ESTIMATION OF PAVEMENT TEMPERATURE IN NIGERIA'S CLIMATOLOGICAL ZONES

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ABSTRACT

Temperature is a critical factor influencing flexible pavement design and performance. This study investigates asphalt pavement temperatures across Nigeria's diverse climatological zones, highlighting the impact on pavement performance and durability. Previous studies have not comprehensively addressed Nigeria's diverse climatic conditions. This research fills the gap by classifying Nigeria into hot dry, temperate dry, hot humid, and warm humid zones, providing a detailed approach to bitumen grade selection based on accurate pavement temperature analysis. The methodology involves obtaining air temperature data and computing pavement temperatures using a validated model. Results indicate that Zone 1 (Sokoto, Borno, Adamawa) requires a 40/50 penetration grade bitumen due to a maximum pavement temperature of 44°C, while Zones 2, 3, and 4 are suited for 60/70 penetration bitumen. Emphasizing pavement temperatures over air temperatures enhances road resilience and longevity. This study provides a foundation for an advanced bitumen grading system, offering criteria for selecting bitumen for various Nigerian climatic zones.

Keywords: *Asphalt Pavement, Bitumen Grades, Climatological Zones, Pavement Durability, Pavement Temperature, Road Construction*

1 INTRODUCTION

The temperature of asphalt pavement is a critical factor in the construction and maintenance of roads, especially in a country like Nigeria with diverse climatological zones. Nigeria's climatic regions range from the humid tropics in the south to the arid, semi-desert conditions in the north. These varying climatic conditions significantly influence the temperature of asphalt pavements, affecting their performance, durability, and the overall quality of road infrastructure (Refiloe et al., 2022).

In designing durable pavements, many factors are considered, with climate being a primary agent influencing pavement performance. Temperature is the most significant climatic factor affecting the mechanical behavior of all pavement layers and thus the overall performance and life of the pavement (Flavio, 2012; Marshall et al., 2001; Gang, 2003). Asphalt mixtures are viscoelastic plastic materials whose strength and modulus change under different temperatures. At low temperatures, asphalt becomes hard and brittle, exposing the layers to thermal and fatigue cracking. Conversely, at high temperatures, asphalt becomes soft and more viscous, making it more prone to rutting. Therefore, the effect of temperature on the bearing capability, performance, damage, and life of asphalt pavement cannot be ignored (Sascha et al., 2013; Kang et al., 2007).

Understanding the temperature dynamics of asphalt pavement in different climatological zones is essential for selecting appropriate materials, designing effective construction processes, and ensuring the longevity of road networks. This knowledge helps mitigate issues such as thermal cracking, rutting, and other forms of pavement distress arising from extreme temperature variations (Refiloe et al., 2022). Temperature variations directly influence the stiffness of the asphalt layers, altering stress, strain, and deflection conditions throughout the pavement. This variation can influence the stiffness of the underlying unbound layers since they usually display stress, strain, and deflection dependence (Gang et al., 2007).

In pavement design, the strength and deformation properties are strongly related to climatic conditions. Therefore, in the flexible pavement design process, attention must be paid to accurately determining temperature in asphalt concrete layers. As modern flexible pavement structures represent multi-layer deformable media, changes in deformations in asphalt concrete layers lead to changes in stresses and deformations in other layers of pavement and subgrade. In practice, changes in stresses and deformations in layers of pavement and subgrade, caused by temperature variations in asphalt concrete layers, are essential and should be considered at the design stage (Hariharan et al., 2023).

Based on literature, the prediction of asphalt pavement temperature can be divided into: (1) Numerical and finite element techniques, (2) Theoretical and analytical approaches, and (3) Statistical and probabilistic models. The improvement of these temperature prediction models is highly dependent on local data (Adwan et al., 2023).

The Performance of the bituminous binder plays important role in the overall performance of the pavement system. One of the major causes of pavement failure is the bitumen grade, i.e. selection of suitable grade of bitumen. Therefore, performance grading of bituminous binder is inevitable for the specific temperature and climatic zones. (Sunita K et al., 2020).

Previous studies provided valuable insights into specific aspects of pavement temperature and compaction behavior but did not address the diverse climatological zones in Nigeria comprehensively. (Adejoh S et al., 2024, Mohammed I. U., 2016). This study fills the gap by classifying Nigeria into hot dry, temperate dry, hot humid, and warm humid zones in accordance with highway manual, providing a detailed approach to bitumen grade selection based on accurate pavement temperature analysis for more effective pavement construction and maintenance.

In this context, this study aims to explore the temperature characteristics of asphalt pavement across Nigeria's climatological zones, providing insights into the challenges and considerations for pavement construction and maintenance in these diverse environments.

2 METHODOLOGY

To achieve the objective of the research air temperature of the various zones from each state were obtained from the highway manure, using annual minimum and maximum temperature values ranging from 10-40 years. The pavement temperatures for each state were computed using temperature model and the minimum and maximum pavement temperature for each zone is determined.

2.1 BITUMEN GRADES

Bitumen, also known as asphalt, is a material mainly used in road construction. There are many types of bitumen grades based on different systems. Penetration, viscosity, and performance are three popular bitumen testing methods used for characterization and classification. Each grade offers unique specifications, allowing for the selection of the most suitable one. In Nigeria, the penetration grading system specified in the Highway Manual, 2013, includes only two grades: 60/70 and 80/100. Ideally, one should select a grade based on factors such as climate and temperature variations, traffic volume, pavement design, and application-specific requirements.

2.2 STUDY AREA

Nigeria is divided into four distinct climatological zones, each with unique temperature characteristics. Figure 1 shows the four zones within Nigeria. These zones are classified in terms of climate as hot dry, temperate dry, hot humid, and warm humid, respectively. (Highway Manual 2013)

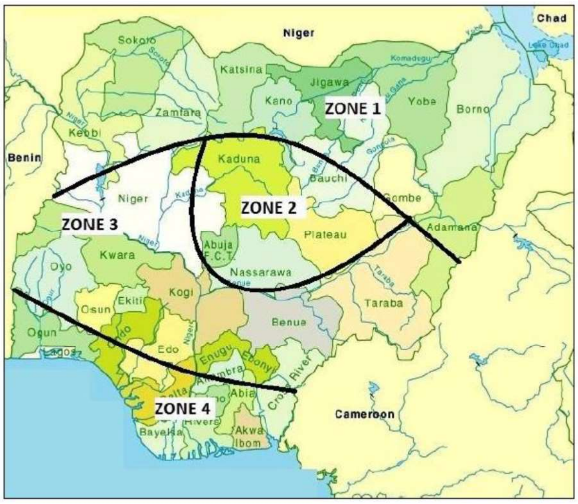

Figure 2.1: Climatological zones of Nigeria Source: Highway manual

Since temperature is considered one of the most important factors when selecting bituminous materials for roads especially because of its sensitivity. Measurement of individual pavement temperatures can time consuming, thus alternative methods can be employed. The Figures 2.2 and 2.3 shows the minimum and maximum air temperatures respectively.

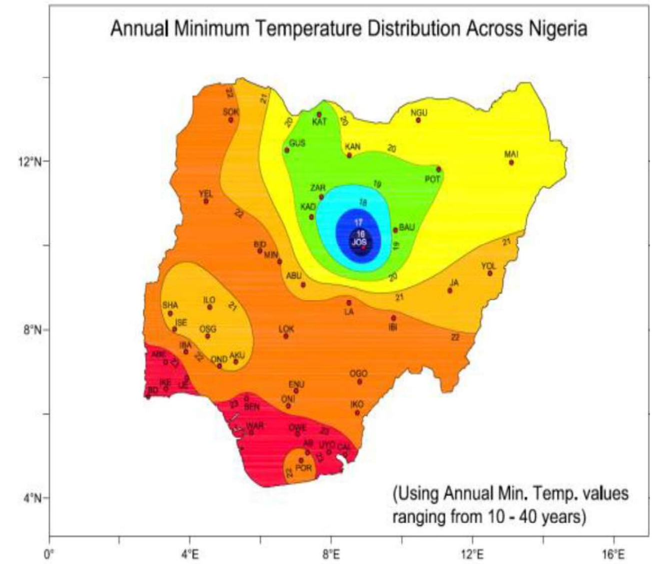

Figure 2.2: Minimum Air Temperature Source: Highway Manual

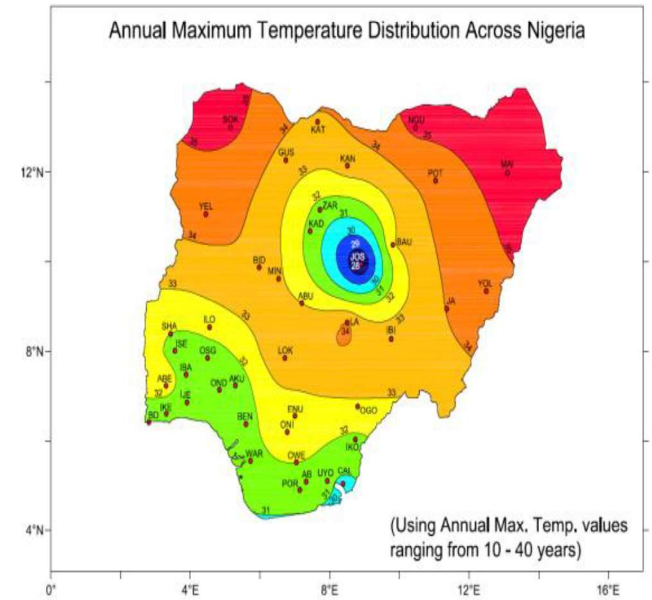

Figure 2.3: Maximum Air Temperature Source: Highway Manual

From the mean air temperatures, pavement temperatures can be estimated using Equation 1 as proposed by Thompson et al., 1987. The pavement temperatures can then be estimated.

$$T_P = T_A\left(1 + \frac{1}{Z+4}\right) - \frac{34}{Z+4} + 6 \qquad (1)$$

Where,

T_p is the average seasonal pavement temperature (°C),

T_A is the average seasonal air temperature (°C),

Z the depth at which temperature is predicted (in)

The Thompson et al. (1987) pavement temperature estimation model demonstrates high accuracy, assumes that pavement temperature is influenced by ambient air temperature, solar radiation, and wind speed, and has been validated using data from various locations to ensure accurate predictions across different climatic conditions. (Thompson et al., 1987, Chaitanya G., et al., 2022)

3 RESULTS AND DISCUSSION

The pavement temperatures were estimated based on Equation 1. The results are presented in Tables 1, 2, 3, and 4, which represent annual average minimum and maximum pavement temperatures. The highest maximum pavement temperatures (44°C) were observed in Zone 1 (Sokoto, Borno, Adamawa) and Zone 2 (Kaduna). Lower maximum pavement temperatures (38°C - 41°C) were found in Zone 4, which generally shows lower maximum temperatures compared to other zones. Bayelsa and Cross River have the lowest at 38°C. On the other hand, Plateau state recorded the lowest minimum temperature at 22°C. Most states have average maximum pavement temperatures exceeding 40°C, except for states in the South-west and South-south parts of Nigeria.

From the results, it can be seen that different climatic zones in Nigeria require specific bitumen grades to ensure optimal performance. Zone 1, experiencing the highest temperatures, requires 40/50 penetration grade bitumen, which offers better resistance to high temperatures. Zones 2, 3, and 4 have relatively lower maximum temperatures, and thus 50/60 or 60/70 penetration grades are more suitable. In Nigeria's Highway Manual, only two grades of bitumen are specified: 60/70 and 80/100. This specification may affect the performance of asphalt mixtures in Zone 1. Although this approach gives an indication of which bitumen to use, there are several limitations that may affect its authenticity. For example, urban areas may experience higher temperatures leading to higher pavement temperatures. Another impact on pavement temperatures is high rainfall in areas such as Zones 3 and 4. Some states within the same zone have slightly different pavement temperatures due to localized microclimates, variations in urbanization, and differences in altitude and vegetation. These factors can influence the amount of solar radiation, wind speed, and ambient air temperature, which in turn affect pavement temperatures. (Yinghong Q., et al., 2022)

Table 1. ANNUAL MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE OF ZONE 1.

States	Air Temperature Min. (ºC)	Air Temperature Max. (ºC)	Pavement Temperature Min.(ºC)	Pavement Temperature Max. (ºC)
Sokoto	22	35	29	44
Katsina	19	33	25	42
Zamfara	19	33	25	42
Kebbi	22	34	29	43
Kano	20	33	27	42
Jigawa	20	34	27	43
Yobe	20	34	27	43
Borno	20	35	27	44
Gombe	20	34	27	43
Adamawa	21	35	28	44

TABLE 2. ANNUAL MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE OF ZONE 2.

States	Air temperature Min. (ºC)	Air temperature Max. (ºC)	Pavement temperature Min.(ºC)	Pavement temperature Max. (ºC)
Kaduna	19	35	25	44
Bauchi	19	33	25	42
Abuja	21	33	28	42
Nasarawa	22	34	29	43
Plateau	16	33	22	42

TABLE 3. ANNUAL MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE OF ZONE 3.

States	Air temperature Min. (ºC)	Air temperature Max. (ºC)	Pavement temperature Min.(ºC)	Pavement temperature Max. (ºC)
Niger	22	33	29	42
Ondo	21	31	28	39
Kwara	21	32	28	41
Taraba	21	33	28	42
Kogi	21	33	28	42
Oyo	21	31	28	39
Osun	21	31	28	39
Ekiti	21	31	28	39
Edo	23	31	30	39
Enugu	22	32	29	42
Anambara	22	32	29	41
Ebonyi	22	32	29	41
Benue	22	33	29	42

TABLE 4. ANNUAL MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE OF ZONE 4.

States	Air temperature Min. (ºC)	Air temperature Max. (ºC)	Pavement temperature Min.(ºC)	Pavement temperature Max. (ºC)
Ogun	23	32	30	41
Lagos	23	31	30	39
Bayelsa	23	30	30	38
Rivers	22	31	29	39
Delta	23	31	30	39
Imo	23	32	30	41
Abia	22	31	29	39
Akwa Ibo	22	31	29	39
Cross River	23	30	30	38

TABLE 5. AVERAGE MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE ACROSS ALL STATE AND ZONES

Zone	Maximum Pavement Temperature (oC)	Minimum Pavement Temperature (oC)
Zone 1	43	27
Zone 2	42	26
Zone 3	41	28
Zone 4	39	28

4 CONCLUSIONS

The estimation of pavement temperatures across Nigeria's diverse climatological zones is essential for selecting suitable bitumen grades. The extreme pavement temperatures, ranging from -10 to 70 degrees Celsius according to the Performance grading system, are not exceeded by any of the states. The analysis shows significant pavement temperature variations, which necessitate different grades of bitumen to ensure pavement durability and performance. High-performance bitumen, such as 40/50 penetration grade bitumen, is required for the highest maximum pavement temperatures (44°C) observed in Zone 1 (Sokoto, Borno, Adamawa) to prevent rutting and thermal cracking. Zones 2, 3, and 4, termed as moderate temperature zones, are recommended to use standard bitumen grades, i.e., 60/70 penetration bitumen. These recommendations, using pavement temperatures rather than air temperatures, can help enhance the resilience and longevity of road pavements in Nigeria, given the unique climate of each zone. It is also important to consider other factors such as rainfall, humidity, climate change, moisture, and traffic load in the selection of suitable bitumen.

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