the theoretical maximum density and the bulk density and should be in the range of 3 – 5 %. Too few air voids will cause rutting and too many will create a situation where moisture will penetrate the material. The VMA (Voids in Mineral Aggregate) test determines the amount of void space between aggregates and is filled with binder and air. The VMA should be at least 14% to be considered sufficient to coat the aggregates with binder to prevent premature cracking and stripping.

3.3.4DETERMINING OPTIMAL OMMT CONTENT TO BE ADDED.

The amount of OMMT in Bitumen was determined to be suitable based on the results from testing of samples with varying levels of MMT. The best type of OMMT mixture had;

1. Highest Marshall Stability within the specified standards indicating that the sample has the ability to resist excessive amounts of rutting.

2. A Flow value between 2-4 mm. This indicated that there is enough flexibility in the sample while also providing adequate resistance to deformities when placed under traffic loads.

3. An Air Voids percentage of 3-5% and VMA percentage of >= 14% to meet the require value necessary for long-term performance.

4. Highest ITS and TSR strengths represented superior cracking and moisture resistances of samples containing OMMT.

3.4To determine the mechanical properties and rutting resistance of Organophilic Montmorillonite nanoclay modified bitumen.

3.4.1THE INDIRECT TENSILE STRENGTH (ITS) TEST (ASTM D6931)

This test provided information on a mixture's ability to resist crack formation and indicated moisture effects on the sample through the application of a diametrical tensile load until failing to measure the ITS value of the sample to show the degree of tensile resistance capacity of the mixture.

The ITS (Indirect Tensile Strength) value is an indicator of how well an asphalt mixture can resist thermal and fatigue cracks. A higher ITS value indicated that a mixture was more resistant to cracking due to either heat or fatigue.

3.4.2MOISTURE SUSCEPTIBILITY (AASHTO T 283 / ASTM D4867)

The Moisture Damage Test also known as the TSR test was used to measure the effect of moisture on the Tensile Strength Ratio (or TSR) of a modified asphalt mixture. It involved subjecting prepared sample pieces of the mixture to freeze-thaw cycles before analyzing their indirect tensile strength (ITS). In this test, the minimum prescribed TSR value is 80%.

The combined effect of both these tests indicated that when modified with nanoclay, the mixture was able to maintain sufficient tensile strength even after exposure to water. In addition, because of their unique chemistry, nanoclays tend to enhance the performance of the variants used for asphalt cement's adhesion to treated aggregates while also improving the ability of those aggregates to drain away moisture efficiently.

Asphalt mixtures made with Nano Clay were tested to determine if it is effectively utilized to increase their performance for “Rutting Resistance” (Permanent Deformation) & “Stripping Resistance” (Water Damage). Standard tests were utilized to evaluate Asphalt Mixtures. Following are summaries of some of the various types of tests and testing procedures:

3.4.3WHEEL TRACKING TEST (EN 12697-22/AASHTO T 324/ASTM D 7064)

The Wheel Tracking test (WTT) was developed to determine the amount of vertical deflection of the Surface of Asphalt Specimens caused by the repeated application of Load, in conjunction with the simulation of real-world traffic conditions, to evaluate the amount of Rutting (Vertical Deformation) of the Specimen being tested. During the test, a Load Wheel is rolled across a Compacted Slab of Asphalt or a Cylindrical Sample held at a controlled Temperature (50-60°C) to determine the Rutting Depth of the asphalt material. The WTT test consists of numerous Repetitive cycles, and the Data collected during the WTT test is utilized to determine the Rate at which Ruts will form, thereby providing an estimate of the Rut Resistance of the asphalt mixture being evaluated. Generally, mixtures that are modified with Nano Clay demonstrate reduced Rut Depths attributed to the increase in stiffness and stability of the Binder material.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

The results from this study, presented in this chapter, show how various tests were completed for objectives one through three and the outcome associated with them. The goal of objective one was to determine the characteristics of organophilic montmorillonite, bitumen, and aggregate materials; therefore, tests were performed on these materials using different test methods including: X-Ray diffraction, aggregate crushing, aggregate impact, ten percent fines, flakiness index and grading for aggregate testing and softening point, penetration, flash point and specific gravity for testing of bitumen material.

4.2PROPERTIES OF BITUMEN

TABLE 1PROPERTIES OF BITUMEN

BITUMEN TESTS	ACHIEVED	BRITISH STANDARDS	REMARKS
PENETRATION	68mm	60-70mm	Within range
SOFTENING POINT	53.5^{0}C	49-65^{0}C	Within range
BITUMEN AFFINITY	97%	>95%	Compliant - strong adhesion between bitumen and aggregates.
SPECIFIC GRAVITY	1.025	1.01-1.06	Within range
VISCOSITY	270Pa.s	200-400Pa.s	Compliant - sufficient workability and stability during laying.

The table above shows a summary of results obtained from tests done which include; Softening Point, Penetration, Specific Gravity for bitumen compared to the standards and are explained below;

4.2.1PENETRATION OF BITUMEN

Test results from the penetration test reveal that the average (0.1 mm) penetration value of this research's bitumen (60/70) is 68 and indicating that it is located within the British Standard's specification of 60-70. The individual readings of the penetration test show little variation from each other, indicating that the produced bitumen is a uniform and stable binder. Furthermore, the results show that the penetration value of the binder is close to the upper limit of the specification and is indicative of its ability to maintain a moderate degree of softness (at 25°C) for use during the mixing and compaction process while also offering adequate adhesion properties between the aggregates. In general, this is typical of binders used in tropical regions where binders must be flexible enough to accommodate low-temperature fluctuations throughout the day (Read and Whiteoak 2003).

Table 2 PENETRATION OF BITUMEN

TEST NO	1	2
PENETRATION (5 SECONDS) AT 25^{O}C	66 68 68	69 67 66
AVERAGE RESULTS (^{0}C)	68	
BRITISH STANDARDS	60-70	

4..2.2BITUMEN SOFTENING POINT TEST

This involves the determination of the semi-solid-to-fluid temperature of bitumen after heating, under controlled conditions. The average softening point was determined from the softening point of two rings (Ring-and-Ball). Ring 1 softened to 53°C; Ring 2 softened to 54°C. The average softening point was 53.5°C. This softening point was very much in line with the temperature range for bitumen with a penetration grade of 60/70 (49-56°C) as outlined by British Standards (BS 2000, 2003). The close agreement of both ring results indicated good thermal uniformity and consistency between the binder samples, thus indicating that prior to the softening point determination there was no indication that the binder had experienced significant oxidation and/or contamination.Softening point results indicate that the binder is relatively stiff under moderately high pavement temperatures. As such, a higher softening point in hotter climates is preferred to assist in limiting the asphalt's potential for excessive flow or rutting under higher temperatures (Huang, 2012).

TABLE 3SOFTENING POINT OF BITUMEN

RING 1				RING 2		
TIME (MINUTES)	TEMP (^{0}C)	TEMP RISE (^{0}C)		TIME (MINUTES)	TEMP (^{0}C)	TEMP RISE(^{0}C)
0	2	2		0	2	2
1	7	5		1	7	5
2	11	4		2	11	4
3	15	4		3	15	4
4	20	5		4	20	5
5	24	4		5	24	4
6	29	5		6	29	5
7	34	5		7	34	5
8	38	4		8	38	4
9	44	6		9	44	6
10	49	5		10	49	5
11	50	1		11	50	1
12	53	3		12	54	4
SOFTENING POINT	53			SOFTENING POINT	54	
AVERAGE VALUE	53.5					
RECOMMENDED (BRITISH STANDARDS)	(49-56)^{0}C					

4.2.3BITUMEN SPECIFIC GRAVITY

Bitumen specific gravity testing provided a Specific Gravity of 1.025. This value falls within the British Standards minimum to maximum limit of 1.01 - 1.06. A high specific gravity indicates that the bitumen has a suitable density relative to the water and will have good quality and refined properties. Additionally, the specific gravity of an asphalt mix is important as it will have an impact on the volumetric design, binder content determination, and mixture stability (Huang, 2012). A Specific Gravity of approximately 1.02 indicates that the bitumen has not been subjected to too much dilution of the lighter fractions or too much aging and therefore both of these factors will greatly affect its performance. The specific gravity value obtained from this study fit well within the expected specification limits, indicating that the binder used in this research study is viable for producing dense, well-compacted asphalt concrete.

4.3PROPERTIES OF AGGREGATES

Table 4 PROPERTIES OF AGGREGATES

AGGREGATE TESTS	ACHIEVED	BRITISH STANDARDS	REMARKS
WATER ABSORPTION	0.20%	<2%	Compliant - Very low, indicating high-quality aggregate
SPECIFIC GRAVITY	2.621	2.5-2.9	Compliant - Within acceptable range
TEN PERCENT FINE VALUE(DRY)	255.6KN	>110KN	Compliant -Strong aggregate
TEN PERCENT FINE VALUE(WET/DRY)	89%	>75%	Compliant - Retains strength under wet conditions
AGGREGATE CRUSHING VALUE	15.80%	<30%	Compliant - High strength aggregate
AGGREGATE IMPACT VALUE	15.0%	<30%	Compliant - Good resistance to impact
LOS ANGELES ABRASION VALUE	16.80%	<40%	Compliant - Excellent resistance to abrasion/wear
FLAKINESS INDEX	19.40%	<25%	Compliant - Within acceptable limits

The table above shows a summary of results obtained from tests done which include; Aggregate Crushing Value, Aggregate Impact Value, Ten Percent Fines Value, Flakiness Index and Grading for aggregates compared to the standards and are explained below;

4.3.1GRADATION OF AGGREGATES

Gradation analysis was performed to evaluate if the combined aggregates are within the recommended range of particle sizes for asphalt concrete manufacturing. The blended final gradation corresponds closely with the target gradation envelope showing an excellent balance of coarse aggregate/fine aggregate/mineral filler elements.

From the larger sieve sizes (20 mm and 14 mm), the percentage that passed through falls into the acceptable specification limits indicating that there is sufficient quantity and coarsening of the coarse aggregates. The intermediate sieve sizes (10 mm, 5 mm, and 2.36 mm) showed that the gradation remains consistent with the target curve displaying a gradual progression of particle size.

This gradation consistency ensures that the aggregate particles lock together properly providing for greater strength and stability.

Regarding the finer fractions of aggregate, (0.6 mm, 0.3 mm, and 0.075 mm sieve sizes) the amount of retained material is within the recommended limits. The fine aggregate content is below the maximum limit which indicates the asphalt concrete is unlikely to have excessive demand for a binder, inadequate stability, or poor moisture resistance. At the same time, there were sufficient fines present to fill voids and promote a dense, well-graded structure.

Table 5 GRADATION OF AGGREGATES

Sieve Size	14/20MM	10/14MM	6/10MM	0/6MM	FILLER	Theoretical actual	TARGET GRADING	BRITISH STANDARDS
28	100	100	100	100	100	100	100	100
20	98.6	99.4	100	100	100	100	90	80-100
14	18.7	70.3	99.4	100	100	76	70	60-80
10	1.6	18.7	93.9	100	100	65	60	50-70
5	0.4	1.3	6.6	83.0	100	47	46	36-56
2.36	0.4	0.9	5.1	53.7	100	31	36	28-44
1.18	0.4	0.8	4.3	37.4	100	22	27	20-34
0.6	0.4	0.7	3.6	27.3	99.8	17	21	15-27
0.3	0.4	0.6	3.0	19.1	95.8	12	15	10-20
0.15	0.4	0.5	2.5	12.0	79.7	8	9	5-13
0.075	0.4	0.4	2.2	6.5	58.4	5	4	2-6

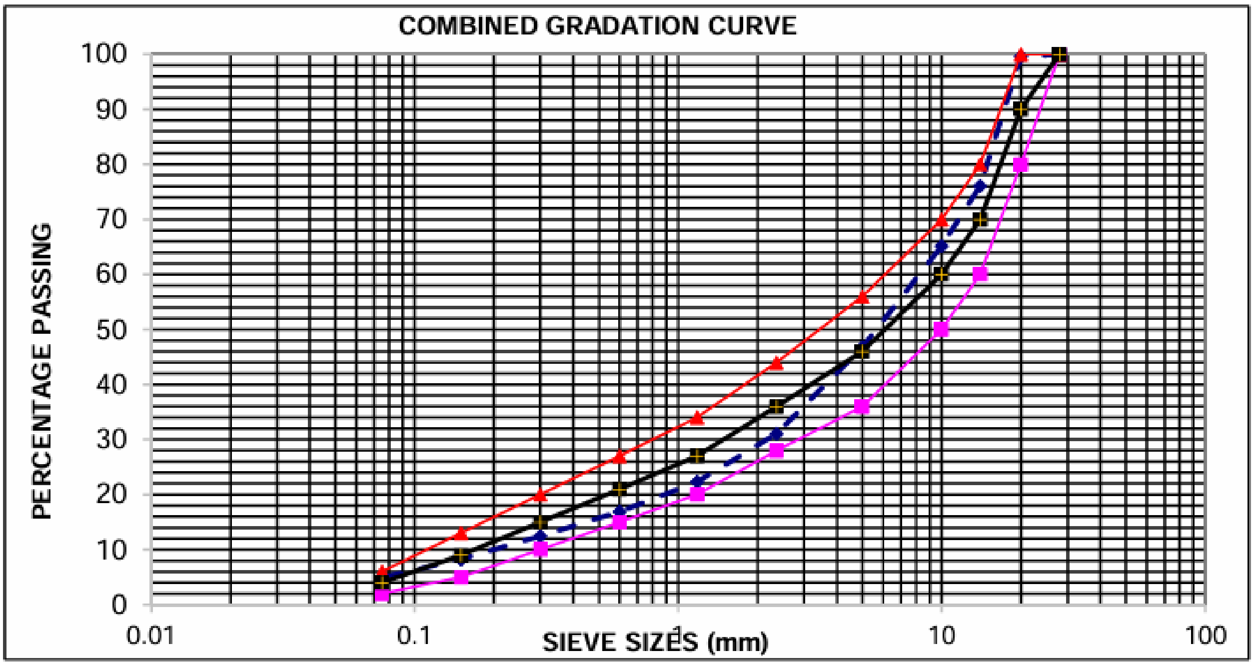


Figure 3 COMBINED GRADING CURVE

4.3.2AGGREGATE CRUSHING VALUE (ACV)

Aggregate crushing value is an indicator of the aggregate's ability to withstand pressure as it is a measure of how much an aggregate can tolerate compressive loads without collapsing. As the test progresses, an aggregate sample is progressively loaded until it breaks. After the sample has broken, the total amount of fines produced is measured. The testing method conforms to the requirements set forth in BS 812 Part 111:1990. An aggregate crushing value of 15.8%, which is lower than the specified limit, indicated that the aggregates can withstand gradual loading with minimal breakage. Therefore, there will be fewer fines produced during construction, impacting the pavement's durability. Furthermore, fewer fines will be produced during Marshall compaction testing, which may adversely affect the mix design by altering the stability and volumetric properties of the mix. Aggregates with lower aggregate crushing values produce stronger aggregates.

Table 6 AGGRGATE CRUSHING VALUE

SAMPLE	1	2
WT. BEFORE CRUSHING (g)	2751.1	2753.2

WT. WT. AFTER CRUSHING (g)	2751	2752.4
WT. RETAINED AFTER CRUSHING (g)	2316	2318.9
WT. PASSING SIEVE 2.36mm	435.1	434.3
A.C.V (%) (D/B)*100	15.8	15.8
AVERAGE RESULTS %	15.8	
BRITISH STANDARDS	<30%	

4.3.3AGGREGATE IMPACT VALUE (AIV)

The 15.0% Aggregate Impact Value exceeded the target and indicated that the aggregates have enough strength to withstand shock due to sudden impact. So, there will likely be fewer fine particles produced that could affect the long-term durability of the roadway. There will also likely be fewer fine particles formed when conducting Marshall Compaction tests that could negatively impact both stability as well as volumetric properties of the mix, resulting in an inaccurate mix design. The lower the Aggregate Impact Value, the greater the aggregate's resistance to impact.

Table 7 AGGREGATE IMPACT VALUE

SAMPLE	1	2
WT. BEFORE TEST (g)	347.5	337.7
WT. WT. AFTER TEST (g)	344.5	337.5
WT. RETAINED AFTER TEST (g)	296.2	286.8
WT. PASSING SIEVE 2.36mm	51.3	50.9
A.I.V (%) (D/B)*100	14.9	15.1

AVERAGE RESULTS %	15.0
BRITISH STANDARDS	<30%

The expected value of the aggregate impact value (AIV) was calculated using the average of approximately fifteen percent average loss of all samples, which is significantly lower than the maximum allowed under British Standards of 30% for aggregate used to make up asphalt concrete. The low values of AIV exhibited by the tested materials indicate that the materials are tough and can withstand sudden shocks and impact loads. The very small difference in aggregate impact value between the two representative samples further reinforces the general quality consistency of the material. Therefore, aggregates have sufficient strengths to support the dynamic loads that pavements are subjected to.

4.3.4SPECIFIC GRAVITY OF AGGREGATES

The specific gravity of coarse aggregate particles used in the asphalt concrete mix was determined through a laboratory-based procedure. The results indicated that the bulk specific gravity of the coarse aggregates was 2.621, and it was also determined that the apparent specific gravity of the coarse aggregates was 2.638. Therefore, the SSD basis for this aggregate was determined to be 2.627, and the measured water absorption rate of 0.2% indicates that these aggregate particles possess a dense structure with very few intern particles about them, which provide better protection from continued crushing and wear from traffic loads than do the more porous aggregates.

Table 8 SPECIFIC GRAVITY OF AGGREGATES

Aggregate size	20-14mm	14-10mm	10-6mm	6-0mm	Filler
Bulk SG	2.621	2.632	2.633	2.632	2.653
Combined SG	2.634				
Water Absorption (%)	0.2	0.4	0.5	0.6	

Combined (%)	0.4
Standard (BS 812-2: 1995)	<2%

The measured water absorption value of 0.2% indicated that this aggregate has a low level of porosity and is, therefore, unlikely to absorb water. BS 812: Part 2 (1995) states that aggregates that absorb less than 1% by dry weight of water are classified as high-quality materials and that a high rate of water absorption can result in a poor bond with bitumen and early failure from stripping due to water (Roberts et al., 1996). Therefore, these aggregates provide an excellent combination of durability and moisture resistance needed to maintain long-term pavement stability.

The amount of water that can be absorbed from the binder of the aggregates and the amount of aggregate that is present in the asphalt concrete will affect its performance. The values of water absorption refer to the total number of aggregate particles that have been in contact with water. The values should not exceed 2% of the weight of the aggregate for the purpose of using them in asphalt concrete surfacing. Therefore, the aggregates tested are acceptable for use based upon their specific gravity and water absorption.

According to standard BS 812:105, aggregates, which contain more than 25% flaky or elongated particles, should not be used as coarse aggregates. The coarse aggregates t contained less than 19.40%, flaky or elongated particles hence are more efficient and desirable for use in asphalt concrete surfacing. This means that the aggregates are more angular in shape, allowing for more interlocking to occur between the aggregates, providing better stability and volumetric properties to the asphalt concrete.

4.3.5TEN PERCENT FINES VALUE (TFV)

It is preferable for aggregates to have a high "Ten Percent Fines Value," (TFV) because this indicates that they are highly resistant to crushing, which positively contributes to the quality, durability, and performance of the asphalt concrete. For both the dry and wet conditions, tested aggregates had a TFV of greater than

110 kN, which is the minimum recommended ten percent fine value for asphalt concrete.

The High 10% Fines Value of the aggregates is preferred because that number indicates how much the aggregate can withstand compression forces (crushed). Aggregates that are strong enough to carry the weight of the asphalt will produce a more robust and durable overall mixture of materials to withstand traffic loads. The results for both dry and soaked conditions have been included in Tables 9 and 10, respectively.

Table 9 10% FINES VALUE DRY OF AGGREGATES

TEST NO	1	2
CRUSHING FORCE (KN)	267	267
WT. OF AGG AFTER CRUSHING,M1 (g)	2746	2754.2
WT. OF AGG RETAINED ON 2.36mm SIEVE, M3 (g)	2466	2463
WT. OF AGG PASSING THROUGH 2.36mm SIEVE, M2(g)	293	291.3
TEN % FINE VALUE (M=M2/M3*100)	10.7	10.6
AVERAGE RESULTS	10.7	
AVERAGE CRUSHING FORCE (KN)	267	
TFV DRY (KN)	255.6	
STANDARD (BS 812-111: 1990)	>110KN	

Table 10 10% FINES VALUE SOAKED OF AGGREGATES

TEST NO	1	2
CRUSHING FORCE (KN)	267	267
WT. OF AGG AFTER CRUSHING,M1 (g)	2792.2	2770.6
WT. OF AGG RETAINED ON 2.36mm SIEVE, M3 (g)	2443	2425
WT. OF AGG PASSING THROUGH 2.36mm SIEVE, M2(g)	349.2	345.6

TEN % FINE VALUE (M=M2/M3*100)	12.6	12.5
AVERAGE RESULTS	12.5	
AVERAGE CRUSHING FORCE (KN)	267	
TFV SOAKED (KN)	226.6	
STANDARD (BS 812-111: 1990)	>110KN	

Dry and saturated revisit obtained TFV more than 110kN, which is the minimum value for aggregates used in asphalt concrete surfacing. In fact, that the W/D strength ratio for the aggregate in table 11 exceeds the recommended value of 75% set out by the British standards indicates that the aggregates still retain substantial strength when subjected to moisture / saturation and therefore will be able to withstand crushing under traffic loading (MoWHC, 2005).

Table 11 WET/DRY RATIO

Sample	Dry	Wet	Wet/Dry ratio
Force (KN)	255.6	226.6	89
Standard (BS 812-111)			>75%

4.3.6LOS ANGELES ABRASION TEST (LAA)

The Los Angeles Abrasion test has evaluated an aggregate's susceptibility to wear, breakdown, or overall abrasion due to the stresses caused by the passage of traffic. The average abrasion value obtained was 16.8% which is much lower than the specified UK maximum of 40% laid out in ASTM C131 and BS 812-11:1990 and therefore confirms that these aggregates have an excellent level of toughness and resistance to mechanical degradation and will be able to meet the demands of heavy pavement applications. Additionally, the fact that these aggregates have such a low abrasion value will help assure users that they will remain intact during the mixing, compaction, and traffic loading processes that occur while vibrating in traffic. This will assist in maintaining the structural stability of the asphalt mixture being formed. (Huang, 2012; Kadiyali & Lal, 2016).

Table 12 LOS ANGELES ABRASION VALUES

Parameter	Sample 1	Sample 2
Weight of material retained on 1 mm sieve	4,155.0	4,165.0
Weight after crushing	4,968.2	4,946.1
Weight of fine material (g)	845.0	835.0
% of wear	16.9%	16.7%
Average	16.8%	
Standard (BS 812-110 1990)	<40%	
Rotational Speed	33 revolution/minute	
Maximum Revolutions	500	
Allowable Time	15 minutes	

The data supports the conclusion that the Mukono Quarry's aggregate material has superior durability and wear resistance, offering superior interlocking performance and, therefore, overall performance, when used in an OMMT-modified asphalt concrete mixture.

4.4Organophilic Montmorillonite nano clay Xray diffractometry

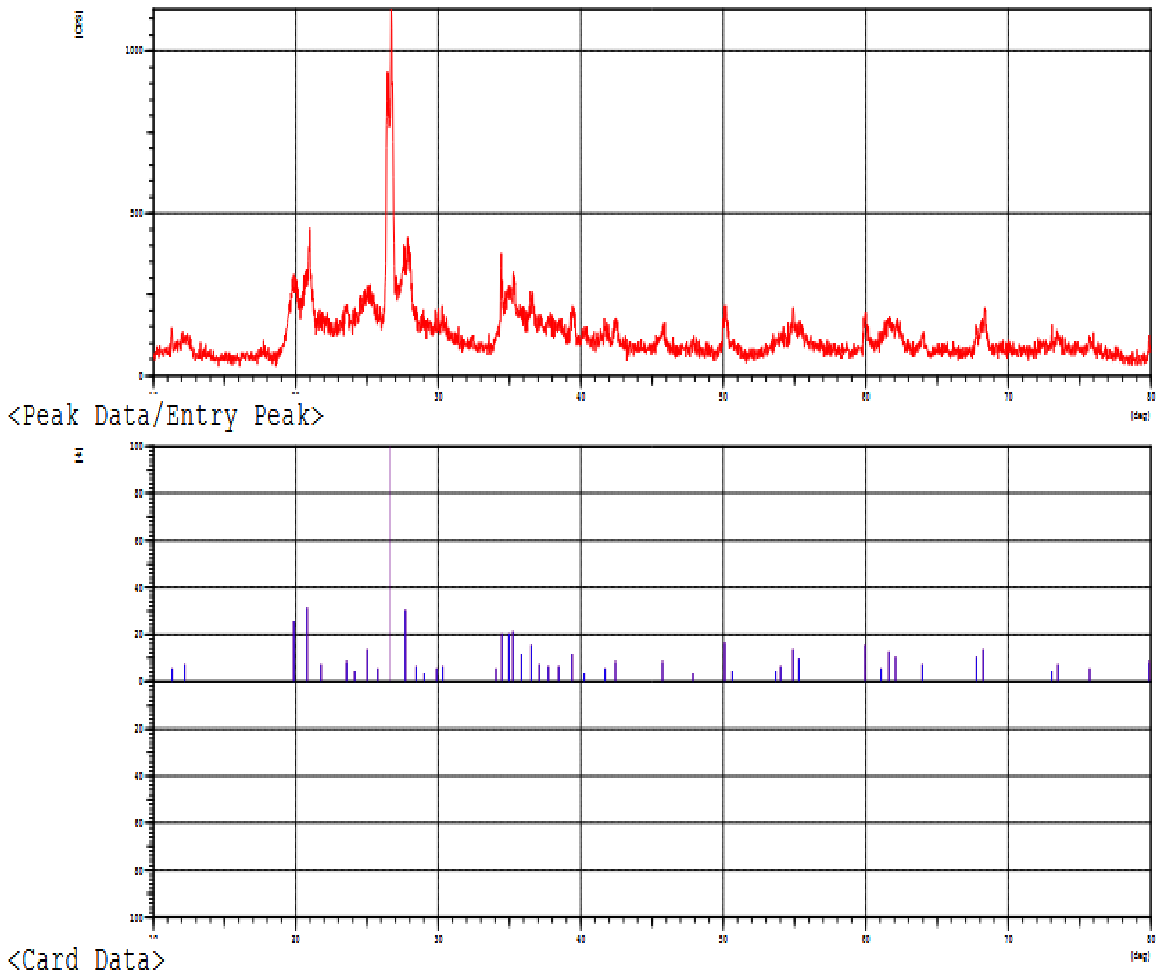


Figure 4 XRAY-DIFFRACTOMETRY OF ORGANOPHILIC MONTMORILLONITE

X-ray diffraction patterns for organophilic montmorillonite illustrate the diffraction patterns associated with montmorillonite. The d-spacings for montmorillonite are represented by distinct peaks at particular 2 theta angles. Montmorillonite has a basal spacing peak at d001, which is a characteristic feature of montmorillonite. The angle and intensity of the d001 peak provide information about interlayer spacing and about montmorillonite dispersion and intercalation in polymers and asphalt. X-ray diffraction patterns support the idea that montmorillonite has a crystalline structure.

If montmorillonite is effectively dispersed and intercalated into asphalt, it is likely to enhance the rutting resistance of the asphalt by changing the viscoelastic properties of the asphalt.

Montmorillonite (D001) is a common component of clays and can be identified by its characteristic 5 to 10° 2θ peak, which corresponds to d-spacings of 1 to 1.8 nm. The sharpness of the peaks may indicate the presence of well-ordered or aggregated structures, whereas broad peaks or shifts may indicate intercalation with mixtures of aspahlt, or partial peeling apart of clay layers.

4.5ASPHALT MARSHALL SAMPLE TESTS

4.5.1MAXIMUM THEORETICAL SPECIFIC GRAVITY (GMM) AND BULK SPECIFIC GRAVITY (GMB)

The Maximum Theoretical Specific Gravity (Gmm) Test provides the specific gravity of an asphalitic mixture without taking into account air voids. Gmm allows us to calculate compaction levels and the volumetric characteristics of the asphalt mixture. The bulk specific gravity test (Gmb) provides the specific gravity of the compacted asphalt sample, factoring in the air voids. Both Gmm and Gmb Values provide the framework for calculating air voids for assessing mixture durability and resistance to permanent deformation due to loading from vehicles (Roberts et al., 1996).

Table 13 GMM AND GMB REULTS

SPECIMEN NO.	OMMT %	Gmm	Gmb
1	0.0	2.450	2.342
2	0.5	2.443	2.346

3	1.0	2.437	2.352
4	1.5	2.438	2.322

As shown by the Experimental Results, the Gmm values produced by Method 3 discarded a slight decrease in value from 2.450 at 0% OMMT to 2.437 at 1.0% OMMT, while 2.438 was produced as the Gmm value for 1.5% OMMT. However, the Gmb values produced with Method 3 showed a general increase from 2.342 to a peak of 2.352 at 1.0% OMMT, followed by a drop in value to 2.322 at 1.5% OMMT. The increase in Gmb produced with 1.0% OMMT may be an indicator of improved compaction and better densification of the mixture and have significant positive correlation with resistance to temporary deformations (i.e., rutting). The addition of OMMT to the mix increased the overall density of the mix and provided an increase in the bond strength between aggregate particles, both of which contribute to the reduced susceptibility to temporary deformations (Brown & Cross, 1992).

There are several factors that may account for the slight decrease in Gmm values and the increase in Gmb values until the addition of 1.0% OMMT occurred. These factors include improved binder stiffness and enhanced dispersion of nano clay within the bitumen matrix, which allows for greater packing density. However, the addition of 1.5% OMMT in this instance may have caused excessive clay content, which has been shown to lead to slight agglomeration of particles and excessive stiffness. This may have resulted in less effective compaction of the mixture, thus providing an explanation for the drop in Gmb values produced. Similar trends in performing workability and compaction studies with nano-modified binders have been noted in past research (Chen et al., 2011), thus supporting the concept that an excessive use of modifiers may have a negative effect on both workability and compaction ability of the mixture.

4.5.2MARSHALL STABILITY

The Marshall Stability Test measures the maximum amount of loads that an asphalt sample can withstand when compressed. It is a measure of how well an asphalt material resists plastic deformation when subjected to heavy or constant movement (over time) from motor vehicle traffic. In addition to this, higher "stability" indicates a more stable structure and as a result has improved "rutting" characteristics (Huang, 2012).

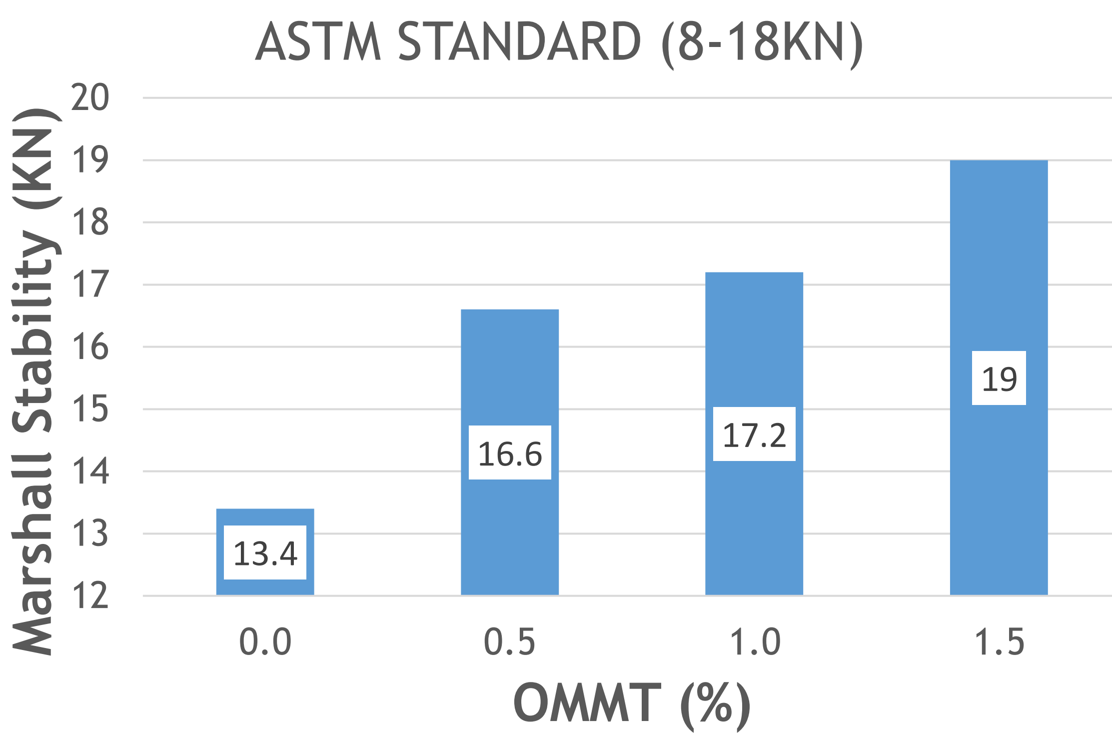


Figure 5 MARSHALL STABILITY OF OMMT SAMPLES

Results indicated a steady increase from 13.4kN (0% OMMT) to 17.2kN (1.0% OMMT) and peaking at 19.0kN (1.5% OMMT). All values fall within the ASTM range of 8–18kN except the highest value, which slightly exceeds the upper limit. While the highest stability at 1.5% suggests robust resistance to deformation, the value at 1.0% provides a more appropriate balance between strength and flexibility, aligning with design specifications. Increased stability with rising OMMT content arises from improved rigidity and reinforcement of the binder phase, enhancing aggregate bonding and shear resistance. However, excessively high stability may indicate reduced flexibility, which could lead to cracking, especially under repeated loading (Khattak et al., 2013).

4.5.3MARSHALL FLOW

The amount of deformation and the amount of stress that the material can take before cracking is measured by Marshall Flow. The amount of stress the material can take without cracking must be between two and four millimetres according to ASTM specifications. When a mix has this amount of stress without excessive deformation, it indicates that the material is suitable for use in practice (Read & Whiteoak 2003). The suitability of a mix for use in practice is defined as being within ASTM specifications, which is between eight and eighteen kilonewtons for all but the highest values that are exceeding the upper limit. The highest stability of the material occurs at 1.5% OMMT (a minimum of one) and indicates that the material can withstand large amounts of deformation. Conversely, the mix that contains one per cent OMMT indicates a greater balance between strength and flexibility, which is what the design requires. As a mix has increased OMMT and binder, the increased rigidity and reinforcement in the binder have enhanced the bond between the aggregate and the shear resistance of the aggregate. However, excessive amounts of stability may result in loss of flexibility, which can result in cracking under repetitive loading (Khattak et al. 2013).

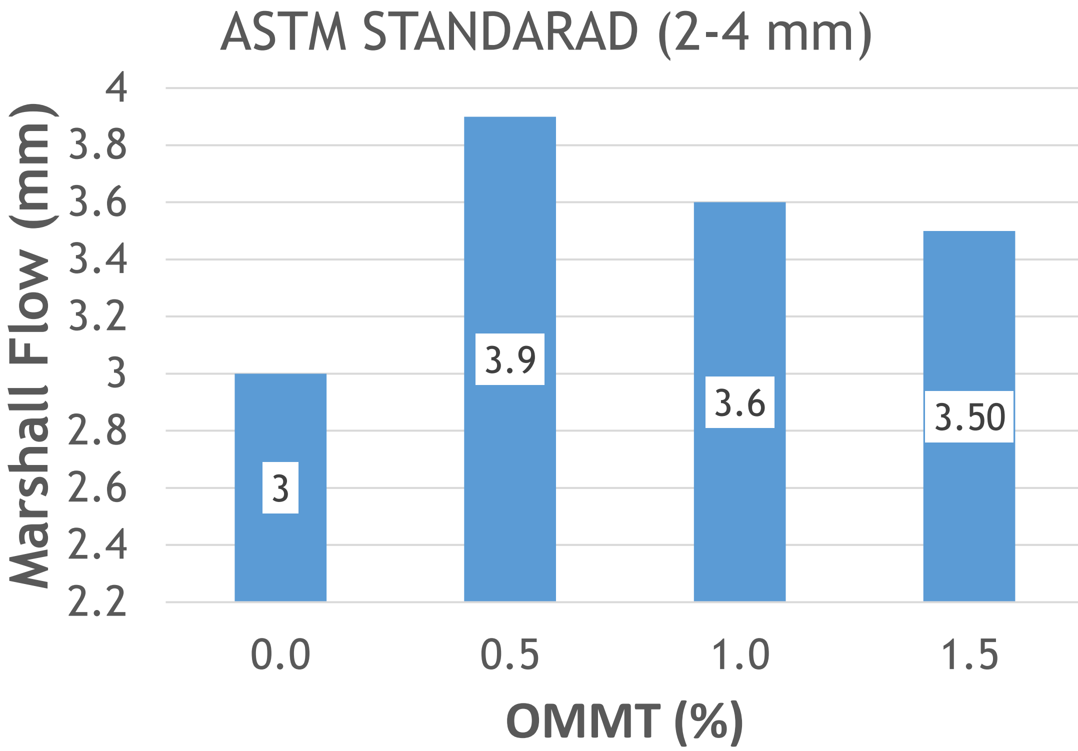


Figure 6 MARSHALL FLOW OF OMMT SAMPLES

The flow value of the 0% OMMT was 3.0 mm, while it was 3.6 mm at 1% and 3.5 mm at 1.5% OMMT. All of these values are considered to be within acceptable limits. The increased flow value at the 1% level indicates a good balance between the stiffness and deformability of the asphalt mixture. When OMMT content is increased, the viscosity and stiffness of the binder increase. However, the increase in structural cohesion produced by the OMMT also allows for a controlled amount of deformation of the mixture when loaded.

4.5.4AIR VOID CONTENT (VA):

Air void content indicates the percentage of air spaces contained in the asphalt mixture after it has been compacted. Testing of air voids is important for determining the durability, moisture resistance and resistance to cracking of the asphalt. The optimal range of air void content in the asphalt is from 3% to 5% so that there will be good compaction and no bleeding or excessive permeability (Roberts et al. 1996).

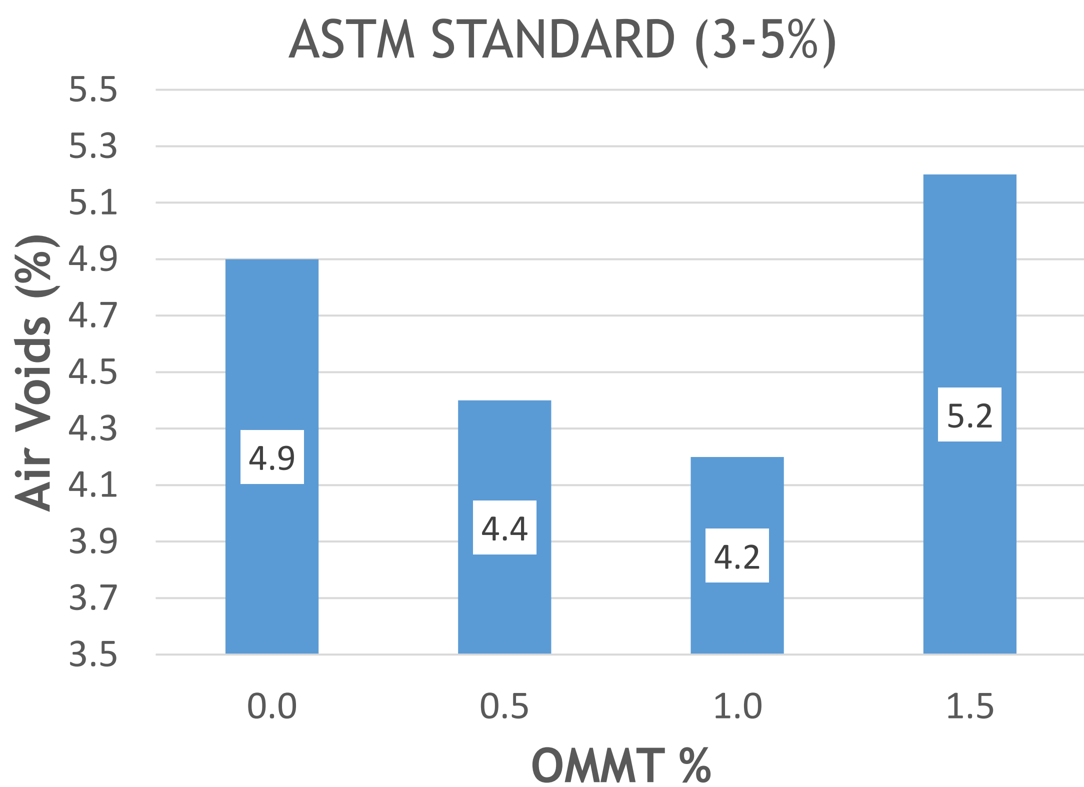


Figure 7 AIR VOIDS OF OMMT SAMPLES

At 0% OMMT, air voids were 4.9%, but they decreased in value to 4.2% after adding 1%, while increasing again to 5.2% due to a 1.5% increase in OMMT. The lowest recorded air voids level was achieved at 1% OMMT, indicating that this had resulting more effective compaction efficiency as well as greater binding/aggregate interaction with that quantity of OMMT.

At 1% OMMT, less air voids were attributed to increased binder stiffness and better aggregate coatings, promoting more effective results Densification of the mixture within this range was also accomplished. However, by increasing OMMT concentration up to 1.5%, it was noted that while binder agglomeration occurred and binder flexibility was increased, more binding properties of the base platform were compromised as evidenced by rising air voids.

4.5.5VOIDS IN MINERAL AGGREGATE (VMA)

The amount of voids formed by adding various types of aggregate to a compacted mix, will vary based upon how much of the total void volume has been filled with either bitumen or air. On average, the higher the VMA, the better it will be to accommodate binder adding more than normal resistance to rutting on newly paved roadways, as noted to be necessary to maintain long term performance (Huang, 2012). The addition of VMA generally offers greater room for the binding of additional grades of solvents and better accommodation to increased fatigue (through VMA).

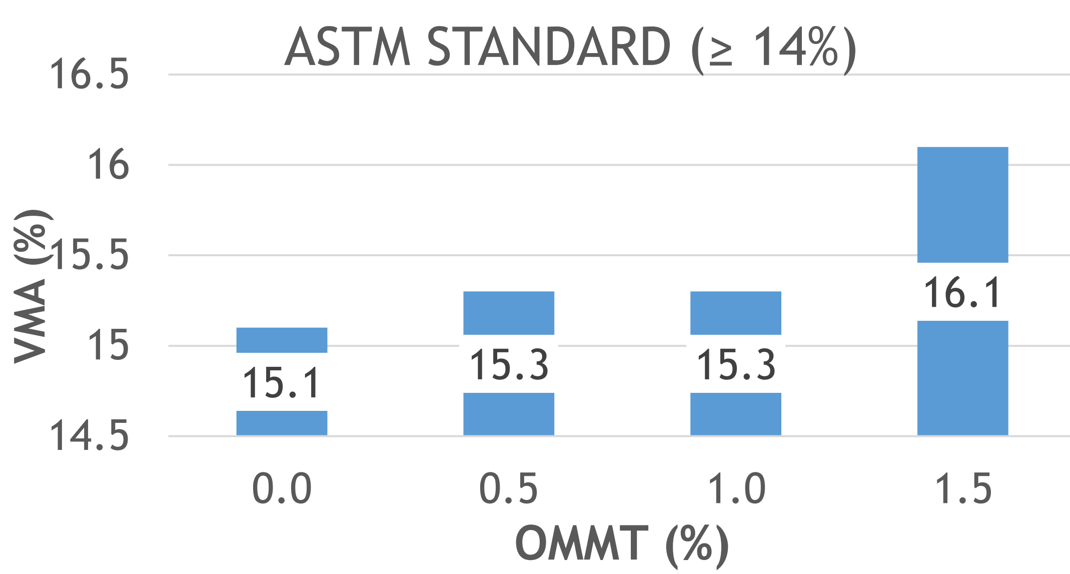


Figure 8 VOIDS IN MINERAL AGGREGATES OF OMMT SAMPLES

The volume of voids (VMA) in the asphalt mixtures increased from 15.1% to 15.3% when comparing 0.0% and 1.0% OMMT respectively, then increased again to 16.1%

when using 1.5% OMMT. All VMA values met the ASTM requirement of 14%, which means that all asphalt mixtures have excellent binder space.

At 1.0% OMMT, VMA remained stable, meaning the aggregates were well-controlled and had sufficient amounts of binder/paving liquid to fill opening left by compactive efforts. The increase in VMA when going to 1.5% OMMT is most likely due to reduced compaction efficiency resulting from increased viscosity within the binder/paving liquid causing limited aggregate displacement during compaction (Khattak et al., 2013). The increase in VMA is also consistent with the observed increase in the air void content at this same level of OMMT (1.5% OMMT).

4.5.6VOIDS FILLED BY BITUMEN (VFB)

VFB measures the percentage of voids filled with bitumen in relation to the total amount of voids and it is indicative of how well the binder/paving liquid fills the void space available in the aggregate. VFB is related to the quality of the aggregate coating and the durability of the asphalt mixture. A typical range for optimum performance is between 65% and 75% (Read and Whiteoak, 2003).

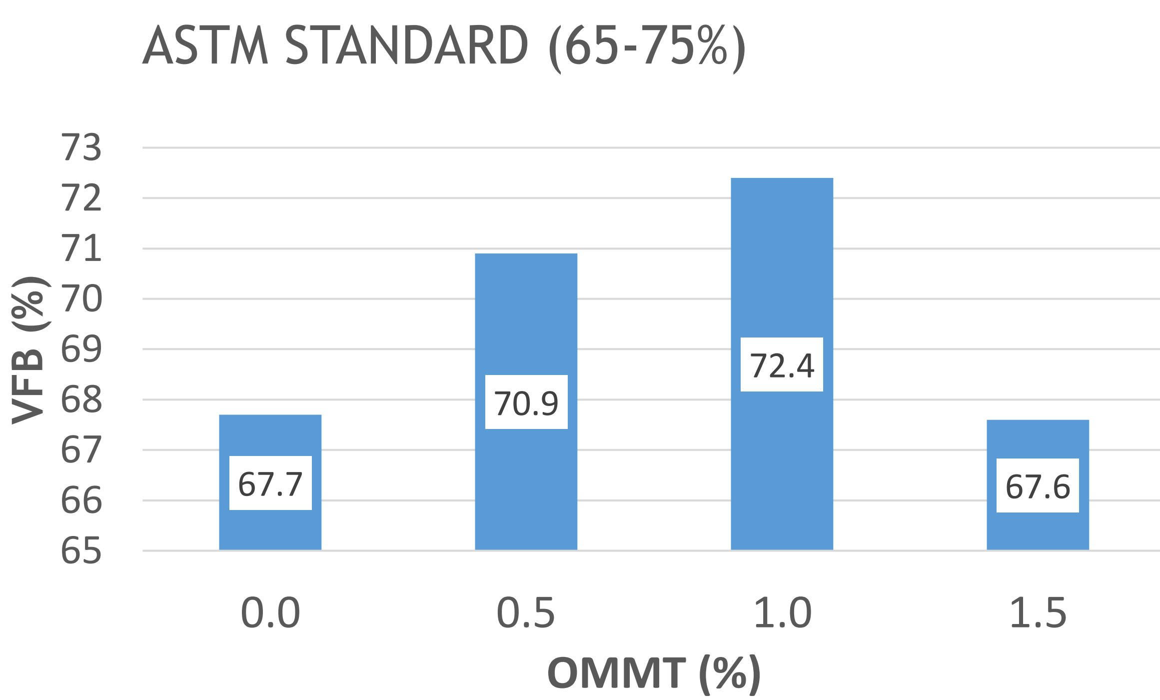


Figure 9 VOIDS FILLED WITH BITUMEN OF OMMT SAMPLES

The VFB increased from 67.7% at 0% OMMT to 72.4% at 1.0% and then decreased again to 67.6% at 1.5%. At 1.0% the VFB is in the upper range of the optimal VFB range, indicating that the Hybrid Binder utilized the maximum amount of Binder efficiently and were less susceptible to moisture absorption.

The increase in VFB at 1.0% is due to better cohesion of Binder and better dispersion of OMMT within the Hybrid Matrix, thereby providing better coverage to the Aggregates. The decrease in VFB at 1.5% can be attributed to the overuse of the modifier, resulting in too much stiffness and poor (non-evenly) distributed Binder. The trend observed here is consistent with previous studies on Nano Clay content where optimal levels allow for better absorption of binder and when too much is used, decrease the workability (Abdullah et al., 2022).

4.6INDIRECT TENSILE STRENGTH (ITS)

Through the ITS testing, we can assess how well the modified asphalt will perform with respect to tensile resistance or strength and therefore also give us an idea of how the asphalt will resist cracking, its internal cohesion and its ability to resist damage from moisture. Also, since tensile strength provides some indication of the amount of shear resistance present in a mixture, ITS results can potentially provide information about the amount of rutting that would occur in the mix (as a mix that maintains a higher tensile strength will generally exhibit less lateral deformation due to repeated loading; Huang, 2012).

Table 14 ITS VALUES OF THE MARSHALL SAMPLES

OMMT %	**ITS (DRY) Kpa**	**ITS (WET) %**
0.0 (CONTROL)	1066	89
1.0 (OPTIMUM)	1249	92
ASTM STANDARDS	>800Kpa	>80% of dry

The 1249 kPa dry ITS of the 1.0% OMMT mixture meets the minimum ASTM specification of 800 kPa, indicating adequate internal bonding and good tensile capacity. The wet ITS is 92% of the dry ITS, which meets the ASTM requirement of maintaining greater than 80% of the dry ITS after moisture conditioning. In comparison to the control mixture (1066 kPa dry and 89% wet), the modified mixture demonstrated a significant increase in dry ITS while retaining comparable wet performance. The addition of 1.0% OMMT resulted in significant increases in tensile strength under normal conditions while providing adequate moisture resistance.

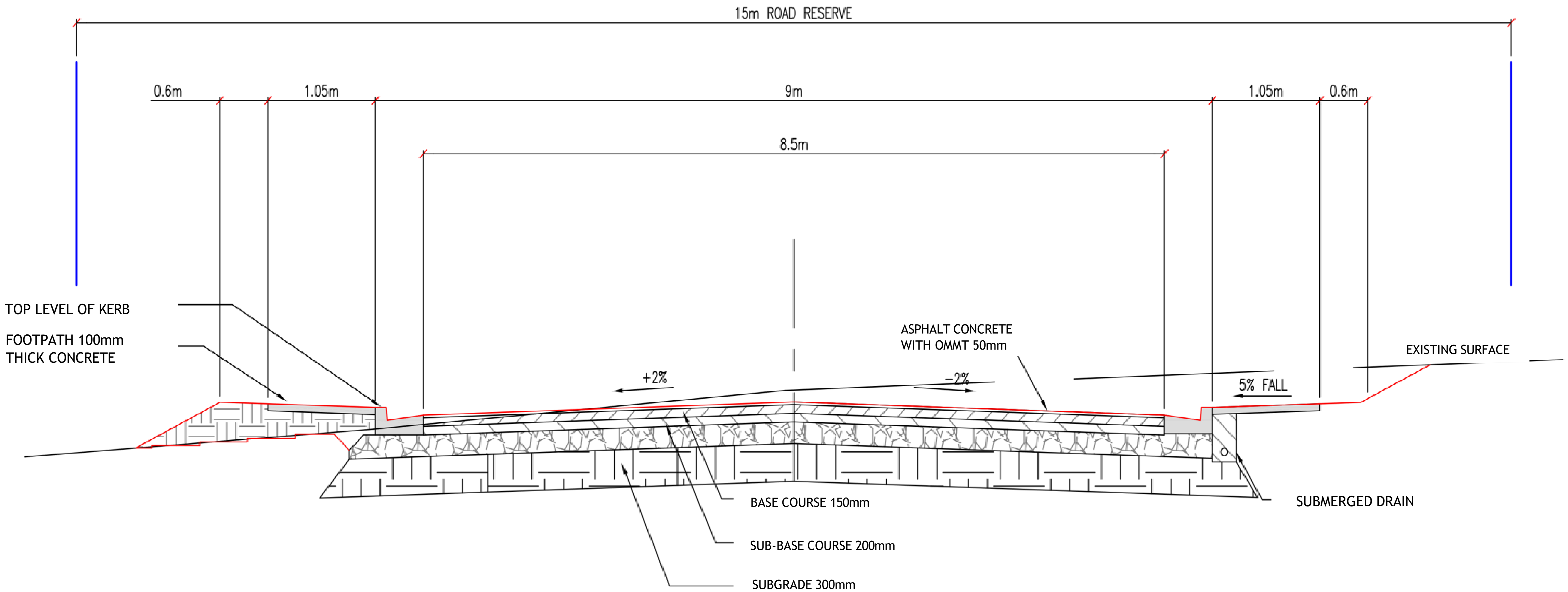
The increase in dry ITS for the 1.0% OMMT modified mixture is due to the reinforcing action of the nano clay platelets dispersed throughout the bitumen. The OMMT increases the stiffness of the binder and strengthens the aggregate-to-binder interface, allowing for improved load transfer and internal cohesion (Chen et al., 2011). The wet ITS remained similar to the control because moisture results in a reduction of adhesion regardless of any modification; however, the modified binder maintained sufficient amounts of tensile strength to meet specification requirements. Collectively, the results of the ITS indicate that the 1.0% OMMT modification increases shear resistance and provides a positive contribution to rutting resistance, whereby an increased tensile strength corresponds to a lower risk of permanent deformation under traffic (Khattak et al., 2013).

4.7RESEARCH DESIGN

Design of Modified Asphalt Mixtures: Table 15 shows the makeup of a modified asphalt combination, including its aggregate fractions, binder, and organic modified mineral (OMMT) additive contents. Each type of the mixture includes the amount (%) and the weight (g) of each component in order to total 8000g.

Table 15 RESEARCH MIX DESIGN

Material in the mix	**% in the mix**	**Mass (g)**
14/20 mm	24	1825.9
10/14 mm	11	836.9
6/10 mm	18	1369.4
0/6 mm	46	3499.7
OMMT (1%)	1.0	76.1
Total Aggregates	100	7608
Binder	4.9	392
Total Mass		8000



TYPICAL ROAD CROSS SECTION

SCALE 1:50

TITLE	EVALUATING THE RUTTING RESISTANCE OF ASPHALT CONCRETE MODIFIED WITH ORGANOPHILIC MONTMORILLONITE NANO-CLAY
NAMES	ASONYA JOHN M22B32/003 GAMUKAMA MICHAEL S18B32/183
SCALE	1:50
DATE	10/12/2025

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1CONCLUSION

From the research conducted in this study, the addition of OMMT to asphalt concrete favoured improvements in the volumetric properties and mechanical behaviour. The asphalt mixture containing 1.0% OMMT exhibited balanced air void content, VMA, and VFB values; all measured values fell within recommended limits. In addition, the increased packing and distribution of aggregate within the asphalt mixture have been attributed as the primary reasons why the addition of OMMT provides an increase in how well the asphalt mixtures compact to create a denser product and less porous product. The asphalt mixture also met both the required stability and flow criteria exhibiting a balance between stiffness and flexibility that is required to resist rutting and allow for any deformation due to traffic.

The results of the ITS testing of the asphalt mixtures demonstrated that modifying the asphalt mixture with nano clay resulted in an increase in mechanical behaviour. The ITS values for both dry and wet conditions for the mixture containing 1.0% OMMT exceeded the minimum requirements of ASTM Standards indicating that the mixture has an improved cohesion and stronger bond between the aggregate and chemical binder even in the presence of moisture. The increase in tensile strength of the asphalt mixture indicates that the asphalt mixture has a greater ability to resist cracking due to moisture damage and shear deformation; all of which are critical considerations when determining how durable a pavement will be.

Overall, these findings indicate that including OMMT as a modifier within the asphalt concrete at a level of 1.0% increases the performance of the asphalt concrete. The inclusion of this modifier increases the ability of the asphalt binder to disperse, compact, and resist cracking without adversely affecting flexibility.

5.2RECOMMENDATIONS

1. Use a dosage of OMMT 1% considered as optimum for asphalt concrete for optimal Volumetric Properties, and superior Tensile Strength which directly increases Rutting Resistance. This dosage will be used as a reference against which other Dosages will be measured for production and performance testing. The use of different aggregate sources or Binder Grades will require a verification testing schedule to ensure the consistency of results from the test method(s) used.

2. Quality assurance procedures provide strict quality control over the dispersion of OMMT in the mixing process so that OMMT can be properly dispersed throughout the mix and maintain the maximum amount of Binder Coherency, however, at higher dosages, the chance of reducing performance should be minimized. All batches should follow the same procedures for mixing time, temperature, and mixing sequence. Periodic checks should be performed on the Binder Consistency and Mixture Homogeneity so that any Dispersion Problems are identified and corrected as soon as possible.

Laboratory test results will require validation through field trials, through wheel tracking tests or pilot Pavement Sites to confirm the Rutting Resistance under actual traffic and Climate Conditions. Performance monitoring activities and measurements of rut depth and surface inspections should be performed periodically. Laboratory test results will be compared to results collected in the field to make informed decisions for implementing this approach on a large scale.

Submission of ongoing monitoring and maintenance plans for modified asphalt pavements to promote long-term durability and performance. Regular inspections should identify early warning signs of rutting and/or surface deformations. Performance data gathered from the above will help to refine the design and construction processes of future projects.

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College of Natural Sciences
School of Physical Sciences
DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

Tuesday, 30 September 2025

Gamukam Michael and Asonya John

Dear Sir,

RE: MINERALOGICAL ANALYSIS OF A SAMPLE BY XRD

The Department received one sample (1) in the laboratory, to be analysed for mineralogical composition. During analysis the sample was ground to fine powder (< 0.063 mm) and scanned using the XRD Spectrometer (Shimadzu -XRD-7000) for mineralogical composition. The results below were obtained.

Minerals	Minerals
Quartz	Tridymite
Hallyoisite	Tetramajorites
Deckite	Anorthite
Gismon	Moganite
Nacrite	Albite
Kaolinite- Montomorinite	Grossite
Chrysotile	Anti Gorrite
Stishovite	Opal

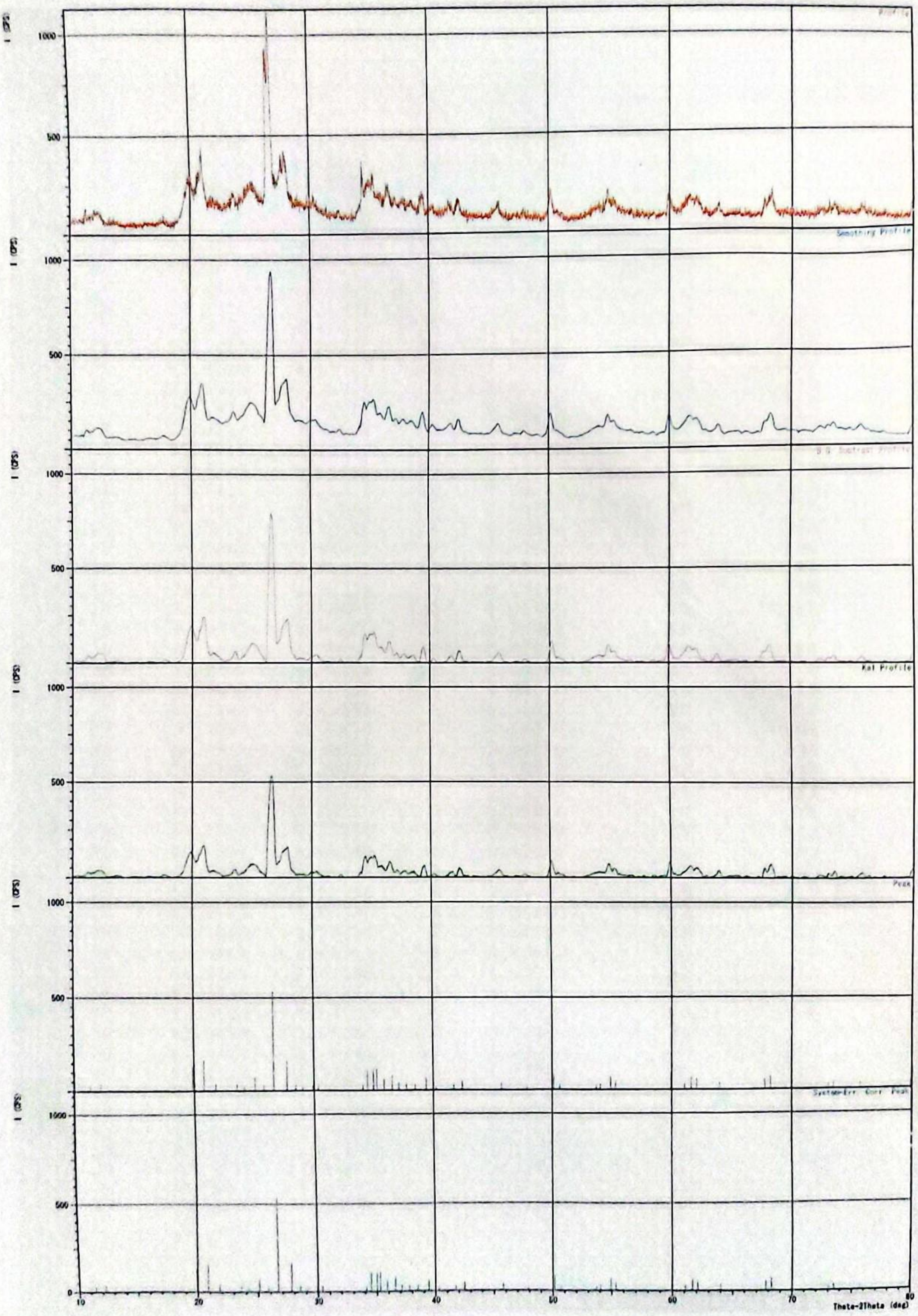
Note: The details about the mineral as obtained from the XRD spectrometer are attached on the report.

Analyst:.....M' Kasaka.....

Kasaka Moses

Geochemistry Laboratory

< Group: Standard   Data: CLAY >



INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	GAMUKAMA MICHAEL REG NO. S18B32/183 & ASONYA JOHN M22B32/003	Stirling

TEST	EVALUATING THE RUTTING RESISTANCE OF ASPHALT CONCRETE MODIFIED WITH MONMORILLONITE NANO CLAY

Test Reference No.:		Lab. Reference No.:	
Sample no:		Technician :	Lab team
Grade	60-70	Sampling date:	Friday, 5 September 2025
Source of the sample		Testing date:	5-Sep-25
Temperature of the Test:			

Cup No.		3	5	2P	AX			Units
Weight of cup in air	A	110.0	113.5	112.4	116			g
Weight of cup filled with water	B	190.8	193.5	192.4	196.8			g
Weight of cup partially filled with bitumen in air	C	169.8	172.5	170.0	181.2			g
Weight of cup filled with bitumen & water	D	192.4	194.5	193.9	198.7			g
Volume of the cup	B-A	80.8	80.0	80.0	80.8			g
Weight of bitumen	C-A	59.800	59.000	57.600	65.200			g
Volume of the water above bitumen le	D-C	22.600	22.000	23.900	17.500			g
Volume of the bitumen	((B-A)-(D-C))	58.200	58.000	56.100	63.300			g
fic gravity of bitume (Gb)	(C-A)/((B-A)-(D-(	1.027	1.017	1.027	1.030			g
pecific gravity of bitumen (Gb)		1.025						

FOR LAB

STIRLING CIVIL ENGINEERING LTD

25 NOV 2025

P. O. BOX 793, KAMPALA (U)

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	GAMUKAMA MICHAEL REG NO. S18B32/183 & ASONYA JOHN M22B32/003	Stirling

PROJECT :	EVALUATING THE RUTTING RESISTANCE OF ASPHALT CONCRETE MODIFIED WITH MONMORILLONITE NANO CLAY

A/C 14 ASPHALT RESULTS

SUMMARY OF A/C 14 TEST RESULTS

			BITUMEN CONTENT		4.9
AGGREGATE TESTS	ACHIEVED	SPECIFIED	MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
			MARSHALL FLOW	3.0	2—4
Sodium Soundness	2.1	<12%	MARSHALL STABILITY 75BLOWS	13.4	9-18
Water Absorption	0.4	< 2%	MARSHALL AIR VOIDS 75BLOWS	4.9	3—5
TFV Dry	255.6	>110kN	VOIDS IN MINERAL AGGREGATES	15.1	>14%
TFV Soaked Wet/Dry ratio	89%	>75%	VOIDS FILLED WITH BINDER	67.7	65—75%
Flakness Index	19.5	< 25%	INDIRECT TENSILE STRENGTH @ 25C	1,066	>800kpa
Plastic Index	N/P	< 4%	INDIRECT TENSILE WET STRENGTH	89	>80% of dry
LAA	16.8		BITUMEN CONTENT AFTER EXTRACTION	5.0	±0.3
ACV	15.8		RATIO STABILITY/FLOW	4.4	>2.5
AIV	15.0				

For CONTRACTOR

Lab technician

Materials Engineer

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PROJECT :	EVALUATING THE RUTTING RESISTANCE OF ASPHALT CONCRETE MODIFIED WITH MONMORILLONITE NANO CLAY

A/C 14 ASPHALT WITH 0.5% MONMORILLONITE NANO CLAY

SUMMARY OF A/C 14 TEST RESULTS

BITUMEN CONTENT		4.9
MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW	3.9	2—4
MARSHALL STABILITY 75BLOWS	16.6	9-18
MARSHALL AIR VOIDS 75BLOWS	4.4	3—5
VOIDS IN MINERAL AGGREGATES	15.3	>14%
VOIDS FILLED WITH BINDER	70.9	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,111	>800kpa
INDIRECT TENSILE WET STRENGTH	89	>80% of dry
MASHAL DENSITY	2.3	....

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INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	GAMUKAMA MICHAEL REG NO. S18B32/183 & ASONYA JOHN M22B32/003	Stirling

PROJECT :	EVALUATING THE RUTTING RESISTANCE OF ASPHALT CONCRETE MODIFIED WITH MONMORILLONITE NANO CLAY

A/C 14 ASPHALT WITH 1.0% MONMORILLONITE NANO CLAY

SUMMARY OF A/C 14 TEST RESULTS

BITUMEN CONTENT		4.9
MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW	3.6	2—4
MARSHALL STABILITY 75BLOWS	17.2	9-18
MARSHALL AIR VOIDS 75BLOWS	4.2	3—5
VOIDS IN MINERAL AGGREGATES	15.3	>14%
VOIDS FILLED WITH BINDER	72.4	65—75%
INDIRECT TENSILE STRENGTH @ 25C	1,249	>800kpa
INDIRECT TENSILE WET STRENGTH	92	>80% of dry
MASHAL DENSITY	2.3	....

For CONTRACTOR

Lab technician

STIRLING CIVIL ENGINEERING LTD

2 5 NOV 2025

P. O. BOX 790, KAMPALA (U)

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	GAMUKAMA MICHAEL REG NO. S18B32/183 & ASONYA JOHN M22B32/003	Stirling

PROJECT :	EVALUATING THE RUTTING RESISTANCE OF ASPHALT CONCRETE MODIFIED WITH MONMORILLONITE NANO CLAY

A/C 14 ASPHALT WITH 1.5% MONMORILLONITE NANO CLAY

SUMMARY OF A/C 14 TEST RESULTS

BITUMEN CONTENT		4.9
MARSHALL MIX TEST RESULTS AFTER MIX	ACHIEVED PLANT PRODUCTION	SPECIFIED
MARSHALL FLOW	3.5	2—4
MARSHALL STABILITY 75BLOWS	19.0	9-18
MARSHALL AIR VOIDS 75BLOWS	5.2	3—5
VOIDS IN MINERAL AGGREGATES	16.1	>14%
VOIDS FILLED WITH BINDER	67.6	65—75%
INDIRECT TENSILE STRENGTH @ 25C	724	>800kpa
INDIRECT TENSILE WET STRENGTH	78	>80% of dry
MASHAL DENSITY	2.3	....

For CONTRACTOR

STIRLING CIVIL ENGINEERING LTD

Materials Engineer

25 NOV 2025

P. O. BOX 793, KAMPALA (U)

INSTITUTION	STUDENT	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	GAMUKAMA MICHAEL REG NO. S18B32/183 & ASONYA JOHN M22B32/003	Stirling

PROJECT	EVALUATING THE RUTTING RESISTANCE OF ASPHALT CONCRETE MODIFIED WITH MONMORILLONITE NANO CLAY

Field Ref. No.:		Lab. no.		Chainage sample 1:	A/C 14 ASPHALT WITH 1.0% MONMORILLONITE NANO CLAY	Sampling date:	15-Nov-25	Test Type	Done by	Test Type	Done by
Sample grade:	AC 14	Compaction:	75 blows	Chainage sample 2:		Testing date:	16-Nov-25	B.R.D	lab team	B.C/Grad.	lab team
Sample Description:					AC 14			T.M.R.D.	lab team	Stab. & Flow	lab team

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

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/m³)	% Air Voids	% VMA	% VFB	Marshall Heights (mm)			Av. Hgt (mm)	Corr. Factor	Stability (KN) Measured	Stability (KN) Adjusted	Flow (mm)	Ratio (Stab./Flow)
1	1184.4	682.40	1186.20	2.351	2.340	4.0	15.1	73.4	64.3	63.1	64.4	63.9	0.99	17.3	17.17	3.41	5.034
2	1189.6	685.20	1192.60	2.345	2.333	4.3	15.3	72.1	64.2	64.4	64.6	64.4	0.98	17.1	16.77	3.52	4.763
3	1192.0	688.70	1197.80	2.341	2.330	4.4	15.4	71.5	64.5	64.2	65.2	64.6	0.97	17.6	17.04	3.75	4.545
4	1189.4	686.70	1193.40	2.347	2.336	4.2	15.2	72.7	64.3	64.5	64.3	64.4	0.98	16.6	16.31	3.71	4.397
Average Sample 1				2.346	2.335	4.2	15.3	72.4	Average Sample 1			64.3	1.0	17.2	16.8	3.6	4.7
-				-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average Sample 2									Average Sample 2								
Average Sample 1 & 2				2.346	2.335	4.2	15.3	72.4	Average Sample 1 & 2								

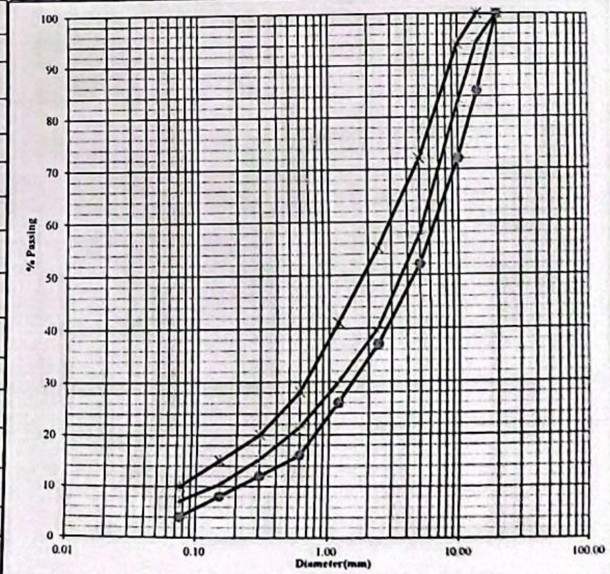
ASTM D 2172- Standard Test Method for Quantitative Extraction of Bitumen from Asphalt Mixtures

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

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

SAMPLE 1			SAMPLE 2		
(Pycnometer with Water)			(Pycnometer with Water)		
Temperature of water (°c)	25°C		Temperature of water (°c)	25°C	
in pycnometer	in water bath		in pycnometer	in water bath	
Test No-	1	2	Test No-	1	2
Asphalt	1318		Asphalt	1278.5	-
Pycn + Water	7479.7		Pycn. + Water	7479.7	-
Pycnometer + Asph. + Water	8256.5		Pycnometer + Asph + Water	8234.1	-
Volume of asphalt	541.2	-	Volume of asphalt	524.1	-
G_{mm}	2.435	-	G_{mm}	2.439	-
Av. G_{mm}	2.435		Av. G_{mm}	2.439	
Av. Gmm (Kg/m3) Sample 1& 2			2.437		

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



Comment:

STIRLING CIVIL ENGINEERING LTD

FOR CONTRACTOR

2025

Materials Engineer

P. O. BOX 793, KAMPALA (U)

INSTITUTION	STUDENT	
UGANDA CHRISTIAN UNIVERSITY	GAMUKAMA MICHAEL REG NO. S18B32/183 & ASONYA JOHN M22B32/003	Stirling

PROJECT	EVALUATING THE RUTTING RESISTANCE OF ASPHALT CONCRETE MODIFIED WITH MONMORILLONITE NANO CLAY

INDIRECT TENSILE STRENGTH

BITUMINOUS MIXTURE SAMPLED ON 15/11/2025 | 102 | GMM 2.437 | Bit.content,% 4.9 | NO OF BLOWS 41

SAMPLE NO	THICKNESS: HEIGHT 1 (mm)	HEIGHT 2 (mm)	HEIGHT 3 (mm)	Av. Thickness (mm)	Compacted material parameters: Weight of Core in Air (g) A	Weight of Core in Water (g) B	Weight of Core in SSD condition (g) C	Volume of Core (cc) D=(C-B)	Bulk Density (g/cm^3) E=(A/D)	GMM (maximum theoretical density) (g/cm^3) F	VOLUME OF AIR	SATURATED SPECIMEN	VOLUME OF WATER	DEGREE OF SATURATION	VIM, AIR VOIDS (%) =100*(F-E)/F spec min 3.0% G
MIX	A/C 14 ASPHALT WITH 1.0% MONMORILLONITE NANO CLAY														
WET															
1	66.8	66.9	66.5	66.7	1182.5	670.1	1189.4	519.3	2.254	2.437	38.998	1209.6	27.100	69.490	7.5
4	66.8	65.0	65.3	65.7	1174.6	671.4	1183.7	512.3	2.270	2.437	35.207	1192.6	18.000	51.126	6.9
3	66.3	65.9	66.5	66.2	1203.4	682.5	1209.0	526.5	2.263	2.437	37.709	1227.8	24.400	64.706	7.2
DRY															
2	64.7	65.7	64.5	65.0	1179.0	672.7	1188.4	515.7	2.263	2.437	36.820				7.1
5	65.8	65.3	65.9	65.7	1176.9	669.1	1183.4	514.3	2.265	2.437	36.273				7.1
6	66.1	66.2	66.6	66.3	1191.7	676.0	1196.2	520.2	2.268	2.437	36.162				7.0

INDIRECT TENSILE STRENGTH

DRY: SPECIMEN No	GAUGE READING (div)	LOAD RING FACTOR (kn/div)	MAXIMUM LOAD,P (kn)	SINGLE TENSILE STRENGTH,S_t (spec min 800 kPa)	AVERAGE TENSILE STRENGTH,S_t	WET: SPECIMEN No	GAUGE READING (div)	LOAD RING FACTOR (kn/div)	MAXIMUM LOAD,P (kn)	SINGLE TENSILE STRENGTH,S_t (kPa)	AVERAGE TENSILE STRENGTH,S_t (kPa)		[illegible] (spec 80%)
2	65	0.231	15.0	1,405.0	1,364.5	1	59	0.231	13.8	1,275.3	1,249	S_t =2P/πtD where P= maximum load(N) [illegible]	92
5	60	0.231	13.9	1,318.0		4	55	0.231	12.7	1,207.5			
6	63	0.231	14.6	1,370.6		3	58	0.231	13.4	1,263.1			

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Lab Technician