IMPACT OF CLIMATE ON ASPHALT PAVEMENT PERFORMANCE

BY

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CERTIFICATION

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DEDICATION

I dedicate this work to Almighty Allah (SWT) who has made it to possible for me to reach this stage of my Education and for also providing the means of sustenance for my parents, my uncle and his family in aiding me throughout my years of stay in this school.

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ABSTRACT

This research work was carried out to understand the impact of climate on asphalt pavement. Climate, changes due to the activities of the human kind as technology advances it leads to the emission of greenhouse gas into the atmosphere, thereby in the long term altering with the climate. It is paramount to always factor in the future climate projection when designing pavement due to the impact climate parameters such as temperature and precipitation have on the performance of the pavement.

The methods used for the determination of the performance of the pavement due to the climate is the pavement temperature model and the rutting depth of the pavement over time. The pavement temperature is determined using the historic temperature data and future projected temperature data of the study area. The data used for the determination of the historic pavement temperature of the road was that of January 2025 using the Viljoen pavement temperature. The future projection of the pavement temperature for the year 2021 to the year 2040 is that gotten from the CMIP6 temperature model used by the world bank for world climate research program. The rutting depth throughout the design life of the pavement is gotten from the MEPDG workbook.

The result of the maximum pavement temperature gave a standard deviation of ±1.6℃ with the coefficient of variation equal to 2.86% with the minimum pavement temperature giving a standard deviation of ±1.89℃ with the coefficient of variation equal to 7.34%.The rutting depth of the pavement in study location was predicted to reach the depth of 11.53mm by the end of the design life.

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Acronyms

AASHTO – American Association of State Highway and Transportation Officials

AC – Asphalt Concrete

API – American Petroleum Institute

CETC – Civil Engineering Total Concept

CMA – Cold Mix Asphalt

CMIP – Coupled Model Inter-Comparison Project

CRCP – Continuously Reinforced Concrete Pavement

HMA – Hot Mix Asphalt

IPCC – Intergovernmental Panel on Climate Change

JRCP – Jointed Reinforced Concrete Pavement

JPCP – Jointed Plain Concrete Pavement

MEPDG – Mechanistic Empirical Pavement Design Guide

NCHRP – National Cooperative Highway Research Program

PCC – Portland Cement Concrete

ROW – Right of Way

TRB – Transportation Research Board

WMA – Warm Mix Asphalt

Chapter One

INTRODUCTION

1.1 Background of Study

Asphalt pavement is a significant part of the transportation system, by providing smooth and durable surfaces for traffic, but are sometimes vulnerable to reduced life due to changes caused by adverse climate. The behaviour of bitumen has a very important effect on the performance of asphalt road pavements. Bitumen, which is a complex chemical material, has shown its ability to portray different characteristics which are dependent on the temperature range. At high temperatures, it behaves in a similar manner as a Newtonian fluid; at intermediate temperatures, it is similar to a viscoelastic liquid; and at low temperatures, it is similar to a viscoelastic solid (Krishnan and Rajagopal, 2005).

Highway design engineers rely on long historical records of climatic data when designing road infrastructures (Bennett et al, 2018). With this conventional practice, roads can withstand local weather and climate (Kirshen, 2013). Unfortunately, climate change has distorted trend in climate, thus this renders the use of historical climate data in the design of road infrastructure unreliable. Road administrators and engineers worldwide are becoming increasingly concerned about the change in climate during the past decades because of its significant impacts on road infrastructure. Some evidence of impacts of climate change on road infrastructure include: excessive solar radiation that damages road surface, uncommon and frequent submergence of road by severe flood events, increased coverage of roads with snow and ice etc (IPCC, 2014).

In recent decades, climate change has been of growing concern considering its impact on the natural and built environment. Some of these changes have been linked to human influences and have resulted in increased warm temperature extremes, decreased cold temperature extremes, an increase in extreme high sea levels as well as an increase in the number of heavy precipitation events. It was estimated in 2011, that the African continent could be liable for up to $183.6 billion to repair and maintain roads damaged from temperature and precipitation events alone, resulting from climate change (Chinowsky et al, 2011). It was observed that climate was already having influence on Nigerian roads, although the impacts are non-uniformly experienced across the country.

In Northern Nigeria, impact of climate change on road pavement is derived from high harmattan temperature whereas in the south, road infrastructure is heavily impacted by extreme rainfall events. The degree at which these climate impacts are felt is dependent on the type of soil, topographical features, condition of previously constructed pavement. The changing environmental conditions have affected humans in various ways, directly and indirectly which has made it imperative to make changes in government policies and personal lifestyles to combat the adverse effects of changing environmental conditions.

Pavement materials are engineering materials that are used in the construction of pavements that helps in giving it strength, makes it durable, reduces the risk of failure and also helps in maintaining its performance for a large period of time. They are various materials used in the construction of pavements, these materials are Soil, Aggregates, Geosythetics, Bitumen, Recycled materials, Cement and more (Dr. S. Raviraj, 2017). Each material has its own property, function and what it adds to the overall durability and performance of the pavement as well as reduce risk of failure.

AASHTO classified the performance of a pavement into structural performance, functional performance and safety. The structural performance is primarily based on physical condition like occurrence of cracking, faulting and other conditions that will adversely affect the load-carrying capability of the pavement structure.

The functional performance concerns how well the pavement serves the users whereas the safety deals with how the condition of the pavement allows for safe movement of the users whether it is a vehicle or a pedestrian. (AASHTO, 1993).

The main subject matter of this research work is to understand the impact of a changing climate on the performance of the asphalt pavement. Pavements are crucial infrastructures that support transportation systems by providing a durable and stable surface for vehicles. However, their performance and longevity are heavily influenced by adverse changes in climate, which introduce a range of environmental stresses. Understanding catalysts of climate change is essential for developing resilient pavement designs and effective maintenance strategies.

1.2 Statement of the Problem

This research carried out is driven towards understanding the impact of climate on the performance of asphalt pavement. Understanding what impact the climate has on the performance of an asphalt pavement is crucial for the improvement in the durability and extension of the lifespan of the pavement. The performance of asphalt pavements is greatly altered by the climatic conditions that affects the structural integrity and serviceability over time. Changes in climate has introduced extreme weather patterns that includes higher temperature and increased variance in precipitation rates. These environmental factors leads to pavement deterioration mechanisms such as rutting, fatigue cracking, thermal cracking, and moisture damage (Huang, 2004; AASHTO, 2015).

One of the environmental factors that directly affects the performance of a pavement is the changes in temperature, it affects the viscoelastic properties of asphalt. Higher temperatures leads to the softening of the asphalt binder thereby increasing the vulnerability to rutting (Bahia and Anderson, 1995), at a lower temperature, it makes the binder to brittle in nature eventually leading to thermal cracking (D'Angelo et al, 2007).

An increase in precipitation caused by adverse changes in climate has rather caused a higher risk of flooding. The flood usually infiltrates the structure of the pavement causing the weakening of the subgrade soils and a general reduction in the overall pavement strength (Khan et al., 2017). In situation whereby the drainage condition is very poor, it causes stripping in the pavement, a condition where the adhesive bond between the binders and aggregates weakens affecting the load bearing capability of the pavement. In regions with high groundwater levels or extended wet conditions, moisture intrusion can lead to subgrade weakening, ultimately causing differential settlements and pavement failures (Zhou and Scullion, 2006).

Climate induced effects in combination with heavy traffic loads have increased the frequency of occurrence of pavement distresses such as permanent deformation, affecting their durability, lifespan and long term performance. Traditional pavement design and maintenance strategies have not been able to fully account for these evolving climate effects thereby needing improved predictive models along with the adaptive engineering solutions during the design period.

1.3 Aim and Objectives

The aim of this research is on the impact of climate on asphalt pavement performance.
The objectives of this study is:

i. Determine the total rut depth of the asphalt pavement as a performance criteria,
ii. Evaluate the variation of the pavement temperature at the surface and at different depths with respect to the air temperature
iii. Determine the corresponding effect on the lifespan of the pavement.

1.4 Scope of Study

The scope of this study focuses on the impact of climate on the performance of asphalt pavements. The study was carried using a section of Irowabaze street and it entails;

1. Forecast of average highest and lowest monthly temperature for a span of 15 years
2. Analysis of pavement temperatures at the surface and various depth using Viljoen model
3. Carrying out traffic study to determine the frequency of usage by heavy duty vehicles
4. Analysis of permanent deformation (Rutting) of the asphalt layer

1.5 Justification of Study

This work is a very important and useful one in the sense that it helps us to understand the challenges that comes with each driving force of climate change for a pavement and what should be done to reduce the adverse effect of each force.

Although when designing a pavement, importance are mostly given to the type of load that the pavement will carry, it is paramount to always put into consideration what the change in season or climate brings upon the materials in the pavement.

Chapter Two

LITERATURE REVIEW

2.1 What is Pavement

A highway pavement is a structure consisting of superimposed layers of various processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade (CETC, 2021). Pavement refers to the durable surface material laid down on roads, walkways, airstrips, and similar areas to facilitate smooth and safe transportation for vehicles and pedestrians. It is a critical component of transportation infrastructure and is essential for economic development, connectivity, and daily activities. Pavement refers to the durable surface material laid on the ground to support vehicular or foot traffic. It is a critical component of transportation infrastructure, designed to provide a smooth, stable surface for travel while distributing loads to the underlying layers. (Huang, 2004). Pavements are designed and constructed to provide durable all-weather traveling surfaces for safe and speedy movement of people and goods with an acceptable level of comfort to users. The study of pavements is a critical area in civil engineering, involving the design, construction, maintenance, and rehabilitation of surfaces used for vehicular and pedestrian traffic. Pavements play a vital role in infrastructure, directly impacting economic activities, safety, and the environment.

This literature review examines the evolution of pavement materials along with the environmental factors that affects its performance by highlighting key research findings and areas of further exploration. The field of pavement design is dynamic. The concepts are changing with time as technology develops and new equipment emerges for site investigation, material testing and traffic data collection, and new data become available.

In the early stage, pavement design was carried out by a rule-of-thumb procedure based on entirely past experience. Observing the performances of the already constructed roads, highway engineers become aware that pavement performance is dependent on the sub grade soils. With the knowledge of soil mechanics, pavement design was made with soil classification. Increase in traffic, usage and development of heavy transport system, The deterioration of pavements due to heavy trucks and aircrafts necessitated a more rational approach of design. This led to full-scale and laboratory experiments in different countries at different capacities. The results of these and other full-scale and laboratory experiments conducted under varying soil, climatic, and loading conditions in different countries have given rise to our understanding and development of the existing design methods.

2.1.1 The Cross Sectional Element Of Pavement

The pavement consists of different elements which are most times shown when the cross section of the pavement is brought out. There are very important aspects of a pavement as they affect the safety and comfort of the users.

The basic cross sectional elements of a highway pavement according to Tom (2015) are :

1. Width of carriageway
2. Right of way
3. Kerb
4. Road margin
5. Width of formation
6. Camber

1.Width of Carriageway: The width of a carriageway, is entirely dependent on how wide the traffic lanes are, and the total number of lanes present on the road. The width of the traffic lane is determined by the width of vehicle along with the clearance. For a single lane roadway, the minimum lane width is 3.75m.

2. Right of way: Right of way, which also known as the land width is the width of land acquired for the road along its alignment. The ROW should be able to accommodate all the cross-sectional elements of the highway and also include additional area for future development.

The width of right of way is guided by:

a) Width of formation: It depends on the category of the highway and the width of the roadway and road margins.
b) Height of embankment or depth of cutting: It is dependent on the topography and the vertical alignment
c) Sides slope of embankment or cutting: It is depends on the height of slope and the soil type
d) Drainage system and their size: This depends on the rainfall and topography of the area
e) Sight distance: When driving through a curve, there is obstruction to the visibility on the inner side curve due to the presence of building structures etc. This affects the ability to see vehicles coming from the other part of the road

3. Kerb: A kerb is used to show the demarcation between the carriage way and the shoulder or footpaths. They are also used for controlling flood along the road, improve aesthetics and reduce right of way. They are different types of kerbs and their various functions

a) Mountable kerbs: These types of kerbs are provided to encourage the traffic to remain in the traffic lanes and also allow the driver to enter the shoulder area with little difficulty. The height of this kerb is about 10cm above the pavement edge with a slope which allows the vehicle to climb easily. This is usually provided at middle of the road as medians and also aid the drainage of flood along the length of the road.

b) Semi-barrier type kerbs: These types of kerb of kerb are provided when the pedestrian traffic is high. They have a height which is 15cm above the pavement edge. This type of kerb prevents encroachment of parking vehicles into the carriageway, during emergency situation it is possible to drive over this kerb with some difficulty.

c) Barrier type kerbs: They are designed to discourage vehicles from leaving the road path, usually provided when there is considerable amount of pedestrian traffic. They are placed at a height of 20cm above the pavement edge with a steep batter.

d) Submerged kerbs: They are used in rural roads, usually provided at pavement edges between the edge and shoulders. They provide lateral confinement and stability to the pavement.

4. Road margins: These are parts of the road other than the carriageway that ensures the proper usage and safety of road users. The different elements that forms the road margins are:

a) Shoulders: Shoulders are provided at the edge of the carriageway and mostly used for the accommodation of stopped vehicles, also as an emergency lane and provide lateral support for base and surface courses. In adverse weather condition, the shoulder should be able to support the maximum load it is designed for, the width should be adequate for vehicles to stop without affecting the usual flow of traffic.

b) Parking lanes: A parking lane as the name implies, is used for the parking of vehicle. It should preferably be parallel to the roadway in order for it to be safe for moving vehicles on the road.

c) Service roads: Service roads are adjacent road that give access to controlled highways like freeways and expressways. They are parallel to the highway and usually isolated by a median with access to the highway given at selected points. These roads are provided to prevent congestion in the expressways

d) Cycle track: These are tracks or roads provided in an urban area where the volume of cycle traffic is high to reduce degree at which traffic congestion occur.

e) Footpath: there are exclusive right of way to pedestrians in urban areas as they provide safety for pedestrians in the case when both the traffic volume of pedestrians and vehicles is high.

f) Guard rails: They are provided at the edge of the shoulder usually when the road is on an embankment. They serve to prevent the vehicles from running off the embankment usually when the height of the fill is very high. For high visibility of curves during the night under a vehicles headlight, Guard stones are usually painted in alternate black and white pattern.

5. Width of formation: Width of formation or roadway width is the total sum of the widths of carriageway in addition to the width of other road margins such as the median and shoulders.

6. Camber: Camber is the cross slope provided to raise the middle of the road surface in the transverse direction to drain off rain water from the road surface. The reasons for the provision of a camber in roadway are

i. Surface protection
ii. Sub grade protection by proper drainage
iii. Quick drying of pavement for increased safety

2.1.2 Characteristics Of A Pavement

They are different characteristics that a pavement should possess that will enhance its performance and make it durable. These characteristics are given by CETC (2021) as the following:

a. It should have sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil,
b. It should be structurally strong to withstand all types of stresses imposed upon it
c. It should provide adequate coefficient of friction to prevent skidding of vehicles
d. It should have a smooth surface to provide comfort to road users even at high speed
e. It should produce low or no noise from moving vehicles,
f. The pavement surface should be dust proof so that traffic safety is not impaired by reducing visibility
g. The surface of the pavement should be impervious, so that sub-grade soil is well protected
h. The pavement should have a long design life with low maintenance cost.

2.1.3 Application of Pavements

There are different types of pavements which are used for various activities and are most times dependent on the traffic load generated around the area, the speed of the users of the road and most important the type of load expected on the pavement. Therefore, the applications of pavements (Nick Thom, 2014) are listed below;

a) High-speed highways
b) Urban Roads
c) Estate Roads
d) Rural Roads

e) Pedestrian areas and cycle paths

f) Car, coach and lorry parks

g) Ports and heavy industrial floor

h) Airport runways

2.2 The Structure of Pavements

A pavement is a system made of layer constructed from geomaterials, designed and built to serve as physical transportation infrastructure. The structure of a pavement is typically divided into the different distinct layer with each layer with its contribution to the overall load bearing and distribution ability of the pavement. Material layers are usually arranged within a pavement structure in order of descending load bearing capacity with the highest load bearing capacity material on the top and the lowest load bearing capacity material on the bottom

i. Surface layer
ii. Subbase layer
iii. Base layer
iv. Subgrade layer

i. **Surface Course**

The surface layer is the uppermost layer of the pavement which is in direct contact with the traffic load, it provides smoothness, skid resistance and waterproofing. The surface course is subdivided into two layers which are the top wearing course and the binder course at the bottom. (Brown et al, 2015) describes the surface course as waterproof and also prevents ingress of water into the lower pavement layers, which would adversely affect their strength ensuring structural integrity over time. The surface course is either made from hot mix asphalt or Portland cement concrete. These layers must be strong enough not to rut under the action of traffic. The surfacing may be susceptible to cracking due to fatigue or from cracks reflecting upward from cracked base layers.

ii. **Base Course**

The layer immediately beneath the surface course. Mills and Smith (2015) described the base layer as the primary load bearing stratum that ensures long term pavement stability. The base layer's function is to distribute the traffic-induced stresses at the bottom of the surfacing layers widely and evenly onto the foundation section. It can be formed from either compacted unbound aggregate, or a bitumen bound aggregate layer and in some cases cement bound aggregate is used.

iii. **Subbase Course:**

The subbase course is the layer between the base course and subgrade. It functions mainly as a structural support and also minimize the intrusion of fines from the subgrade into the pavement structure (Johnson et al., 2015) and improve drainage. The subbase generally consists of lower quality materials than the base course but better than the subgrade soils. A subbase course is not always used as a pavement layer in the construction of a some type of road. Subbase courses are generally constructed out of crushed aggregate or engineered fill.

iv. **Subgrade Course:**

The subgrade course is the foundation of the pavement that contains natural soil which is compacted to achieve the desired strength and stability. Taylor and Anderson (2015) stated that the condition of the subgrade course greatly influences the performance of a pavement, which necessitates proper soil preparation and evaluation. The upper surface of the subgrade is known as the formation. If the road surface is to be constructed below the original ground level, the formation will be in a cutting, whereby the material is excavated to the required depth but if the level of road surface is above the ground level, the formation will be filled with materials to the required depth.

2.2.1 Classification of Pavement Surfaces

The classifications of highway pavement structures are typically divided into three main categories based on their structural behaviour and composition, as well as their intended functions. Each type of pavement utilizes various materials and construction techniques, leading to distinct physical characteristics. (Andrew Lees, 2021).The different types of pavement along with their characteristics are listed below;

i. Flexible pavements
ii. Rigid pavements
iii. Composite pavements

i. Flexible pavement

In flexible pavements, loads are transferred to the subgrade through grain-to-grain interactions at the points of contact within the granular structure. The stresses from the wheel loads acting on the pavement are spread over a broader area, and the stress diminishes with depth (Andrew Lees, 2021). Flexible pavements are types of pavement that are topped with bituminous or asphalt materials. These can include surface treatments like bituminous surface treatments or hot mix asphalt surface layers (Mills et al, 2015). Flexible pavements can exhibit deflection or bending under traffic loads. The structure of a flexible pavement consists of multiple layers of materials that accommodate such flexing. This type of pavement employs a more pliable surface layer and distributes loads across a smaller area. It depends on a combination of layers to transmit the load to the subgrade. The expected lifespan of flexible pavements is generally around 20 years. Failures may arise due to rutting, cracking, or the aging of asphalt layers. Regular upkeep of the surface layer can significantly extend the lifespan of the pavement.

ii. Rigid Pavement

When rigid pavements are constructed, a concrete slab reinforced with steel bars or mesh is placed over a prepared subbase (Brown et al., 2018). Loads are supported by the pavement's flexural strength, functioning as a stiff plate that redistributes the load over a wider area of the subgrade (Andrew Lees, 2021). Rigid pavement can either consist of a cement concrete slab or cement reinforced concrete laid directly on the subgrade or an enhanced subgrade using a dry lean concrete layer.

In rigid pavements, it is crucial to manage joints effectively through adequate reinforcement or aggregate interlocking. The design is determined by the slab's stiffness, which is supported by the subgrade soil's stiffness. Concrete roads represent rigid paving types, often featuring joints in the concrete to prevent cracking. Rigid pavements comprise a PCC surface course that is significantly "stiffer" than flexible pavements due to the high modulus of elasticity of the PCC material. Additionally, these pavements may include reinforcing steel, which is typically used to reduce or eliminate joints. Concrete road pavements can accommodate very heavy traffic and high axle loads, making them increasingly prevalent in urban centers, ports, and areas with slow-moving heavy trucks. These pavements are durable and require low maintenance but entail high initial construction costs and complex repair processes (Smith and Clark, 2019). The typical lifespan of a rigid pavement is around 40 years, with failures primarily due to slab cracking or degradation at the joints.

2.2.2 Types of Rigid Pavement

Rigid pavements are made of concrete and are designed to distribute loads over a wide area, providing a durable and long-lasting surface for roads, airports, and other heavy-duty applications. There are three common types of rigid pavement:

a) Jointed Plain Concrete Pavement (JPCP)

JPCP, the most commonly used type of rigid pavement, consists of elongated concrete slabs with both transverse and longitudinal joints. To control cracking caused by the natural expansion and contraction of concrete with temperature changes, transverse joints are regularly spaced. Longitudinal joints, which are located at the edges of the pavement, provide lateral support to the slabs. JPCP is a cost-effective and relatively simple pavement to construct

b) Jointed Reinforced Concrete Pavement (JRCP)

JRCP is similar to JPCP but includes steel reinforcement integrated into the concrete slabs. This reinforcement helps manage cracking and boosts the overall strength of the pavement. It is often used in areas that anticipate heavy truck traffic or substantial wheel loads.

c) Continuously Reinforced Concrete Pavement (CRCP)

CRCP is a type of rigid pavement characterized by the absence of transverse joints and continuous steel reinforcement throughout the pavement section. This continuous reinforcement removes the need for joint maintenance and reduces the risks of faulting and pumping. CRCP is commonly utilized on highways and roads subjected to heavy traffic loads.

iii. Composite pavement

Composite pavements have been researched extensively worldwide. They consist of either a high-quality, relatively thin hot asphalt layer placed over a new Portland cement concrete

(PCC) structural layer, or a relatively thin PCC surface positioned atop a thicker PCC structural layer (TRB, 2014). An asphalt surface is laid over an existing or new concrete slab to improve durability and ride quality (Anderson and Taylor, 2020). Composite pavement has demonstrated exceptional surface characteristics that can be quickly renewed, along with long-lasting structural capacity suitable for any traffic level Such composite pavements offer considerable flexibility for engineers to optimize pavement design concerning life-cycle costs, reducing future lane closures, and enhancing sustainability.

2.3 Introduction to Asphalt Pavement

Flexible asphalt pavements consist of a layered system, with the upper bound layers and the lower unbound layers resting on a subgrade. The upper portion is composed of various asphalt layers—surface, binder, regulation, and base—primarily made from mineral aggregates held together by a bitumen binder. Bitumen, a byproduct of the petroleum refining process (Hu et al., 2022), is a complex material whose properties are highly temperature-sensitive. It behaves as a brittle solid in cold conditions and transforms into a viscous fluid at higher temperatures (Speight, 2016). This temperature-dependent rheology is critical to asphalt mixture performance, requiring the binder to be flexible enough to prevent cracking in cold weather while maintaining sufficient stiffness to resist rutting under hot conditions. The pavement's durability, especially when exposed to moisture, also relies on the bond between the bitumen and the aggregates (Cui et al., 2014).

With climate change driving up temperatures and altering rainfall patterns, it is increasingly important to select materials that can withstand these evolving conditions. This includes using improved asphalt binder grades and optimized aggregate gradation (Swarna et al., 2022). Studies on climate change and infrastructure suggest that both the frequency and severity of pavement deterioration are likely to rise (Mills et al., 2009; Meagher, 2012).

2.3.1 Types of Asphalt Pavements

Asphalt pavements are generally utilized in road construction due to their durability, cost-effectiveness and flexibility. Asphalt pavements are categorized based on their structure, application, and composition. The different types of asphalt pavements include hot mix asphalt (HMA), warm mix asphalt (WMA), cold mix asphalt (CMA), porous asphalt, and perpetual pavement. Each pavement type has its specific characteristics that makes it suitable for different environmental conditions and traffic loads.

i. Cold Mix Asphalt (CMA)

Cold mix asphalt (CMA) is created at ambient temperatures by utilizing bitumen emulsions or cutbacks to coat aggregates. It doesn't require heating like both hot mix asphalt (HMA) and warm mix asphalt (WMA), making it a more sustainable option (Miller et al., 2017). Typically, Cold Mix is prepared by mixing aggregate, bitumen emulsion, and a small quantity of water, resulting in a workable mixture that can be applied to the road surface. After being compacted, it is left to cure, forming a sturdy and long-lasting surface.

ii. Hot Mix Asphalt (HMA)

Hot mix asphalt (HMA) is the most widely used type of asphalt pavement for road construction. It is made by heating asphalt binder and aggregates to high temperatures ranging from 150°C to 190°C before mixing and laying (Brown et al., 2018). The mixture is then transported to the work site, where it is placed and compacted while still hot. The elevated temperature ensures that the aggregates are adequately coated and enhances the mix's workability. HMA is a flexible and robust choice for various projects, but it necessitates careful handling and skilled workers to ensure correct installation.

iii. Warm Mix Asphalt (WMA)

Warm mix asphalt (WMA) is a modified version of hot mix asphalt, typically produced at lower temperatures between 100°C and 140°C. It employs additives, foamed bitumen, or organic waxes to decrease viscosity and enhance workability (Anderson & Taylor, 2021). Warm asphalt mix is an innovative solution that provides numerous advantages, including lower emissions and energy consumption, more flexibility during application, and suitability for a variety of projects such as roads, highways, and airports, among others.

iv. Porous Asphalt

Porous asphalt is engineered with a high percentage of interconnected air voids, generally between 15 to 20%, to facilitate water infiltration. It is composed of a standard asphalt mix but lacks finer aggregates, making it highly permeable (Brown et al., 2019). This type of asphalt is specifically designed to allow water to flow through the surface, mitigating the risk of flooding and erosion. It is produced using a unique combination of aggregates and asphalt binder that creates small voids in the surface, permitting water to pass through to the subgrade. Porous asphalt is a sustainable and innovative option that is environmentally friendly, benefits stormwater management and water quality, can be coloured and stamped for distinctive surfaces, helps reduce the "urban heat island" effect, and lessens the need for conventional drainage systems.

v. Perpetual Asphalt

Perpetual pavement is a multi-layered asphalt structure designed to endure for over 50 years with minimal structural upkeep. It features three main layers: the high-quality and rut-resistant surface layer, the flexible and fatigue-resistant intermediate layer, and a strong base layer that provides a durable foundation to effectively distribute loads (Smith & Clark, 2019).

2.3.2 Importance of Asphalt Pavements

Asphalt pavements are integral to modern transportation systems, offering a reliable, economical, and adaptable surface solution for roads, highways, airports, and parking areas. Their widespread adoption stems from their capacity to endure significant traffic stress and diverse environmental conditions. The following points highlight the key advantages of asphalt pavements in highway construction:

i. Durability and Longevity: Asphalt pavements are favoured for their long service life. When properly designed and maintained, they can perform effectively for 15 to 30 years, influenced by traffic intensity, climate, and upkeep practices (Brown et al., 2018). Their resistance to wear makes them suitable for busy roads. Moreover, surface repairs can be carried out without disturbing the underlying structure, thereby extending the pavement's lifespan and reducing maintenance costs when compared to rigid alternatives like concrete (Johnson & Smith, 2017).
ii. Cost-Effectiveness: Compared to rigid pavements, asphalt options are more economical to build and maintain. Their lower initial construction cost makes them a practical choice for public agencies and contractors. Asphalt's flexible nature allows for phased construction, facilitating gradual road network expansion (Taylor et al., 2020). Regular, low-cost maintenance such as sealing cracks or adding overlays helps prolong service life.
iii. Reduced Noise Pollution: The smooth texture of asphalt absorbs sound better than concrete, helping to reduce traffic noise levels (Miller et al., 2017). This feature contributes to decreased noise pollution in urban and suburban areas.
iv. Energy Efficiency: Asphalt production and installation consume less energy than concrete, resulting in fewer carbon emissions during construction (Anderson & Taylor, 2021).

v. Recyclability: Asphalt is fully recyclable. Existing pavement can be reclaimed and reused in new road construction, minimizing the demand for new raw materials (Smith & Clark, 2019).

vi. Permeability Options: Specialized types, like porous asphalt, allow water to pass through the surface, which helps reduce runoff and promotes groundwater recharge.

vii. Smooth Surface: A well-laid asphalt pavement ensures a smooth and comfortable driving experience, reducing vehicle wear and tear while improving fuel efficiency (Brown et al., 2019).

viii. High Skid Resistance: Asphalt pavements provide good friction between tires and the road surface, reducing the risk of accidents caused by skidding (Taylor & Johnson, 2018).

ix. Adaptability to Climate Conditions: Asphalt pavements adjust well to various climates. In colder areas, they flex with temperature changes, resisting cracking, while in hotter climates, modified binders help prevent deformation from heat (Anderson et al., 2021)

2.3.3 Functions of an Asphalt pavement

They are various reasons why an asphalt pavement is constructed, this reason are closely linked to it's functions. These functions are given below;

i. Capacity to Handle Traffic Loads: Asphalt pavements are specifically designed to endure varying traffic loads. Highways and expressways require robust asphalt mixtures that can resist rutting and fatigue, whereas local streets typically use standard-grade asphalt (Johnson et al., 2016). The inherent flexibility of asphalt allows it to absorb fluctuations in load intensity without cracking or failing, making it suitable for use in roads, airports, and parking areas (Taylor et al., 2020).

ii. Waterproofing and Drainage Capabilities: A critical function of asphalt is to shield the pavement structure from water infiltration. Its impermeable nature prevents moisture from reaching the underlying layers, preserving structural integrity and preventing early deterioration (Smith & Clark, 2019). Additionally, porous asphalt variants are designed to allow water to drain through the surface, reducing pooling and enhancing safety during rainfall (Miller et al., 2017).

iii. Structural Load Distribution: Asphalt pavements are engineered to distribute vehicular loads evenly across the subgrade, minimizing deformation and the risk of structural failure.

iv. Visual Appeal and Urban Development: Asphalt enhances the visual quality of urban spaces, offering clean and uniform surfaces. Colored asphalt is often used in designated lanes for pedestrians, cyclists, and buses, improving organization and safety in urban traffic (Miller et al., 2017). Furthermore, the rapid installation and maintenance of asphalt pavements support the swift growth of urban infrastructure (Brown et al., 2019).

v. Smoothness and Driving Comfort: Smooth asphalt surfaces contribute to a comfortable driving experience while lowering fuel use and reducing vehicle wear. Uneven roads can lead to higher fuel consumption and maintenance costs (Smith et al., 2020). Innovations like Superpave mix designs further enhance smoothness and durability by tailoring materials to specific traffic and climate conditions (Johnson & Smith, 2017).

vi. Noise Mitigation: Asphalt is effective in reducing road noise due to its ability to absorb sound. Research shows that porous asphalt can reduce noise by up to 5 decibels compared to traditional surfaces (Anderson & Taylor, 2021). This makes it especially advantageous for use in residential neighbourhoods and along busy highways where noise control is important.

2.4 Asphalt Pavement Materials

Asphalt pavement materials are the building blocks used in construction of a pavement (Nick Thom, 2014). These materials, their associated properties, and their interactions determine the properties of the resultant pavement. The pavement industry deals in high-volume, low-cost materials. The choice of materials is then limited to those that can be easily and cheaply produced in large quantities which inevitably means the raw materials of the earth, namely rock, sand and clay.

In achieving a desirable pavement, there are various materials each with its unique properties and qualities that are used in the construction of asphalt pavements. These materials are classified into

a. Soil
b. Granular materials (Aggregate)
c. Bitumen

2.4.1 Soil

Soil is a naturally occurring, unconsolidated material composed of minerals, organic matter, water, and air. It forms the uppermost layer of the Earth's crust and serves as a critical component in engineering, agriculture, and environmental sustainability. Soil develops over thousands of years through the weathering of rocks and minerals, influenced by factors such as climate, biological activity, and topography (Das, 2017).

In civil engineering, soil is fundamental for infrastructure development, serving as the foundation for roads, buildings, bridges, and embankments. Understanding soil behaviour is crucial for designing stable and durable structures. The study of soil mechanics helps in analysing the load-bearing capacity, permeability, and settlement characteristics of different soil types, ensuring the safety and longevity of construction projects (Holtz et al., 2021).

2.4.1.1 Types of Soil

Soils are classified based on their particle size, composition, and physical properties. The primary types of soil include gravel, sand, silt, clay, and loam.

i. Gravel: Gravel comprises coarse rock particles larger than 2 mm in diameter. It features high permeability and excellent drainage properties, making it ideal for use in road base layers, building foundations, and drainage systems. Its strong shear resistance enhances stability and minimizes settlement issues in geotechnical applications (Coduto, 2019)
ii. Sand: It consists of granular particles ranging from 0.06 mm to 2 mm. It is non-cohesive, drains quickly, and resists frost action. These characteristics make it suitable for use in concrete, masonry, and as a foundation stabilizer (Bowles, 2020).
iii. Silt: Silt is a fine-textured soil with particles between 0.002 mm and 0.06 mm. It retains moisture well and offers moderate drainage but is vulnerable to erosion. Commonly found in floodplains, riverbanks, and lakebeds, silt contributes to soil fertility but poses challenges in construction due to its tendency to compress under load (Craig, 2019).
iv. Clay: it consists of extremely fine particles, smaller than 0.002 mm, and exhibits high plasticity. It expands significantly when wet and has very low permeability, making drainage difficult. Clay is commonly used in dam construction, embankments, and waterproofing applications. However, its tendency to shrink and swell presents engineering challenges that require stabilization techniques (Das, 2017).
v. Loam: Loam is a well-balanced blend of sand, silt, and clay. It combines good moisture retention with effective drainage and air circulation, making it ideal for agricultural

use. Its rich nutrient content and versatility also make it valuable in landscaping and soil reinforcement projects (Holtz et al., 2021).

2.4.1.2 Soil Classification

Several classification systems are used to categorize soils based on their engineering properties and suitability for construction.

i. The USCS is commonly used in geotechnical and civil engineering, especially for designing foundations and roadways. It classifies soils into two main categories: coarse-grained (such as gravel and sand) and fine-grained (such as silt and clay), depending on particle size and plasticity characteristics. Typical soil designations include well-graded gravel (GW), poorly graded sand (SP), low-plasticity clay (CL), and high-plasticity silt (MH) (Coduto, 2019).
ii. The American Association of State Highway and Transportation Officials (AASHTO) classification system is used for pavement and highway engineering. It divides soils into granular soils (A-1 to A-3) and silt-clay soils (A-4 to A-7) based on grain size and plasticity index (Bowles, 2020).

2.4.1.3 Properties of the Soil

Soil exhibits a range of physical, mechanical, and chemical characteristics that influence its performance in civil engineering applications. A thorough understanding of these properties is essential for civil engineers, geotechnical experts, and environmental scientists to ensure the safe, stable, and efficient use of soil in construction and land development.

i. Bearing capacity is the ability of soil to support loads from structures without undergoing excessive settlement or failure. Sandy soils typically have high bearing capacity, while clayey soils require stabilization techniques to improve load-bearing performance (Craig, 2019).

ii. Soil structure pertains to how individual particles are grouped together into aggregates or peds. It plays a vital role in determining water infiltration, aeration, and root development. Common structural types include granular, blocky, platy, and columnar forms. Granular structures, typical in topsoil, enhance drainage, while blocky and columnar structures, often found in subsoils, influence compaction and stability (Coduto, 2019).

iii. Soil texture is defined by the relative content of sand, silt, and clay in a soil sample. These proportions affect water retention, fertility, and load-supporting capability. The USDA classification system categorizes soil textures as sandy, silty, clayey, and loamy, each with distinct implications for construction and agriculture (Das, 2017).

iv. Expansive soils, such as clay, exhibit swelling when wet and shrinkage when dry. This property causes structural damage to buildings and pavements, requiring soil stabilization methods such as lime or cement treatment to mitigate movement (Holtz et al., 2021).

v. Compressibility describes a soil's tendency to reduce in volume under loading. Highly compressible soils like clay can undergo substantial settlement over time, potentially compromising foundation integrity. Engineers use consolidation testing to predict this behaviour and design suitable foundations (Bowles, 2020)

2.4.1.4 Methods of Soil Stabilization

Soil stabilization is a crucial process that enhances soil strength, durability, and performance in construction projects. It is an essential practice in civil engineering aimed at improving the strength, stability, and overall performance of soil for construction purposes. Various techniques are used depending on soil conditions and engineering requirements. These techniques are

i. Mechanical stabilization involves physically enhancing soil properties through methods such as compaction, blending with other soils, and proper grading. It improves load-bearing capacity without changing the soil's chemical nature, making it well-suited for roadbeds, embankments, and foundations (Das, 2017).

ii. Chemical stabilization utilizes additives such as lime, cement, and bitumen to alter soil properties. Lime reduces plasticity and improves the strength of clay soils, making it an effective stabilizer in expansive soils. Cement enhances soil bonding, increasing compressive strength, while bitumen improves waterproofing and reduces permeability, making it suitable for road construction.

i. Geosynthetics stabilization involves the use of geotextiles and geogrids to reinforce soil structures. These materials provide additional strength, prevent erosion, and improve load distribution in construction projects, particularly in weak or loose soils (Bowles, 2020).

ii. Electrochemical stabilization employs electrical currents to reduce soil moisture and improve soil cohesion. This method is particularly useful for fine-grained soils with high water content, enhancing their stability for engineering applications (Craig, 2019).

iii. Biological stabilization involve the use of vegetation and bioengineering strategies to control erosion and reinforce slopes. Plant root systems bind soil particles, enhancing natural stability and reducing landslide risk. This eco-friendly technique is commonly used in slope restoration and environmental conservation projects.

2.4.2 Granular Materials

Granular material is unbound material with relatively large particle sizes, and includes natural gravel, crushed rock and granulated industrial by-products such as slag from steel production. They form the major portion of pavement structure and form the prime materials used in pavement construction. Granular materials have to bear stresses occurring due to the wheel loads on the pavement and on the surface course they also have to resist wear due to abrasive action of traffic. These are used in pavement construction in cement concrete, bituminous concrete and other bituminous constructions and also as granular base course underlying the superior pavement layers. Therefore the properties of the aggregates are of considerable significance to the highway engineers. They form the foundation layers (subbase and base courses) in pavements and play a vital role in load distribution, drainage, and structural integrity.

2.4.2.1 Origin of Aggregates

Most aggregate particles are gotten from two processes which are

I. Natural rock formation
II. Waste products from industrial process as slag

I. Natural rock formation

Rocks gotten from natural processes are classified into three types which are

i. Igneous rocks:

These rock types are crystalline in nature and are formed from the cooling of motten magma from the earth crust. Igneous rocks are further classified into rocks based on grain size and rocks based on composition

Igneous based on grain size

a) Coarse rocks: These are igneous rocks whose grain sizes are greater than 2mm
b) Medium: These are igneous rocks that their sizes ranges between 0.2mm to 2mm
c) Fine: These are igneous rocks that possess grain sizes less than 0.2mm

Igneous rocks based on composition

a) Felsic Rocks

   Rocks with silica content greater than 65% by weight with a relatively high content of potassium and sodium.

b) Intermediate Rocks

   Igneous rocks with silica content between 55% to 65% in weight in addition to a significant amounts of dark ferromagesian minerals like pyroxene and amphibole as well as light coloured plagioclase feldspar and small amounts of quartz.

c) Magic Rocks

   These are rocks with between 45% to 55% by weight of silica in addition to oxides of aluminium, calcium, magnesium and iron

d) Ultramafic Rocks

   Ultramafic rocks contains less than 45% of silica but it is rich on the oxides of iron, magnesium and calcium.

ii. Sedimentary rocks

These are rocks formed from the deposition of insoluble granular material resulting from the disintegration of pre-existing rocks or from the inorganic remains of marine and animals which are deposited in great quantities on the sea floor. These rocks are deposited in layers, that is they have stratified structure. Sedimentary rocks are classified into

a) Detrital rocks: They are rocks formed from the weathered and eroded remains of bedrock

b) Chemical rocks: These are rocks are precipitated from a low temperature aqueous environment either through inorganic processes or by the actions of organisms.

c) Organic rocks: These are rocks formed the continuous decay and compaction of dead plants and animals.

iii. Metamorphic rocks

These are sedimentary or igneous rocks that have been subjected to great heat or to great pressure or both, that has resulted in the formation of minerals and in textures different from those of the original rock.

2.4.2.2 Requirements of Pavement Aggregates

a) It should be crushed.

b) It should be clean, hard, durable and cubical in shape.

c) It should be free from the dust, organic matter and other deleterious matter.

d) It should not be flakey or elongated.

e) It should not consist of injurious or harmful materials such that they reduce the strength of structure.

f) It should be able to resist wear due to abrasive action of traffic on the surface course

2.4.2.3 Properties of Granular Materials Used In Pavements

a) Gradation: Granular materials are classified based on their particle size distribution, known as gradation. The grading influences how well the material compacts, its stability, and its ability to drain water. Well-graded aggregates, which include a wide range of particle sizes, are preferred as they compact into a dense and stable structure.

b) Strength: The strength of granular materials is influenced by particle shape and their resistance to crushing. Aggregates intended for pavement surface layers must endure significant stresses from traffic loads. Crushed stone and angular aggregates offer superior interlocking, enhancing load support. The resilient modulus (Mr) is commonly used to measure the stiffness and elastic recovery of granular materials under repeated loading.

c) Permeability: Adequate permeability is essential for granular layers to facilitate drainage and prevent water buildup within pavement systems. This is especially critical in flexible pavements, where trapped moisture can compromise structural integrity and lead to failure of the subgrade.

d) Durability: Long-term performance of pavements depends on the durability of the materials used. Granular materials should be resistant to weathering, moisture damage, and the effects of freeze-thaw cycles. Durable aggregates help maintain structural integrity and reduce maintenance needs over time..

e) Hardness: Surface course aggregates must resist abrasion from vehicular traffic. Therefore, materials selected for the top layers of pavement should be sufficiently hard to withstand wear from continuous vehicle movement.

f) Adhesion with bitumen: Aggregates in asphalt mixtures must exhibit strong adhesion to bitumen while having minimal affinity for water. Poor adhesion can lead to stripping, where bitumen is displaced by water, compromising pavement performance. A good bitumen-aggregate bond is essential for durability and resistance to moisture damage

2.4.3 Bitumen

Bituminous materials are essential components in road construction, composed of aggregates bound with bitumen—a viscous, petroleum-derived binder. These materials form the foundation of flexible pavement structures and are widely used for constructing highways, roads, and airport runways due to their adaptability and resistance to both traffic loads and environmental stress. Bituminous materials primarily include either bitumen or tar as their binding agent. Regardless of type, they share common features: strong adhesive properties and a color spectrum ranging from dark brown to black. Their consistency can vary significantly, allowing them to be classified as liquids, semisolids, or solids. In its solid state, bitumen is typically hard and brittle at ambient temperatures, but it can deform and flow under prolonged loading. The liquid form of bituminous materials is produced by either heating solid or semisolid forms, dissolving them in suitable solvents, or dispersing finely broken particles in water using emulsifiers to create asphalt emulsions (Nicolas & Lester, 2009).

2.4.3.1 Sources of Bitumen

Bitumen are typically gotten form both the remains of dead animals and plants and through the process of the refining petroleum.

I. Product of petroleum refining

Bituminous materials derived from petroleum refining are primarily found in various forms of asphalt. The amount of asphalt produced from crude oil depends largely on its American Petroleum Institute (API) gravity; lower API gravity crude oils tend to yield more asphalt. Two refining processes are typically used to obtain bitumen: fractional distillation and destructive distillation.

In fractional distillation, bitumen is left as a residue after crude oil is heated to high temperatures, separating the volatile components. This process produces asphalt that is widely used in road construction due to its stability and resistance to weathering.

Destructive distillation, on the other hand, is used when there is a need for greater quantities of lighter petroleum products. While asphalt is also produced during this process, it is generally less weather-resistant and thus not commonly used for paving applications

II. Natural deposits

Bitumen also occurs naturally and is formed over millions of years from the remains of microscopic algae and other organisms. These remains settled in aquatic environments, where they were buried under layers of sediment. Over time, heat and pressure transformed the organic matter into bitumen and other hydrocarbon materials (Vinod, 2023).

2.4.3.2 Forms/types of Bituminous Materials

i. Bitumen emulsion: Bitumen emulsion is a liquid mixture in which bitumen is finely dispersed in water and stabilized with an emulsifying agent to prevent separation (Vinod, 2023). This emulsion remains stable as long as the water does not evaporate and the emulsifier holds the particles in suspension. Typically, bitumen emulsions contain about 55% to 70% bitumen by weight, along with water and stabilizing agents. Depending on the electric charge on the dispersed particles, bitumen emulsions are classified as anionic, cationic, or non-ionic (Nicolas & Lester, 2009). They are further categorized by their setting time into Rapid Setting (RS), Medium Setting (MS), and Slow Setting (SS) emulsions (Tom & Krishina, 2007). These emulsions are widely used in cold-mix asphalt applications, surface dressing, and pavement maintenance.

ii. Cutback bitumen: Cutback bitumen is produced by blending bitumen with solvents like naphtha, kerosene, diesel, or furnace oil to reduce its viscosity, making it easier to work with in cold weather. This type of bitumen is commonly used in road construction and repair where heating is not feasible. Based on the evaporation rate of the solvent, cutbacks are classified into: Rapid Curing (RC)-used for surface dressing and patchwork, Medium Curing (MC)-suitable for premix work, Slow Curing (SC)-ideal for premix containing significant fine aggregates (Tom & Krishina, 2007). .

iii. Asphalt cement: Asphalt cement is a semi-solid hydrocarbon derived from the distillation of crude oil, typically obtained after the removal of lighter components such as lubricating oils. Due to its strong adhesive and waterproofing properties, it is widely used as a binder in hot-mix asphalt for constructing pavements, airport runways, industrial floors, and parking areas. The application of asphalt cement depends on its grading, which reflects its consistency and performance under specific conditions.

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2.4.3.3 Properties of Bituminous Materials

a) Consistency: The consistency of asphalt materials is highly temperature-dependent. While temperature changes can significantly affect the flow characteristics of asphalt, they do not alter its chemical composition. Different types of asphalt may exhibit varying degrees of consistency change for the same temperature variation

b) Durability: A key attribute of bituminous materials is their durability—the ability to endure repeated traffic loading, temperature fluctuations, and exposure to environmental elements over extended periods without significant degradation.

c) Water Resistance: Bitumen provides excellent water resistance in pavement applications. By preventing moisture infiltration, it protects the underlying pavement layers from water-induced damage, such as weakening of the subgrade or stripping of the binder.

d) Noise Reduction: Certain bituminous materials, like porous asphalt, helps to reduce noise caused by the movement of vehicles over the pavement structure, due to their open structure.

e) Ageing: Over time, bituminous materials undergo ageing due to exposure to air, sunlight, and moisture. These environmental factors cause chemical and physical changes in the material, leading to hardening, loss of flexibility, and eventually, brittleness. This natural deterioration affects the performance and service life of asphalt pavements

2.5 Effect Of Seasonal Variation In Weather On Pavement Performance

The long-term performance of pavements is influenced by a variety of factors, among which environmental and climatic conditions are particularly significant. Climate encompasses long-term patterns in temperature, precipitation, humidity, and other atmospheric conditions observed over several decades. Traditionally, pavement design has relied on the assumption of climate stationarity, which posits that climate conditions remain consistent within a predictable range over time. This assumption has enabled engineers to design infrastructure with acceptable reliability against failure risks. However, recent research challenges the validity of this assumption in light of observed climatic shifts (Lins and Cohn, 2011).

In recent decades, climate change has emerged as a critical concern due to its effects on both natural ecosystems and engineered systems. Pavement structures, in particular, are susceptible to reduced service life resulting from rising temperatures induced by climate change. The increase in greenhouse gas emissions has contributed to a global rise in temperatures since the mid-20th century, with projections indicating further acceleration. Many studies have adopted a top-down approach to assess this risk, applying future climate scenarios to model the reduction in pavement life. Pavement performance is highly sensitive to temperature variations and moisture fluctuations within its sublayers. Elevated temperatures result in reduced stiffness and strength of asphalt layers (Meyer et al., 2014), while increased moisture content diminishes the load-bearing capacity of unbound layers (Mallick and El-Korchi, 2013). The two most influential environmental factors affecting pavement longevity are temperature and water (Qiao et al., 2013).

To enhance sustainability in pavement design, Pereira and Pais (2017) recommend incorporating a climatic databank comprising temperature, moisture, and ageing profiles into design models. This would allow engineers to capture the impact of climate change more effectively across the pavement's life cycle. They further suggest separating core design parameters such as geometry, traffic, climate, materials, and design methodology to enable better integration of performance models and environmental data. The evolution of pavement design methodologies reflects a shift from purely empirical approaches to mechanistic-empirical (ME) methods. The empirical framework widely adopted in the United States is based on the AASHTO Design Guide (AASHTO, 1993), which, while accessible, often oversimplifies complex variables particularly those related to climate (Dumont and Bressi, 2014). The development of the Mechanistic-Empirical Pavement Design Guide (MEPDG) (NCHRP, 2004), which has been updated and refined (AASHTO, 2015; AASHTO, 2018), offers a more nuanced method that explicitly incorporates variations in temperature and moisture into the mechanical behaviour of pavement layers.

According to projections presented by Meyer et al. (2014), average annual temperatures are expected to increase by approximately 2.2°C between 2010 and 2050, based on one of ten climate models analysed. This anticipated rise underscores the necessity for incorporating climate-adaptive strategies into modern pavement design and maintenance planning

2.5.1 Pavement Performance Indicators

There are various indicators used in assessing the performance of a pavement. According to AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG)

2008 Edition, the different indicators of asphalt pavement performance are given as shown;

a) Rut Depth: This is the permanent deformation in each layer of the pavement which is a result of continuous application of wheel load on the pavement which leads to longitudinal surface depression in the wheel path. The rut depth represents the maximum vertical difference in elevation between the transverse profile of the hot mix asphalt surface and a plumb line across the lane width. The unit of rutting calculated is inches or centimeters and it represents the maximum mean rut depth between both wheel paths.
b) Longitudinal Cracking: This is a type of wheel load related cracking that occurs within the wheel path which in nature are predominantly parallel to the line of the pavement center. Longitudinal cracks starts at the surface of the HMA pavement and initially show up as short longitudinal cracks that become connected longitudinally with continued truck loadings. The unit of longitudinal cracking is ft/mile (m/km).
c) Alligator Cracking: This cracking type is a form of fatigue which occurs as a series of interconnected cracks with an alligator pattern that starts at the bottom of the asphalt layers. Alligator cracks initially show up as multiple short, longitudinal or transverse cracks in the wheel path that become interconnected laterally with continued truck loadings. Alligator cracking is a type of crack caused by the wheel load and it is calculated as a percent of total lane area.

d) Transverse Cracking: This type of cracking is not caused by load from a wheel rather it is usually caused by low temperature. It formed in the perpendicular direction to the pavement centerline. The unit of transverse cracking is ft/mile (m/km).

2.6 Previous Contributions to This Research

Pajtim Sulejmani (2020) in his thesis studied the impact of climate change on the durability of asphalt pavement, he concluded that temperature and moisture content have shown significant contributions to explaining the strain at the bottom of the AC layer. Refiloe Mokoena et al (2019) in their research used the present and future climate to predict the pavement binder grades that is suitable roads for the different region in South Africa. Rahma et al (2020) applied two mechanistic-empirical methods to study the effect of climate on asphalt pavement performance in two different locations in France (Bordeaux) and United States (Seattle and Phoenix). The result of their research showed that more permanent deformation was as a result of taking temperature and moisture of unbound materials into consideration. My research will be based on determining the impact the climate has on the performance of Asphalt pavement in terms of rutting.

Chapter Three

METHODOLOGY

3.1 Study Area

Figure 3.1 Map of the Study Area (Source: Google Earth)

The study area of this project work is a section of the newly constructed Irowabaze street that spans from benin technical road (6°22'49''N, 5°37'13''E) to federal government girls college road (6°23'19''N, 5°37'07''E) with a total length of 950m.

3.2 Method of Sample Collection

3.2.1 Climate data collection

The climate data used for the analysis was gotten from the Climate Change Knowledge Portal for Development Practitioners and Policy Makers by the world bank. It is a very high resolution climate model simulation of present-day climate and projections of future climate for Nigeria. The spatial resolution of the model simulation over Nigeria was 25 by 25 km. The regional climate model used to create the high-resolution dataset was Coupled Model Inter-comparison Projects (CMIPs) from the global climate model overseen by the

World Climate Research Program. Data presented is CMIP6, derived from the Sixth phase of the CMIPs. The CMIPs form the data foundation of the IPCC Assessment Reports.

3.2.2 Properties of the Asphalt Pavement

The properties of the asphalt pavement of the study was obtained through site investigation of the study area. The properties such as the thickness of the different layers were obtained for use in this study from through the investigation of the site.

3.3 Methods of Analysis

3.3.1 Determination of the Rut Depth of the Asphalt Pavement

The rut depth of an asphalt pavement is a measure of the surface distortion caused by the vertical deformation in the asphalt layer, unbound layers, and foundation soil. The approach used is based upon calculating incremental distortion or rutting within each sublayer using the MEPDG. The plastic deformation for a given season is the sum of the plastic vertical deformations within each layer. The model for calculating total permanent deformation uses the plastic vertical strain under specific pavement conditions for the total number of trucks within that condition. Conditions vary from one month to another, so it is necessary to use a special approach called the "strain hardening" approach to incorporate those plastic vertical strains within each month in a cumulative deformation subsystem.

$$\nabla_{P(HMA)} = \varepsilon_{P(HMA)} h_{HMA} = \beta_{1r} k_z \varepsilon_{r(HMA)} 10^{K_{1r}} n^{k_{2r}\beta_{2r}} T^{k_{3r}\beta_{3r}} \qquad (3.1)$$

where

$\nabla_{P(HMA)}$= Accumulated permanent vertical deformation in HMA layer, in

$\varepsilon_{P(HMA)}$= Accumulated permanent vertical axial strain in the HMA layer, in/in

$\varepsilon_{r(HMA)}$= Resilient or elastic strain calculated by the structural response model at the mid-depth of each HMA sublayer, in/in

h_{HMA} = Thickness of the HMA layer/sublayer, in

n = Number of axle-load repetitions

T = Mix or pavement temperature, °F

$k_{1r,2r,3r}$ = Global field calibration parameters (from the NCHRP 1-40D recalibration;

k_{1r} = –3.35412, k_{2r} = 0.4791, k_{3r} = 1.5606)

β_{1r}, β_{2r}, β_{3r}, = Local or mixture field calibration constants; for the global calibration, these constants were all set to 1.0

k_z = Depth confinement factor

$$k_z = (C_1 + C_2 D)0.328196^D \tag{3.2}$$

$$C_1 = -0.1039(H_{HMA})^2 + 2.4868H_{HMA} - 17.342 \tag{3.3}$$

$$C_2 = -0.0172(H_{HMA})^2 - 1.7331H_{HMA} + 27.428 \tag{3.4}$$

Where

D= Depth below the surface, in

H_{HMA}= Total HMA thickness, in

$$\nabla_{P(soil)} = \beta_{sl} k_{sl} \varepsilon_v h_{soil} \left(\frac{\varepsilon_o}{\varepsilon_r}\right) e^{\left(\frac{p}{n}\right)^{\beta}} \tag{3.5}$$

where:

$\nabla_{P(soil)}$= Permanent or plastic deformation for the layer/sublayer, in.,

n = Number of axle-load applications,

ε_o = Intercept determined from laboratory repeated load permanent deformation tests,

ε_r = Resilient strain imposed in laboratory test to obtain material properties eo, e and ρ,

ε_v = Average vertical resilient or elastic strain in the layer/sublayer and calculated by the structural response model, in/in.,

h_{soil}= Thickness of the unbound layer/sublayer, in.,

k_{sl}= Global calibration coefficients; k_{sl}=1.673 for granular materials and 1.35 for fine-grained materials.

$$\log \beta = -0.61119 - 0.017638(W_c) \qquad 3.6$$

$$p = 10^9 \left(\frac{C_o}{(1-(10^9)^{\beta})}\right)^{\frac{1}{\beta}} \qquad 3.7$$

$C_o = 0.0075$

$W_c = Water\ content,$%

The standard error of the rut depth is the sum of the standard error for the HMA and unbound layer rut depths and is a function of the average predicted rut depth. The standard error of the individual layers is given below:

$$S_{e(HMA)} = 0.1587(\nabla_{HMA})^{0.4579} + 0.001 \qquad 3.8$$

$$S_{e(Gran)} = 0.1169(\nabla_{Gran})^{0.5303} + 0.001 \qquad 3.9$$

$$S_{e(soil)} = 0.1724(\nabla_{soil})^{0.5516} + 0.001 \qquad 3.10$$

3.3.2 Viljoen Model for Pavement Temperature

The pavement temperature is estimated using the Viljoen's model, which was developed from empirically derived algorithms based on recorded pavement temperatures and the zenith angle which accounts for the seasonal and diurnal effect on the pavement temperatures. The algorithms were able to predict 80% of the recorded asphalt pavement temperatures within a margin of 3°C using the same dataset from the study by (Everitt et al, 1999). In developing the algorithm, best fit values for variables in the energy balance equation were identified. The variables were asphalt surface heat transfer coefficient, transmission coefficient of air, the conductivity of the asphalt material, asphalt absorptivity and emissivity of the asphalt surface.

The Viljoen algorithms is used in this study to compute the 31-day maximum and minimum pavement temperature obtained from the air temperature data obtained from the climatic model data. This is the design temperature range and is representative of the asphalt pavement layer 20 mm below the pavement surface. This model will also be used to determine the pavement temperature at different depth of the pavement.

$$T_{S(\max)} = T_{air(\max)} + 24.5(\cos Z_n)^2 . C \qquad 3.11$$

Where:

$T_{s(max)}$ = the daily maximum asphalt surface temperature in ºC

$T_{air(max)}$ = the daily maximum air temperature in ºC

Zn = Zenith angle at midday

C = Cloud cover index with: C = 1.1 if $T_{air(max)} > 30$ ºC

C = 1.0 if monthly mean air temperature < $T_{air(max)} < 30$ ºC

C = 0.25 if $T_{air(max)}$ < monthly mean air temperature

Zenith angle is a function of the solar declination as shown in below:

$\cos Z_n$= sin(latitude).sin(declination)+cos(latitude).cos(declination)

An approximation of the solar declination is provided in (3) below:

$$Declination = -23.45°. \cos\left(\frac{360°}{365}.(N+10)\right) \qquad 3.12$$

Where N = Day of the year (first day of January =1)

$$T_{d(\max)} = T_{s(max)}(1 - 4.237 \times 10^{-3}d + 2.95 \times 10^{-5}d^2 - 8.353 \times 10^{-8}d^3) \qquad 3.13$$

Where:

$T_{d(max)}$ = Maximum daily asphalt temperature at depth d in ºC

$T_{s(max)}$ = Maximum daily asphalt surface temperature in ºC

d = depth in mm.

The minimum pavement temperature given by the Viljoen model is

$$T_{s(\min)} = 0.89T_{air(\min)} + 5.2 \qquad 3.14$$

Chapter Four

RESULTS AND DISCUSSION

4.1 Properties of the pavement

The pavement used for the construction of the road used as the study area is a hot mix asphalt pavement, it has four layers which are the surface course, base layer, the subbase layer and the subgrade. The thickness of the layers of the pavement is given as follows; the asphalt surface is 50mm, the base layer is 150mm and the subbase layer is 150mm.

4.2 Maximum Pavement Temperature

The maximum temperature of the pavement was determined for the month of January using data collected from the site. The temperature of the pavement was determined at the surface and 50mm, 100mm, 150mm and 200mm below the surface for each day using the viljoen model. The results are represented using graph of the temperature against the day of the month.

4.2.1 Maximum pavement temperature at the surface

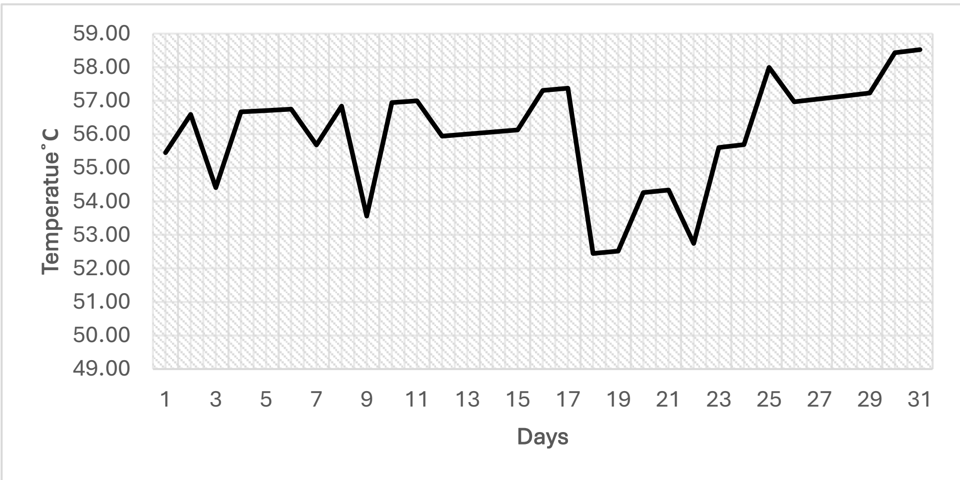

Figure 4.1 Graph of daily maximum pavement temperature at the surface

The figure 4.1 shows the changes in the maximum temperature at the surface of the pavement for the duration of a month. The highest maximum temperature that was experienced at the surface of the pavement during the month was 58.52℃ on the 31st day of the month. The standard deviation of the maximum temperature at the surface of pavement is ± 1.6℃ with the coefficient of variation equal to 2.86%.

4.2.2 Maximum pavement temperature at 50mm below the surface

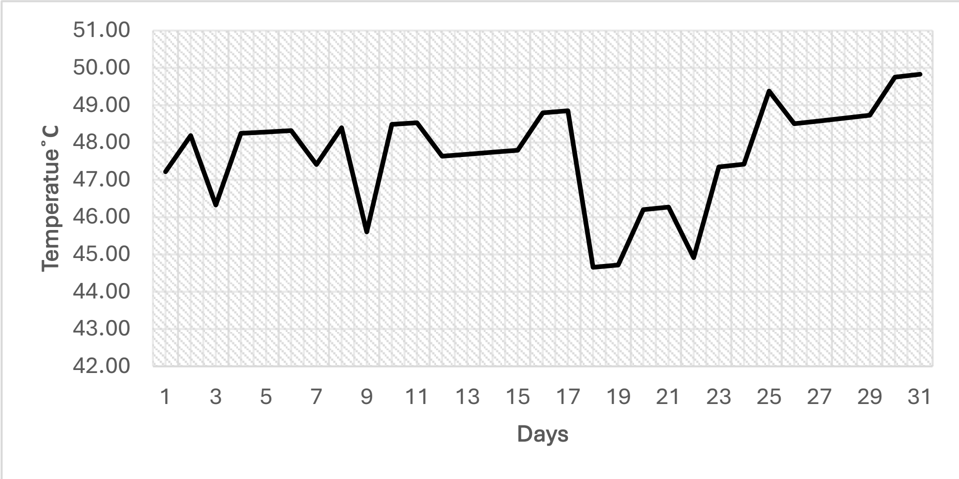

Figure 4.2 Graph of daily maximum pavement temperature at 50mm below the surface

The figure 4.2 shows the changes in the daily maximum temperature at 50mm below the surface of the pavement. The highest maximum temperature that was experienced at this level of the pavement during the month was 49.83℃ coinciding with the 31st day of the month. The standard deviation of the maximum temperature data of pavement at 50mm depth is ± 1.36℃ with the coefficient of variation equal to 2.86%.

4.2.3 Maximum pavement temperature at 100mm below the surface

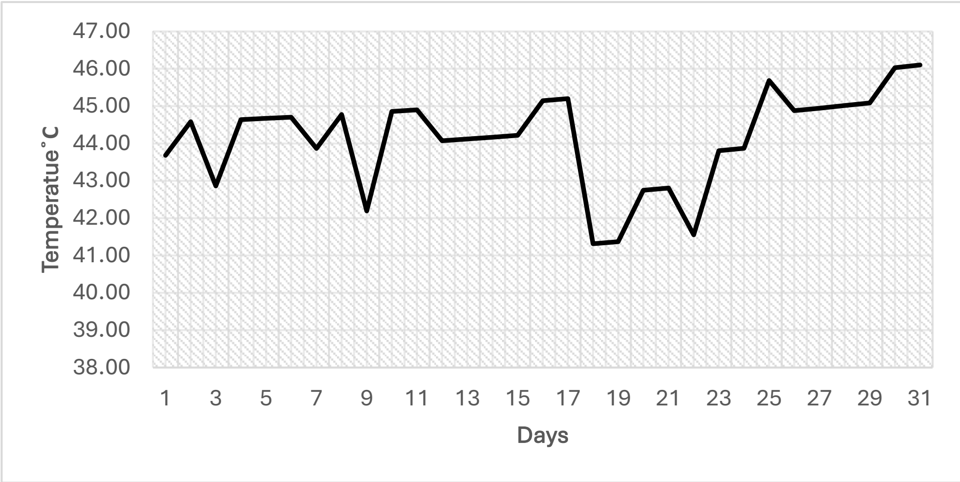

Figure 4.3 Graph of daily maximum pavement temperature at 100m below the surface

The figure 4.3 shows the graph which illustrates the maximum temperature experienced by the pavement on a daily basis at a depth of 100mm below its asphalt surface. The highest maximum temperature that was experienced at that depth of the pavement during the month was determined as 46.10℃ on the 31st day of the month. The standard deviation of the daily maximum temperature at the 100mm depth below the pavement surface is ± 1.26℃ with the coefficient of variation equal to 2.86%.

4.2.4 Maximum pavement temperature at 150mm below the surface

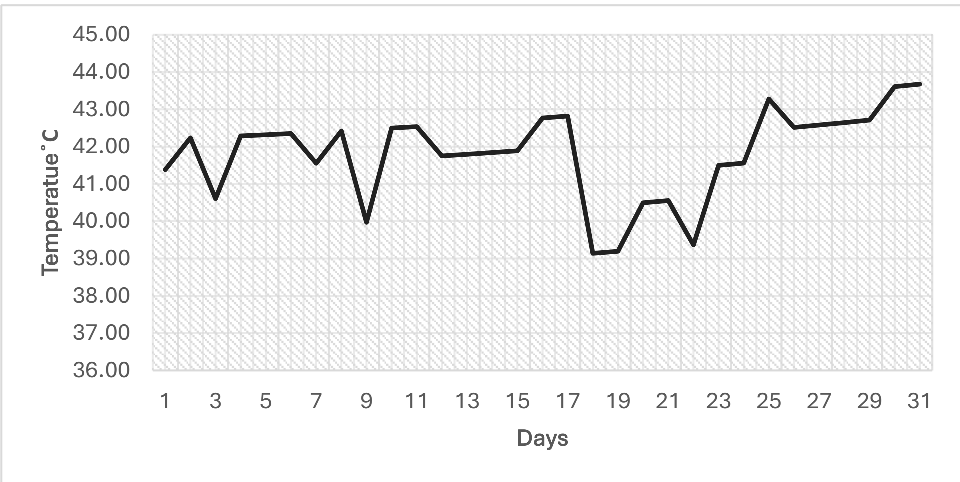

Figure 4.4 Graph of daily maximum pavement temperature at 150mm below the surface

The figure 4.4 shows the graph which illustrates the maximum temperature experienced by the pavement on a daily basis at a depth of 150mm below its asphalt surface. The highest maximum temperature that was experienced at that depth of the pavement during the month was determined as 43.67℃ on the 31st day of the month. The standard deviation of the daily maximum temperature at the 100mm depth below the pavement surface is ± 1.19℃ with the coefficient of variation equal to 2.86%.

4.2.5 Maximum pavement temperature at 200mm below the surface

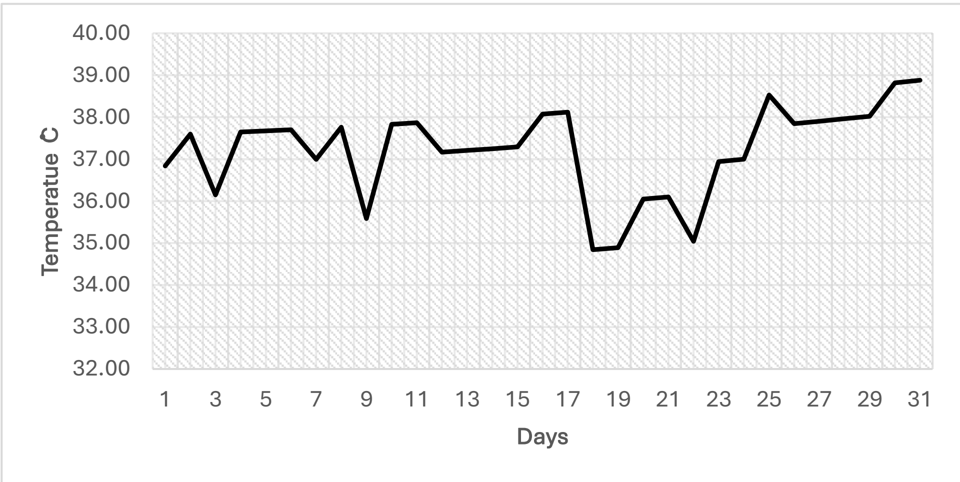

Figure 4.5 Graph of daily maximum pavement temperature at 200mm below the surface

The figure 4.5 shows the graph which illustrates the maximum temperature experienced by the pavement on a daily basis at a depth of 200mm below its asphalt surface. The highest maximum temperature that was experienced at that depth of the pavement during the month was determined as 38.88℃ on the 31st day of the month. The standard deviation of the daily maximum temperature at the 200mm depth below the pavement surface is ± 1.06℃ with the coefficient of variation equal to 2.86%.

4.3 Minimum Pavement Temperature

The minimum temperature of the pavement was also determined for the month of January using the same data collected from the site. The temperature of the pavement was determined also at the surface and at depth of 50mm, 100mm, 150mm and 200mm below the surface for each day using the viljoen model. The results are represented using graph of the temperature against the day of the month.

4.3.1 Minimum pavement temperature at the surface

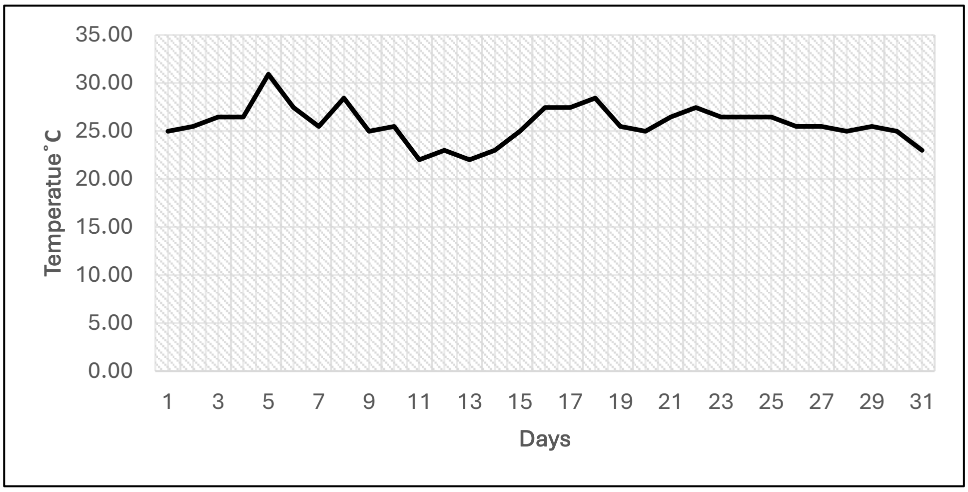

Figure 4.6 Graph of daily minimum pavement temperature at the surface

The figure 4.6 shows the graph which illustrates the minimum temperature experienced by the pavement on a daily basis at the surface. The lowest minimum temperature that was experienced at the surface of the pavement during the month was determined as 22.01℃ on the 11th and 13th day of the month. The standard deviation of the daily minimum temperature at the pavement surface is ± 1.89℃ with the coefficient of variation equal to 7.34%.

4.3.2 Minimum pavement temperature at 50mm depth below the surface

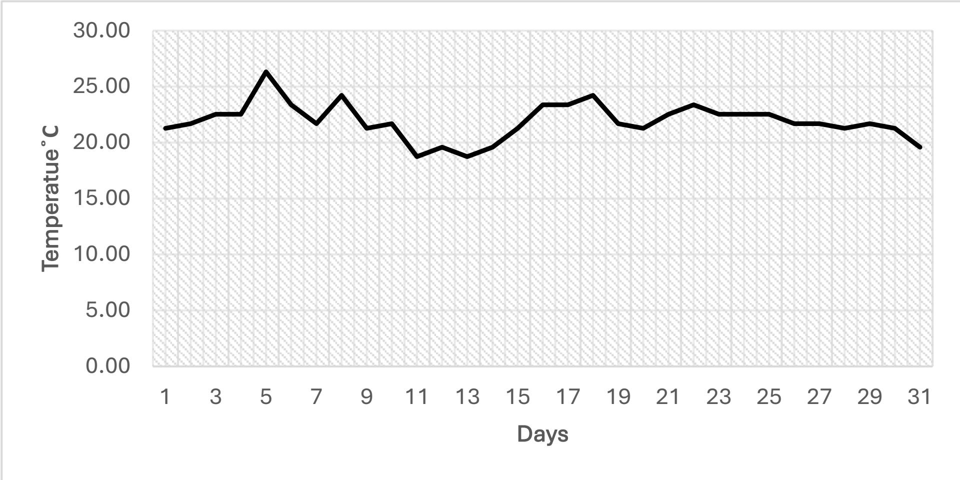

Figure 4.7 Graph of daily minimum pavement temperature at 50mm below the surface

The figure 4.7 shows the graph which illustrates the minimum temperature experienced by the pavement on a daily basis at a depth 50mm below the surface. The lowest minimum temperature that was experienced at this depth below the surface of the pavement during the month was determined as 18.74℃ which occurred on the 11th and 13th day of the month. The standard deviation of the daily minimum temperature at the pavement surface is ± 1.61℃ with the coefficient of variation equal to 7.34%.

4.3.3 Minimum pavement temperature at 100mm depth below the surface

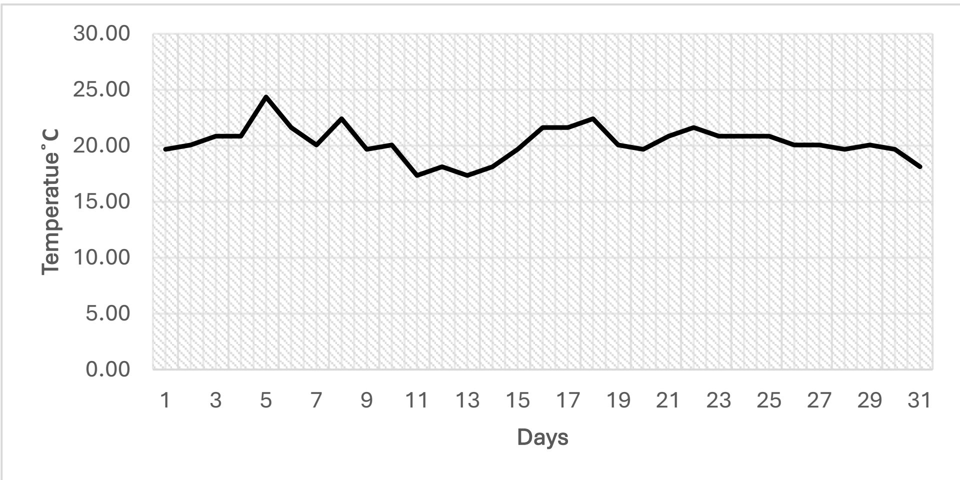

Figure 4.8 Graph of daily minimum pavement temperature at 100mm below the surface

The figure 4.8 shows the graph which illustrates the minimum temperature experienced by the pavement on a daily basis at a depth 100mm below the surface. The lowest minimum temperature that was experienced at this depth below the surface of the pavement during the month was determined as 17.34℃ which occurred on the 11th and 13th day of the month. The standard deviation of the daily minimum temperature at the pavement surface is ± 1.49℃ with the coefficient of variation equal to 7.34%.

4.3.4 Minimum pavement temperature at 150mm depth below the surface

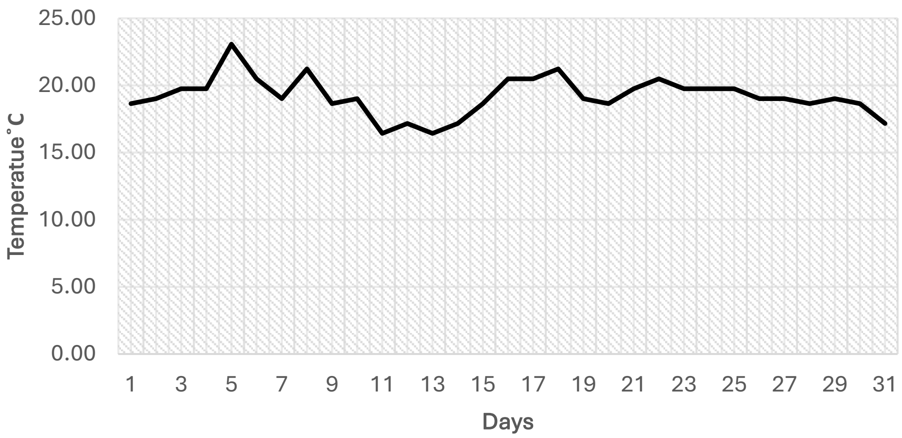

Figure 4.9 Graph of daily minimum pavement temperature at 150mm below the surface

The figure 4.9 shows the graph which illustrates the minimum temperature experienced by the pavement on a daily basis at a depth 150mm below the surface. The lowest minimum temperature that was experienced at this depth below the surface of the pavement during the month was determined as 16.43℃ which occurred on the 11th and 13th day of the month. The standard deviation of the daily minimum temperature at the pavement surface is ± 1.41℃ with the coefficient of variation equal to 7.34%.

4.3.5 Minimum pavement temperature at 200mm depth below the surface

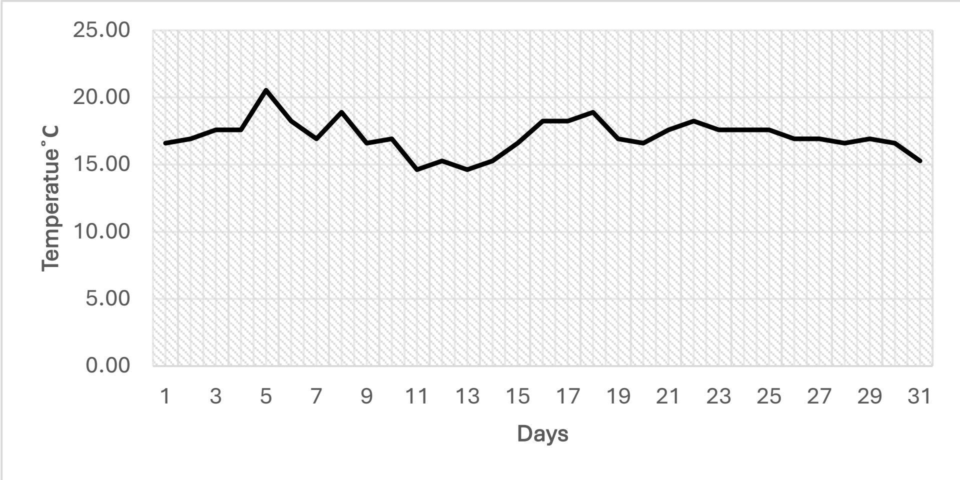

Figure 4.10 Graph of daily minimum pavement temperature at 200mm below the surface

The figure 4.10 shows the graph which illustrates the minimum temperature experienced by the pavement on a daily basis at a depth 200mm below the surface. The lowest minimum temperature that was experienced at this depth below the surface of the pavement during the month was determined as 14.62℃ which occurred on the 11th and 13th day of the month. The standard deviation of the daily minimum temperature at the pavement surface is ± 1.25℃ with the coefficient of variation equal to 7.34%.

4.4 Projection of Future Pavement Temperature

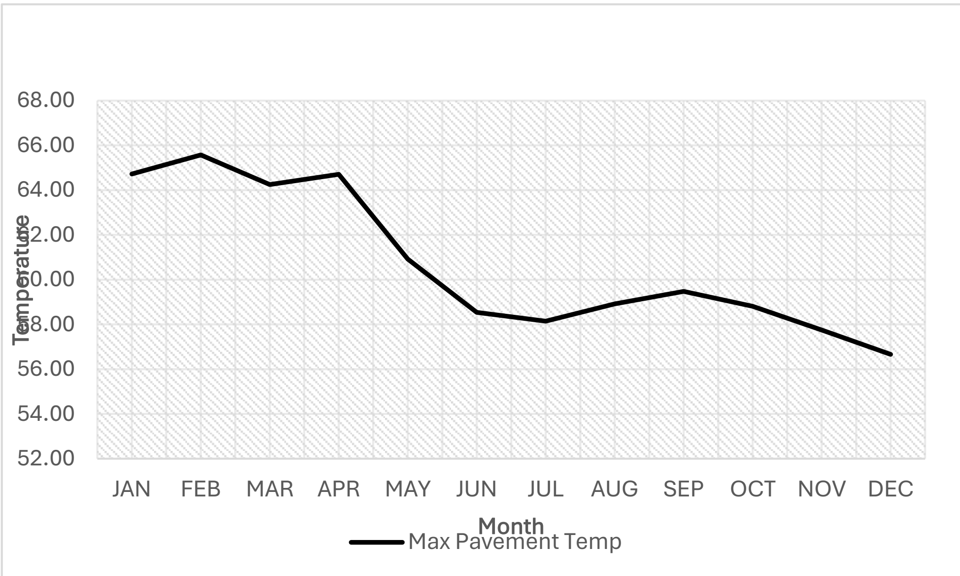

Figure 4.11 Graph of Future Pavement Temperature

This figure 4.11 gives the average of the future projected maximum pavement temperature that will be experienced at the study location from the year 2025 to 2040. The maximum temperature of the pavement over time at the surface is given as 65.57℃ recorded in the month of February. The standard deviation and the coefficient of variation of the pavement data is given as ±2.43℃ and 4.04%.

4.5 Permanent Deformation of Asphalt Layer

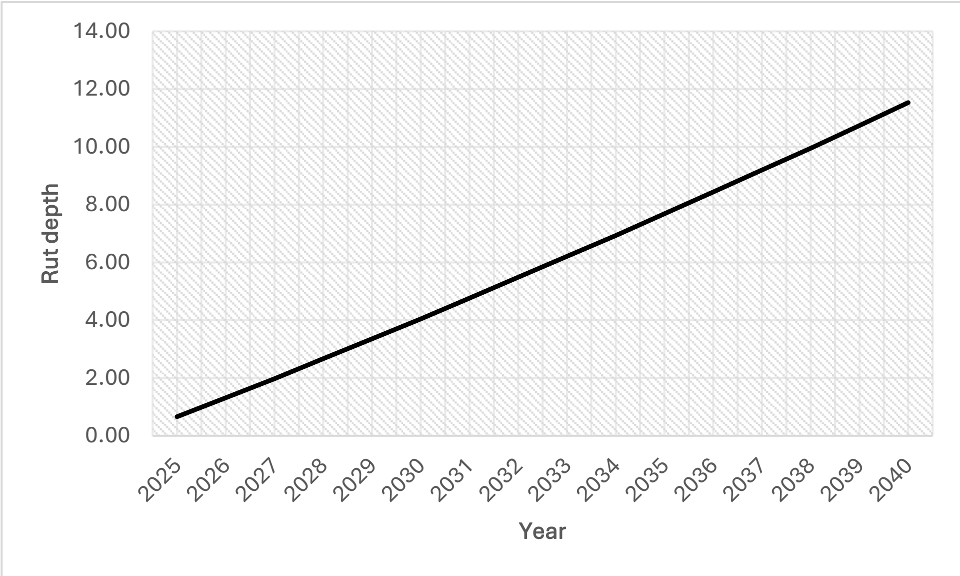

Figure 4.12 Graph of the Rut depth of the asphalt layer.

The figure 4.12 gives the depth of deformation of the asphalt layer caused by accumulation of strains throughout the duration of pavement lifespan caused by vehicle load. From this study, it has been shown that the pavement would have experienced a rutting of about 10mm during the year 2038, The threshold or allowable depth of deformation of the asphalt pavement is given as between 12 to 15mm using the AASHTO MEPDG. By the end of the design life of the pavement, the asphalt pavement has accumulated deformation that is equal to the 11.53mm depth which lower than threshold given by AASHTO MEPDG.

Chapter Five

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The results of this research work carried out has shown that with proper usage of the road, that is, provided that the vehicle load and type in which it was constructed for, is not exceeded, the depth of the deformation experienced by the users of the road will be within the comfortability range given in the AASHTO manual.

From the study carried out, it is now clear that the impact of climate change will definitely affect the rate of rutting of the asphalt layer and also the binder selection process. The practice currently employed is to use historical temperature data for the design of roads however it has become paramount to incorporate the expected increases in temperatures that will be experienced during that period of the pavement active service to properly design the road and account for any distress resulting from climate change, in order to prevent costly repairs associated with unprepared maintenance and construction. The knowledge that has been gained from this research can be used to develop guidelines for designing asphalt mixes with respect to climate impact, predicting the service life of asphalt pavement based on functional properties under the influence of various climate conditions, and reducing maintenance costs for highway agencies by minimising the risk of prematurely deteriorated pavements. Climate models show that we are moving towards an era of higher temperatures, scenarios in which intense increase in precipitation may lead to greater moisture damage of AC and reduced bearing capacity of the unbounded layers.

5.2 Recommendation

More studies should be carried out on how to effectively incorporate climate change into the design of asphalt pavement in the country by the also considering the traffic load that the pavement will support throughout its design life. The selection of the asphalt binder of a pavement should be done using the maximum and minimum pavement temperature of the area where the pavement is located. For this particular site location used for the study, the binder grade should not be below grade 80.

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