



FEDERAL MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION
(NIGERIA BUILDING AND ROAD RESEARCH INSTITUTE)

TECHNICAL GUIDELINE:

THE INTRODUCTION OF A PERFORMANCE GRADE SPECIFICATION FOR
BITUMINOUS BINDER IN NIGERIA.

Version 1
MARCH 2022

Technical Specification on the Implementation of Superpave Mixture Design: A Binder Scale Criteria.

TECHNICAL WORKING GROUP

Names	Affiliation Organization.
1. Prof. Samson Duna	DG/CEO NBRRI & Chairman
2. Mohammed Kangiwa	NIMET
3. Site Onyejekwe	RSMT
4. Engr. Bature Mohammed	SON
5. Dappa Dabota G.	JBN
6. Engr. Celestine S. Shausu	FMW&H
7. Engr. Michael Esenwa	McAsphalt
8. Engr. Omoragbon M. Idahor	FCDA
9. Engr. Adamu A. Gumel	FCDA
10. Engr. Cecilia U. Daniel	FERMA
11. Engr. Tony Tonade	Ringardas Nig. Ltd. (ASCA)
12. Engr. Nuruddeen Mutawalli	Ringardas Nig. Ltd. (ASCA)
13. Engr. Francis A. Ejim	FMW&H
14. Engr. Akinmade D.O.	NBRRI & (Desk Officer)
15. Engr. Tyoden J.N.	NBRRI
16. Engr. Chukwuma G.O.	NBRRI
17. Monde Joseph Monde	NBRRI
18. Muntari Y. Sakadadi	NBRRI
19. Munir H. Isa	NBRRI

FOREWORD

The process of shifting from the current practice of penetration grade specification framework for road construction in Nigeria to one which strives to define bitumen properties more closely related to the performance of bituminous layers has commenced. This is due for trial implementation between 2022-2023 after engagement with various stakeholders in the road sector. It is imperative to note that the Institute has investigated pavement failures over the years.

One of the major problems is the binder selection, which is 60/70 grade. This grade has been used over the last six decades without considering the effect of climate change, dynamism in traffic, and loading of today's reality. In addition, from experience and practice, the softening point of 60/70 grade bitumen is always lower than the pavement temperature, which is a major contribution to most of the rutting on our highways, especially in the high-temperature zones.

The Nigerian Building and Road Research Institute sponsored a national workshop on Superpave Mix Design based on this background, with many engineers participating from the public and private sectors. To expedite a direction towards this new performance-related specification, NBRRI inaugurated a technical working group in 2021. This technical working group comprises professionals in the road construction industries, relevant stakeholders, and a Nigerian working with McAsphalt Industries in Canada to develop this specification for the design and implementation at this scale.

The technical Working Group on Performance Grade Bituminous Binder Specifications considered it suitable to make the document available, presenting principles guiding the development of this specification. The Nigerian Building and Road Research Institute under the Federal Ministry of Science, Technology & Innovation (FMSTI) spearheaded the development and publicising of this document. It is predicted that the shift to a performance grade specification will be implemented within two years.

As mentioned above, this technical specification will be introduced nationally on a trial basis during the implementation. Hopefully, this publication and the implementation of the principles contained therein will further help the robust interaction between members of the engineering practice, eventually motivating the adoption of a performance-related specification in Nigeria.

Dr. Ogbonnaya Onu
Honourable Minister of Science, Technology and Innovation

EXECUTIVE SUMMARY

Asphalt pavement performance significantly depends on the behaviour and performance of the binder, and one of the major factors resulting in pavement deterioration is the grade of bitumen. For example, the selection of a suitable grade of bitumen can affect performance. Therefore, the performance grading of the bituminous binder is critical for the specific temperature and climatic zones where it would be utilized.

This study aims to determine the performance grading of bituminous binders for various temperature zones in Nigeria. In this study, daily maximum and minimum secondary temperatures were collected and analyzed for temperature zoning. In addition, field pavement temperature for a specific month was used to validate pavement temperature computed using the Strategic Highway Research Program (SHRP) model. Performance grading of bituminous binder was conducted with the help of SHRP prediction models. This concept of Superpave, which stands for **SU**perior **PER**forming Asphalt **PAVE**ment, has been adopted in this study.

The bituminous binder grades for Nigeria have been determined based on air and pavement temperatures. The study has determined three different performance grade zones based on SHRP models. The research produced the Performance Grade (PG) map of the country and further buttressed that the current 60/70 grade bitumen currently being used across the country is unrealistic, hence there is the need to call for action by stakeholders in the road sector to begin to adopt the grade for better road performance.

Professor Samson Duna

DG/CEO NBRRI & Chairman Superpave Specification Development Committee

TABLE OF CONTENTS

TECHNICAL WORKING GROUP	3
FOREWORD.....	4
EXECUTIVE SUMMARY	5
TABLE OF CONTENTS	6
LIST OF TABLES	7
LIST OF FIGURES	7
1. Introduction.....	8
2. Road Development in Nigeria.....	8
3. Background.....	12
3.1 The need to shift from a Penetration grading system to a Performance grading system.	12
3.2 The need for the criteria.....	13
3.3 Characteristic of Bitumen	13
3.4 Binder Characterization	14
3.5 Temperature Grade	15
3.6 Selection criteria of PG considering the Traffic Volume and Speed	17
4. Research Methodology	18
4.1 Reliability.....	18
4.2 Performance Grade Specification	20
4.3 Superpave Background.....	21
5. Bitumen	22
5.1 Brief Description of Superpave Tests.....	24
5.1.1 Rolling Thin Film Oven (RTFO) Test.....	24
5.1.2 Pressure Aging Vessel (PAV) Test.....	24
5.1.3 Rotational Viscosity (RV) Test.....	24
5.1.4 Dynamic Shear Rheometer (DSR) Test.....	24
6. Results and Discussion.....	25
6.1 PG Classification for Bitumen Binder	25

7. Performance Criteria	27
7.1 Safety and Handling.....	28
7.2 <i>Temperature</i>	28
7.3 <i>Low-Temperature Cracking</i>	28
7.4 <i>Storage Stability</i>	28
7.5 <i>Safety</i>	28
7.6 <i>Pumping and Handling</i>	28
9. Conclusions and recommendations	30
10. Acknowledgment	30
12. Reference	30

LIST OF TABLES

Table 1 Summary of Total Road Length in Nigeria	9
Table 2 Inventory Of Federal Roads In Nigeria	10
Table 3 Binder grades based on SUPERPAVE criteria	16
Table 4 Adjustment to the High-Temperature grade of binder based on traffic level and traffic speed	17
Table 5 Test Results - Bitumen Binder Properties	26

LIST OF FIGURES

Figure 1 Map of Africa showing Nigeria.....	8
Figure 2 Map of Nigeria showing the six geopolitical zones	9

1. Introduction

Nigeria is located within the co-ordinates 9.0820°N, 8.6753°E as shown in Figure 1 and has a population of over 200 million [1] with over 250 ethnic tribes and 500 indigenous languages. These tribes were grouped under the three most popular groups, namely the Yoruba, Hausa, and Ibo, forming Nigeria's primary three ethnic groups. Its lingua franca is the English language [2]. Nigeria, with a land mass of 923,768Km² is the largest country in West Africa. The terrain and the climate differ from one region to another, hence dividing Nigeria into six (6) geographical zones: North Central, South East, South West, South-South, North East, and North West, as shown in Figure 2. The states are linked together with various road networks developed over many years.



Figure 1 Map of Africa showing Nigeria

2. Road Development in Nigeria

In 1904, a new road linking Zaria and Zungeru in the Northern area of Nigeria was constructed, marking the beginning of road development in Nigeria [3]. The road built in 1906 linking Oyo and Ibadan was the first motorable way. A Road Board was then put in place in 1925 by the Federal Government to facilitate road development. The year 1937/38 witnessed an increase in total road length to 6,160Km while in 1938/39, it increased to 9,453km[3]. As of 1951, Nigeria had 44,414km of road length, out of which only 1,783km length of the road was surfaced[4]. The road had no standard design but was mainly single lane roads with a poor drainage system, without road markings and signs. The traffic on these roads was light; hence, there were not many crashes despite the unsafe curves. In 1952, due to the rapid growth of economic activities, the quality of road development and construction improved, with the nation having a total length of 15, 785km road of a bituminous surface and 75,200km of both earth and earth gravel surface roads[4].

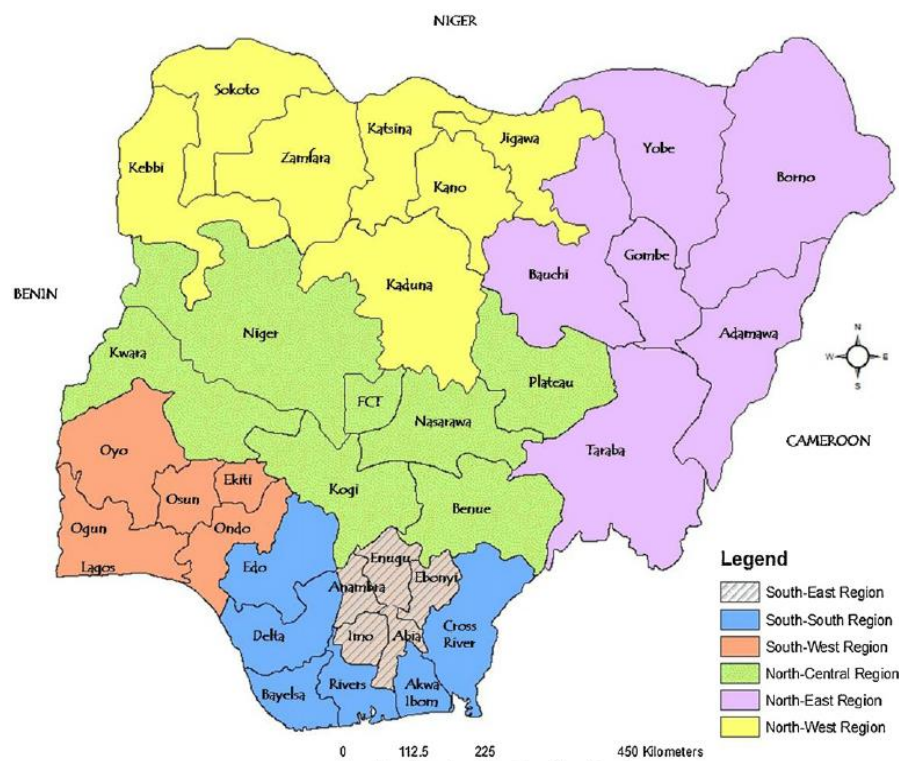


Figure 2 Map of Nigeria showing the six geopolitical zones

There was a continuous increase in road length due to the opening of many rural areas within the country, and as of 1980, the total road length had increased from 44,414km in 1951 to 114,768km with 28,632Km tarred surfaces. By 2003 Nigeria had a total road length of 200,000km, as documented by the Central Bank of Nigeria and shown in Table 1[5]. Currently, the nation has invested funds in increasing the total road network such as the tarred surfaces, the untarred like gravelled road networks. The Local Governments have 136,600km of the road while 30,500km of roads belong to the State Governments. The remaining 32,100km representing 17% of the total road length, are Federal roads. The inventory of the Federal Highway is given below in Table 2:

Table 1 Summary of Total Road Length in Nigeria

Category	Federal Roads	State Roads	Local Govt Roads	Total	Percentage
Paved main roads	26,500	10,400		36,900	19%
Unpaved main roads	5,600	20,100		25,700	13%
Urban roads			21,900	21,900	11%
Main rural roads			72,800	72,800	38%
Village access roads			35,900	35,900	19%
Total	32,100	30,500	130,600	193,200	100%
Percentage	17%	16%	67%	100%	

Source: Central Bank of Nigeria[3]

SUPERPAVE MIX DESIGN MANUAL: BITUMEN SCALE DESIGN

Table 2 Inventory of Federal Roads In Nigeria

State	Trunk Routes	Secondary Routes	Branch Routes	Boarder Spur	Asphalt Concrete	Surface Dressing	Earth Roads
Abia	364	218	25	0	373	226	8
Adamawa	247	1069	0	0	691	214	411
Akwa-Ibom	84	392	98	27.5	348.9	213	40
Anambra	171	325.4	58	0	400.4	122	32
Bauchi	562	718			814	240	226
Bayelsa	36	131.8			67		100.8
Benue	572	1039			1237	87	287
Borno	699	1508			1040	379	788
Cross River	635.1	410.09	30		807.35	163.8	104.04
Delta	239	439.5			657.5	37	38
Ebonyi	117	385.8			176	222.8	104
Edo	510	406.5			781.5	135	
Ekiti	54.6	312.6			114	253.2	
Enugu	622	236			533	300	25
Gombe	185	314			437	18	44
Imo	203	314.5	82		473	126.5	
Jigawa	256	495			591	80	80
Kaduna	995	569	124		1530	150	8
Kano	495	413.5			743.5	165	
Katsina	282	560			495	292	55
Kebbi	240	511.4		111	248.4	273	341
Kogi	642	215	276		500	401	232
Kwara	513	406		125	421	236	387
Lagos	602.86	73			675.86		
Nasarawa	324	563			522	123	242
Niger	1574	603.2			969.2	807	401
Ogun	560	511.8			1001.8	70	
Ondo	562.4	162			577.4	147	
Osun	98	478.5	52		438.9	185	4.6
Oyo	693.3	326	41.2		440.3	409.2	211
Plateau	426	553			401.5	264	313.5
Rivers	253	404			417.8	157	82.2
Sokoto	251	331			153	346	83
Taraba	590	1034			566	357	701

Yobe	234	643.4			378	347.4	152
Zamfara	131	904			373	454	308
FCT	138	98.6			158	78.6	
	Total Of Asphalt Concrete Roads				20,452.31		
	Total Of Surface Dressed Roads				8,000.90		
	Total Of Earth Roads				5,887.74		
	Total 34,340.95						

Source: Federal Ministry of Works and Housing

Road development in Nigeria has suffered severe setbacks due to various factors such as geological/geographical variation, social state of the economy, inadequate data, corruption etc. [6]. In addition, it has been observed that management/administration, workforce & indigenous contractors, politics and lack of maintenance culture contributed to these setbacks. Though road transportation had been identified to play a significant role in a developing nation like Nigeria, it has not been adequately harnessed. Some commonly found failures that occur within a few months or years after construction without completing their design life include rutting, fatigue and thermal cracks. Binder is a viscoelastic material, and its behaviour is temperature and frequency-dependent, as such susceptible to rutting at high temperatures and cracks at low temperatures.

The binder selection system currently used in Nigeria is the penetration grading test system, and the commonly used grade is 60/70. This test is conducted at a specific temperature of 25°C and a fixed load, usually 100g. These are in contrast to the actual behaviour of binders in the field, making it challenging to use a penetration grading system to evaluate binder rheological properties at low and high temperatures and determine the temperature for mixing and compaction in the asphalt plant and the construction site. As highlighted above, the Superpave PG system can help address this drawback of the penetration grade test system. Therefore, adopting the Superpave binder selection system will enhance pavement performance in Nigeria.

Furthermore, it is critical to analyze the trends of climatic data such as minimum and maximum temperatures of States in Nigeria to determine the binder grades by predicting temperature changes. Based on the above, this study aims at establishing acceptable binder performance grades based on historical air temperature and the field air temperature collected to predict the maximum and minimum pavement temperatures at 98% and 50% reliability levels. Finally, the most common performance grades were proposed for the country. The finding of this study further shed more light on the deficiency of the current practice in pavement design and construction in Nigeria, which has negatively affected pavement performance. Moreover, this study could also definitely elucidate further studies to be established and conducted on pavement performance at a wide range of climatic conditions in Nigeria, mainly focusing more on the mixture scale.

3. Background

The United States Congress approved a five (5) year program (1987-1992) and 150million dollars to develop a new method for testing and designing asphaltic materials. This aimed at having a highway system that would be safe, durable, productive and effective in-service delivery to taxpayers. The program was coded as a strategic highway research program (SHRP). Furthermore, the SHRP later developed a Long-Term Pavement Monitoring Programme (LTPP) to extensively support pavement performance analysis improve engineering tools for designing, managing and constructing pavements. In 1991, a seasonal monitoring program (SMP), a component of LTPP, was initiated to assess temperature effect and moisture on the performance of pavements. Based on the initial SHRP testing and SMP data, many pavement temperature approaches were established adequately for PGs selection[7].

These concepts were based on the theory of heat and energy transfer as reported in [8, 9], developed an analytical approach and Proposed a procedure for the computation of pavement temperatures. In some studies, regression approaches were developed and used based on the temperature data collected to compute pavement temperatures. Other researchers[10, 11]. Based on the heat transfer approaches reported in [12, 13], they developed a simulation model to compute the pavement temperatures during the summer. There has never been an attempt in Nigeria or the sub-region to develop and adopt this SUPERPAVE PG grade selection of binder for Highway design to the best knowledge of the authors and the research team. This study used the SHRP model and compared it with the actual temperature collected on-site across 6 geopolitical zones of Nigeria to predict the asphalt binder Performance Grades (PGs).

3.1 The need to shift from a Penetration grading system to a Performance grading system.

Over the years, the road construction industry in Nigeria has relied on the penetration grading system, as earlier stated in the previous section. However, major fora and conferences had argued that there was the need to revise the current standards, which do not meet the engineering properties. This implies that performances of flexible pavements would not be able to perform optimally, mainly in networks having higher traffic. In addition, the PG grade system, which was developed in the USA, have shown to have enormous benefits, which includes:

- i. It considers test conditions based on environmental conditions of climate and traffic where the binder would be utilized.
- ii. It gives a better understanding of the rheological properties of binders under a range of operating conditions.
- iii. It gives the need to assess binder under short term and long-term ageing conditions. It further provides an insight into how a straight run bitumen could be modified to meet the requirements bitumen would be used.
- iv. The flexibility of accommodating regional needs in terms of binder grades.

One can argue that the current specifications can best be described as an industrial grading system with limitations and cannot meet today's pavement designs and construction challenges, especially regarding the technological advancements and innovations mentioned above. In addition, it can only define the consistency of binder over a range of temperatures (from 25°C to 135°C) in terms

of proxy properties such as penetration, softening point and dynamic viscosity. There is also no assessment to review the behaviour of short-term ageing, which includes binder mixing with aggregates, transportation and laying on site. Furthermore, the specification cannot predict or assess the long-term performance of the binder in-service. Finally, the current specification cannot address traffic levels, speeds and climate issues (mainly temperature ranges). The viscous nature of the binder at high temperature or cracks development in the binder during ageing and temperature variations are always unknown in the use of the penetration grading system. Hence due to all these limitations, the basis of binder selection is usually arbitrary.

3.2 The need for the criteria

Binders are designed to resist any form of distress, such as permanent deformation and fatigue due to temperature variations and loadings. In addition, the binder should exhibit optimal durability and maintain its properties to resist any form of distress for a long duration. As highlighted in the previous paragraph, the concept of damage characteristics was developed to measure the binder's resistance to damage resulting from rutting fatigue crack (intermediate temperatures and high temperature) to complement the feedback of the development of SHRP in 2010. This was made to enable the selection of binder within the framework based on:

- traffic volumes and speed
- climate (max and min temperatures)
- binder durability

However, based on resource economic consideration, the specialize equipment is limited to the following: Dynamic shear rheometer (DSR), Bending Beam Rheometer (BBR), Rolling Thin Film Oven (RTFO) and Pressure Ageing Vessel (PAV). In addition to the above performance-related properties. Storage stability and viscosity limits to enhance handling and application at high temperatures.

3.3 Characteristic of Bitumen

Bitumen behaves as elastic and viscous material depending on temperature and loading conditions. Hence, this viscoelastic nature of bitumen makes the response behaviour under varying loading times, and temperatures differ. Bitumen can behave as an elastic material which could be divided into 3 different categories such as:

- a. At a short time loads under low temperature, bitumen acts like an elastic solid that would return to its original position after removing the load.
- b. Under extreme low temperatures with fast loading, bitumen will crack and brittle.
- c. Under continued low temperature would result in the bitumen having internal stress, resulting in thermal fracture.

Bitumen can also behave as a viscous material at high temperatures and low-frequency loads linked with slow-moving traffic. Hence, it would undergo plastic deformation at this condition, which means that the deformation would be fully recovered. However, this plastic behaviour can be counter-balanced with the interlocking action of aggregates to resist permanent deformation. Furthermore, bitumen can also behave as a visco-elastic material, as shown in Figure 3.

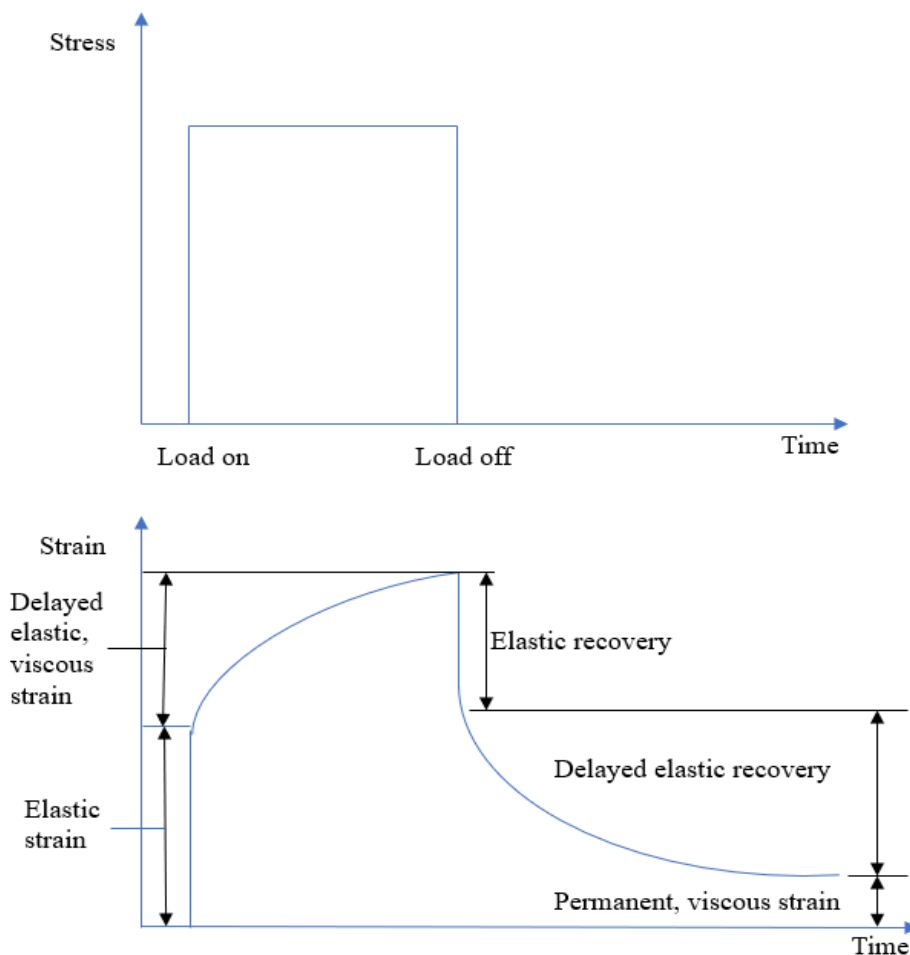


Figure 3 Response of Asphalt in a simple Creep test

The load and associated deformation of an asphalt mixture subjected to constant stress is illustrated schematically in Figure 1. After an instantaneous elastic response to the application of the stress, a gradual increase in deformation (or strain) takes place until the load is removed. The viscous behaviour of the material causes this ongoing deformation. Upon removal of the stress, the elastic strain is recovered instantaneously, and some additional recovery occurs with time – known as delayed elasticity. Ultimately a permanent residual deformation remains, which is non-recoverable and is directly caused by the viscous behavior of the binder.

3.4 Binder Characterization

The Superpave PGAC binder specification according to AASHTO M320 (AASHTO, 2010) was followed to characterize each modified binder (Bitumen) used to produce asphalt mixtures. This was to ensure binder used are exhibiting similar high and low-temperature performance grades and the targeted Penetration Grade. The AASHTO M320[14] includes rheological tests associated with the control of workability, rutting (permanent deformation), fatigue cracking, and thermal cracking at specific temperatures and ageing conditions. While the Figure 4 below illustrates how such

rheological tests are used in combination to establish the Penetration Grade, it Provides a brief description of each test.

3.5 Temperature Grade

The principle of the SUPERPAVE system relies on the minimum and maximum pavement design temperature where the binder is to be used when selecting the binder grade. Although the physical properties of the binder would remain the same, temperature requirements would be different based on the maximum and minimum pavement design temperature. For instance, a binder grade of PG 58-10 should meet the desired need up to a maximum temperature of 58 and a minimum temperature value of -10°C. As specified by Superpave specifications, table 1[15] represents the conventional binder grades. The maximum temperature of 58°C has a similar low temperature of -16, -22, -28, -34-40°C resulting in PG58-16, PG58-22, PG58-28, PG58-34, and PG58-40. However, the performance grades presented are not limited to those shown in the table; hence it is possible to obtain PG58-10.

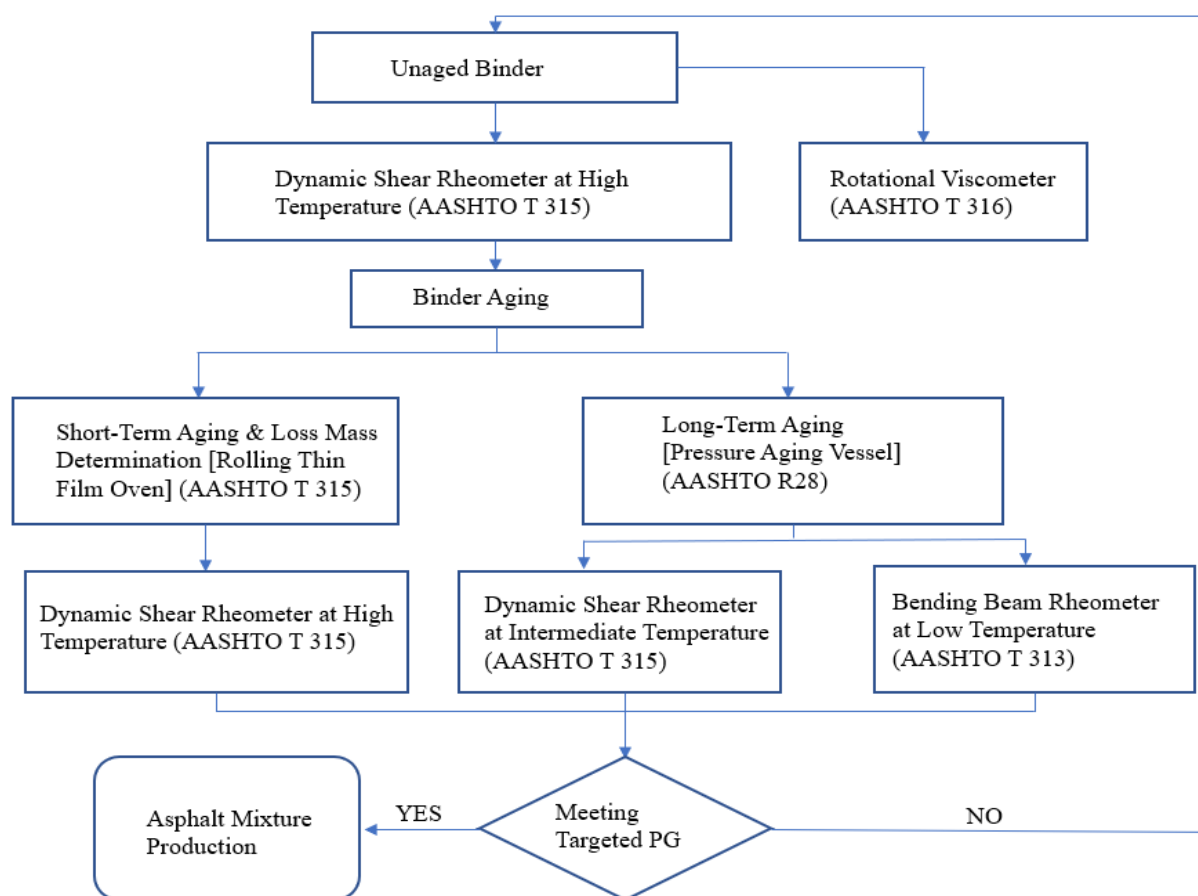


Figure 4 Binders Characterization Flow Chart and Test Method

Table 3 Basic equipment for bitumen design

Binder Test	Purpose	Equipment
Rotational Viscometer (RV)	Measuring viscosity of asphalt binder at different temperatures to establish mixing and compaction temperatures. In addition, it is used to ensure efficiency pumping through the plant	
Dynamic Shear Rheometer (DSR)	Measures Physical properties of the binder at high and intermediate pavement temperatures to ensure an adequate level of resistance to rut and fatigue, respectively	
Short Term Ageing (RTFO)	To simulate binder ageing (Hardening) during production, transportation, and laying	
Long Term Ageing (PAV)	Simulate the ageing behaviour of binder during its in-service use	
Bending Beam Rheometer (BBR)	Measures the property of binder at low temperatures to ensure an adequate level of thermal crack resistance	

Table 4 Binder grades based on SUPERPAVE criteria [15]

High-Temperature Grade °C	Low-Temperature Grade
PG46	-34,-40,-46
PG52	-10,-16,-22,-28,-34,-40,-46
PG58	-16,-22,-28,-34,-40
PG64	-10,-16,-22,-28,-34,-40
PG70	-10,-16,-22,-28,-34,-40
PG76	-10,-16,-22,-28,-34
PG82	-10,-16,-22,-28,-34,-40

3.6 Selection criteria of PG considering the Traffic Volume and Speed

The principle of SUPERPAVE is based on assumed traffic volume in selecting the binder [16]. Although the loading speed also contributes to the pavement's ability to resist rutting under high-temperature conditions at different traffic conditions [17]. When there is slow traffic (15-70) km/hr., the selected asphalt binder should be shifted to one high-temperature grade based on the procedure described earlier.

Also, when standing traffic (0-15) km/hr., the selected binder should be shifted to two high-temperature grades. Hence, selecting the binder grade for a specific traffic level and speed should always be increased by a grade for high pavement temperature designs, which is usually equal to 6°C [18]. A level shift is generally used for slow-moving vehicles, while two grades are used for load conditions design that is static, as presented in Table 5.

In considering a high number of heavy traffic loads, there is always an additional shift based on recommended design lane traffic which is expected to exceed 10million Equivalent Single Axle Load (ESAL). In a scenario where the expected traffic load is between (10-30) million ESAL, a shift by one high-temperature asphalt binder grade is considered higher than the one selected based on climate condition. However, if the expected design traffic exceeds 30million ESAL, the binder grade selection should be shifted with one grade higher as presented in *Table 5* [19].

Table 5 Adjustment to the High-Temperature grade of binder based on traffic level and speed [20]

Design ESALs (Million)	Adjustment to Binder PG Grade		
	Traffic Load Rate		
	Standing (Avg. speed<20km/hr)	Slow (Avg.speed 20 to 70Km/hr)	Standard (Avg.speed>70km/hr)
<0.3	-	-	-
0.3to<3	2	1	-
3to<10	2	1	-
10to<30	2	1	-
>30	2	1	1

4. Research Methodology

To achieve the objectives of this study and determine the asphalt binder PGs, the following were considered (1). The air temperature and pavement temperature data collected was collected for the six geopolitical zones at some selected federal highway network. All stations are presented in Table 6, and the following parameters were extracted from the station's database to be used as preliminary data for every station. The maximum daily temperature was selected as the maximum temperature recording for 24 hours, the minimum daily temperature recorded for 24 hours, and the latitude for each of 36 specific weather stations sourced online.

This study is intended to establish locally acceptable binder performance grades (PGs) using historical temperature data. Another aim of this study lies in presenting a map of binder performance grades with statistical reliability that can resist rutting at high temperatures and low temperature cracking at Intermediate and low temperatures. The key steps below summarize this methodology.

- 1) Acquisition historical climate data of 36 states cities in Nigeria provided by World Meteorological Organisation using Global telecommunication system.
- 2) Identify the average 7-day highest and 1-day lowest temperatures for the last 15 years.
- 3) Analyzing the temperature trends to figure out if the temperature changes can be predicted.
- 4) Determination of reliable asphalt binder PGs using hottest and coldest pavement temperatures.
- 5) Presentation binder PG maps of Nigeria with 50% and 98% reliability.
- 6) Suggestion of the most common PGs for Nigeria. The reason may be high temperature, low temperatures, precipitation, overloading and practicing old methods, etc.

The Superpave mix design method addresses all these problems. Furthermore, binder characterization is given tremendous importance in this System [21]. According to the Superpave mix design, "A Performance Grade (PG) is a new asphalt binder specification for selecting the appropriate binder for pavement performance in rutting, fatigue and low temperature cracking."

This PG belongs to the Superpave mix design, an acronym for **S**Uperior **P**ERforming Asphalt **P**AVement, and is the Strategic Highway Research Program (SHRP) [22]. The binders are selected using the performance-based binder specification and based on the climate of the pavement where they will be used[23]. According to studies conducted by some researchers [24], bituminous binder softens as the temperature increases and stiffens as temperature decreases. The measurements have shown that the deflection and rebound of the bituminous pavements are more affected by temperature than load. Temperatures can cause pavements to expand and contract, creating pressure that can cause pavements to buckle or crack.

4.1 Reliability

The Superpave System defines reliability as the percent probability in a single year that the actual temperature (one-day low or seven-day high) will not exceed the design temperature[21]. The typical reliability used is 50% and 98%. The 98% means when the PG 70-10 binder is selected, the bituminous binder should perform satisfactorily under normal traffic conditions. The extreme pavement temperature is between -10°C and 70°C with a minimum 98% confidence level.

SUPERPAVE MIX DESIGN MANUAL: BITUMEN SCALE DESIGN

Table 6 Maximum and Minimum Air Temperature

State	Maximum and Minimum Air Temperature				
	Max	Min.	St.dev.	50% reliability	98% reliability
Abia	30	28	1.068	29	32
Adamawa	39	31	2.507	34	44
Akwa Ibom	31	27	1.134	29	31
Anambra	35	29	2.575	31	41
Bauchi	39	30	2.843	34	40
Bayelsa	32	27	1.992	30	34
Benue	39	28	3.912	34	42
Borno	43	33	3.367	38	44
Cross-River	35	28	2.611	32	37
Delta	35	28	3.260	32	38
Ebonyi	37	29	3.275	33	38
Edo	34	28	3.029	32	39
Ekiti	36	28	3.551	33	40
Enugu	40	27	3.289	32	38
Gombe	37	29	3.881	35	43
Imo	42	29	3.129	33	39
Jigawa	39	34	3.467	37	44
Kaduna	39	27	3.631	34	41
Kano	39	29	3.232	34	40
Katsina	41	32	3.433	36	43
Kebbi	42	34	2.949	37	43
Kogi	40	29	3.893	35	43
Kwara	39	29	3.606	35	43
Lagos	33	28	1.832	31	35
Nasarawa	39	28	3.987	34	42
Niger	41	29	4.316	36	44
Ogun	38	29	3.147	33	40
Ondo	37	27	3.499	32	40
Osun	38	28	3.655	33	40
Oyo	38	29	3.486	34	41
Plateau	35	26	3.251	30	37
Rivers	33	26	2.431	30	35
Sokoto	41	33	3.088	37	43
Taraba	42	31	3.872	36	44
Yobe	41	32	3.143	36	42
Zamfara	41	30	3.257	36	43
Abuja					

4.2 Performance Grade Specification

The backbone of Performance grade specification is to reduce the tendency of binder to cause permanent deformation fatigue at low, intermediate, and high temperatures in pavements. The concept involves the grading of binder in relation to their usage and application, considering specific climate, load intensity and rate of loading. Performance grade specifications do not give preference to either modified or unmodified binder rather, and it only considers the traffic and climatic condition to be met during the binder usage. Pavement distress is usually caused by two main factors if not appropriately designed. The traffic and environmental condition such as water and temperature, especially in tropical regions like Nigeria, contribute to pavement failures. The rainfall intensity and the differential air temperature can profoundly impact pavement distress mechanisms and performance in different climate regions.

Bitumen is commonly graded using the penetration grading system in Nigeria. However, researchers [26] have reported that this grading system developed for lower-traffic loading conditions in the past is prone to many drawbacks and limitations, which includes:

- Penetration as an empirical test cannot adequately predict the performance of pavements over its lifetime.
- The testing temperature is constant, regardless of the actual field service temperature.
- The testing temperature does not cover the entire pavement service temperatures. The test is conducted at a fixed temperature of 25°C, and the in-field service temperatures as observed are actually between 23°C to 35°C.
- The test does not consider long-term binder ageing to account for fatigue cracking.
- Due to different chemical properties, different material properties could exist for the same binder grading.
- It is inappropriate to grade modified bitumen binders because they were originally developed to grade regular, non-modified binders.

Owing to all the above limitations, a new binder grading system, the Superpave performance grading (PG) system, was developed based on further tests and specifications to address some of the issues highlighted above. In addition, the penetration grading system did not address the three major pavement structural distresses, fatigue cracking, low-temperature cracking, and rutting. The PG system tends to fill in the gap. The philosophy behind the PG system is to simulate the properties of Hot-Mix Asphalt and binder to reflect actual field conditions such as load, ageing, climatic conditions experienced while in use. Researchers (Roberts *et al.* 1996) have reported that the PG grading system simulates the actual behaviour of the pavement under service conditions having the following criteria:

- The performance of the pavement in the field as related to the properties of asphalt material measured in the laboratory.
- The same testing criteria is considered when testing the materials at different temperatures.
- The test temperatures during the binder testing would consider the location where the pavement would be used.

- Different ageing conditions are considered, including the original asphalt binder condition, short-term binder ageing condition (RFTO) and the long-term binder ageing condition (PAV).

The PG system can characterize new, innovative, aged, modified, and unmodified binders.

The performance grade of the binder was determined by the adaptation of the chart provided by the Superpave System [22]. The PG system is based on climate, so the grade notation consists of two portions: high and low pavement temperatures [27]. A binder identified as PG 70-10 must meet performance criteria on the maximum pavement temperature of 70°C and at a minimum of -10°C, where PG stands for performance grade. For both high and low-temperature grades, PG is graded in 6°C increments. The average 7-day maximum pavement temperature typically ranges from 46°C to 82°C, and minimum pavement temperature typically ranges from -46°C to -10°C [22]. This present study would rely on the temperature topo map of different zones developed based on temperature data for the other regions in Nigeria. The main scope of this study is the following:

1. To develop PG grade appropriate for the climatic zones in Nigeria according to the Superpave asphalt binder PG system.
2. To evaluate available 60/70 Bitumen available in Nigeria.
3. To select the proper PG of bitumen for the different climatic regions in Nigeria.
4. To work toward the implementation of the Superpave System in Nigeria.

In the following subsection, the background behind this PG system will be discussed and what has been presented in previous sections.

4.3 Superpave Background

The United States started the Strategic Highway Research Program (SHRP). The main goal of this research programme was to design and construct a road system that would have a linkage between field and laboratory. In addition, the programme was meant to improve the performance, durability, safety, and efficiency of the US highway system. They invested in research and development in laboratory equipment, material testing, etc., to adequately simulate this linkage. The Superpave of **S**Uperior **P**ERforming Asphalt **PA**VEments was part of the outcome of the asphalt research part conducted during 1987 – 1992.

The resulting Superpave System includes:

- Asphalt binder PG system.
- Asphalt binder tests and specification
- Aggregates tests and criteria
- A new selection of asphalt binders and design aggregate structure and gradation.
- The compaction process, criteria and specification adopted are different.
- The field performance of asphalt pavements in the field is simulated.

The Superpave asphalt binder PG system classifies asphalt binders accurately predicted based on prevailing climatic conditions. The following factors are considered in the Superpave asphalt binder PG system:

- a) The overlapping scenario of temperatures between performance grades is minimized.
- b) The prevailing climatic and environmental conditions at the construction site should be strictly considered.
- c) The temperature range in a specific site and simulating short and long-term ageing that usually takes place during mixing and lay down and during the service life of asphalt pavements.
- d) Physical consensus properties measured for aggregates are directly related to field performance.
- e) Tests and specifications of asphalt binders aim at including both unmodified and modified asphalt binders, and the evaluation process is based on pavement performance.
- f) In the Superpave System, the traffic loading is considered in the design lane over a 20-year design period in addition to the traffic speed during the asphalt mixture design process.

4.4 Development of Performance Grading Map of Nigeria

While making a performance grading map, maximum and minimum pavement temperature (design pavement temperature) determined by the SHRP model based on a 98% level of reliability were used. The 98% reliability provides an additional safety margin against high traffic levels and uncontrolled axle loadings[25].

Figure and Figure shows the PG map of Nigeria using the SHRP models, respectively.

5. Bitumen

Highway construction in Nigeria is mainly flexible pavements. The grade used is 60/70; however, this study has shown from the air temperature and pavement temperatures data that some states in the northern part of Nigeria would need a harder bitumen or a grade that would resist high temperature. The binder grade, which is mainly imported, are derived from refinery produced quality; hence this grade would be engineered to suit the needs in line with the Superpave asphalt binder PG classification system.

According to Superpave PG Procedures and AASHTO Practices, steps should be considered to characterize the binder based on the specification. The fresh and short-term aged samples using the rolling thin-film oven (RTFO) or the oven method should be tested using the Dynamic shear rheometer (DSR) to determine the viscoelastic properties at various temperatures 54, 58, 64 and 70°C. The binder should be tested for short term behaviour using the RTFO Methods which the material is usually subjected to 163 °C. However, oven tests following ASTM. The short-term ageing samples subjected to RTFO should be tested under the DSR at 54, 58, 64 and 70°C to determine the $G^*/\sin\delta$ at 1.5Hz. The binder that has been subjected to short term ageing should be subjected to long term ageing at 100°C and pressure of 300 psi

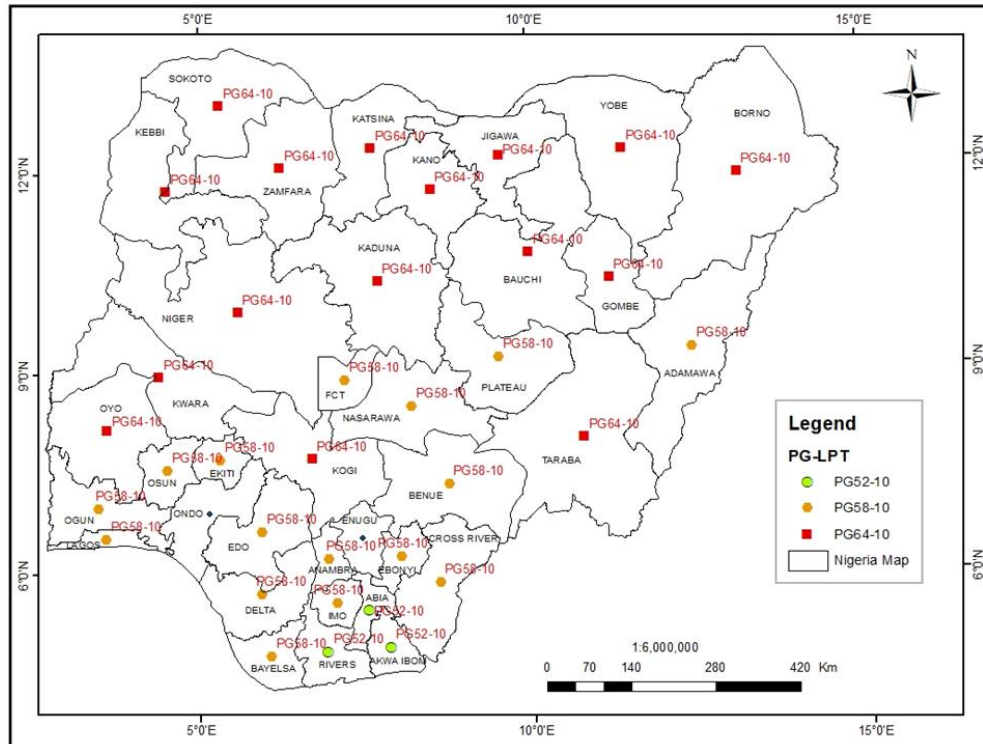


Figure 5 Low Pavement Temperature map

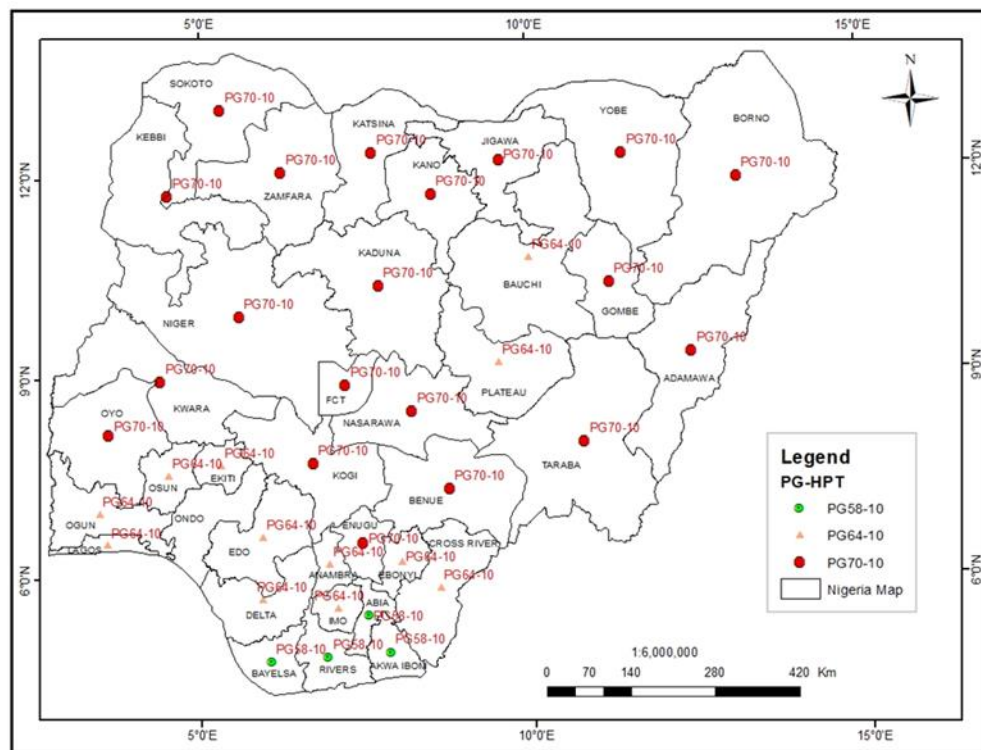


Figure 6 High Pavement Temperature map

The dynamic shear rheometer test should be conducted on the long-term aged sample subjected to PAV to determine the fatigue parameter $G^*\sin\delta$ at 1.5Hz at different temperatures of 25, 28, 31, 34 and 37°C. The aged binder based on PAV long term procedure should be carried out to obtain the creep stiffness, $S(t)$ and Slope, m -value at the 60s at temperatures ranging from 0, -6 and -12°C to determine the low-temperature properties of the binder. Although from experience, the lowest temperature observed from the site was within the range of 10-0 °C, however, in extreme and adverse conditions, the technical specification would extend the severe case to a temperature of -22 °C.

5.1 Brief Description of Superpave Tests

5.1.1 Rolling Thin Film Oven (RTFO) Test

The prediction of the performance of asphalt and bitumen during the process of mixing in the plant and the construction using the HMA at the site is done using the rolling thin film Oven test. According to the AASHTO T240 test method, it is conducted at a temperature of 163degree in the laboratory. This is done by placing the bitumen in a pan and placing the RTFO in the oven, as shown in the figure below. The test analyses are considered by computing the mass loss of the test samples calculated as the percentage of change in mass of the original sample before testing and the sample after testing mathematically shown below. The criteria based on the Superpave System is the maximum limit should not be more than 1.0% for a non-modified bitumen.

5.1.2 Pressure Aging Vessel (PAV) Test

A pressure ageing vessel test is conducted to predict the long-term performance of asphalt in the field. Based on AASHTO R28 test criteria, the test is performed between the test temperature of 90 to 110 °C at high-pressure 300psi for 20hrs. For this project, we would be using 95 °C.

5.1.3 Rotational Viscosity (RV) Test

The RV test samples for 60/70 bitumen binder were prepared according to the AASHTO T316 test method procedures. A rotational viscosity test is a test conducted to examine the behaviour of bitumen during missing and laying, which indicates the workability of bitumen and mixability ability. According to ASTM 4402, the test apparatus is shown below, having a cylindrical spindle rotated at 20rpm. The material's sensitivity towards temperature during mixing and compaction was carried out using Brookfield rotational viscometer, as shown in Fig. 29. The thermo-chamber spindle speed and temperature were set at 135°C and 20 rpm. As the temperature increases, the viscosity decreases. The Maximum value of RV should be less than or equal to 3.0pas at 135 °C.

5.1.4 Dynamic Shear Rheometer (DSR) Test

Dynamic shear rheometer helps evaluate the visco-elastic properties of bitumen and helps develop the PG grades in tandem with the previous test mentioned above. According to AASHTO T315 methods, ASTM, the test was conducted at four different temperatures, 54,58,64 and 70 degrees at frequency 1.59HZ. The working principles of DSR involve that the bitumen is placed between 2 parallel plates of 25mm thickness using the 1.5HZ frequency to load it in a

strain-controlled mode. The upper plates are fixed while the lower plates rotate in an oscillatory manner. The complex shear modulus (G^*) and the phase angle (δ) are collected during the DSR testing. These two parameters depict how elastic the material is and how viscous the material relates to the field performance.

5.1.5 Bending Beam Rheometer (BBR) Test

The BBR test was conducted on the bitumen samples based on AASHTO T313 standard test methods. As shown in the figure below, an example of 100g was placed on the beam for 240s and loaded on both RTFO and PAV samples. Deflection and load were recorded during the test through the data acquisition system. From the deflection data acquired, Creep stiffness $S(t)$ and the Slope m -value, the rate of stiffness change with time would be calculated mathematically using the below formula. The Superpave criteria specify a maximum value of 300 MPa for the Creep Stiffness, $S(t)$ and a minimum of 0.300 for the Slope m -value.

6. Results and Discussion

6.1 PG Classification for Bitumen Binder

RV's results were conducted at 135° C and 165°C to assess the 60/70 bitumen fluidity, workability, mixing and laying down criteria based on Superpave specifications. As shown *Table 7* RV results showed that the binder has 1.775pas which is within the criteria. The DSR test results obtained from the test of 60/70 binder, which was conducted on both fresh, short term aged and long-term aged bitumen, were obtained for four at four test temperatures: 54, 58, 64 and 70°C. The plot of $G^*/\sin \delta$ value versus test temperature for the original bitumen binder, RFOT, PAV binders met the minimum criteria specified by the Superpave grading system at the maximum temperature test 64°C. The plot shows that the $G^*/\sin \delta$ value for fresh and RTFO-aged bitumen binders met the minimum of 1.0kPa and 2.2 kPa, respectively. The graph shows clearly that the 60/70 RTFO-aged bitumen binder pass the Superpave specifications at a maximum test temperature of 64°C. *Table 7* shows the Superpave Test Results for 60/70 Penetration Grade bitumen.

Therefore, the 60/70 bitumen binder were classified for the high PG grade according to the Superpave asphalt binders grading system as PG 64. Based on the BBR Test Conducted ON THE 60/70 bitumen at the test temperature of -12°C where the stiffness, $S(t)$ and the Slope of the creep stiffness, m -value at 60 s were computed. The maximum value of BBR creep stiffness $S(t)$ and the minimum value for the m -value for the PAV-aged bitumen binder. The Superpave grade system is 300Mpa and 0.300 respectively for PAV-aged binder. Considering the study conducted, the current used 60/70 can be graded as PG-22. Based on the current 60/70 binder been currently in use in Nigeria, the binder performance based on SuperPave criteria is a of PG 64-22 grade. It is also recommended that higher grades are considered for the country's Northern region, and the 64-22 grade can be used for the Southern part of Nigeria. The following phase of this project would be studying the mixtures scale of the binder based on the established grades for the two zones.

SUPERPAVE MIX DESIGN MANUAL: BITUMEN SCALE DESIGN

Table 7 Test Results - Bitumen Binder Properties

TEST	NBRRI-sourced 60/70	Superpave Specification	Status
Brookfield, 135°C, Pa.s	1.775	Maximum - 3.0 Pa.s -	Pass
Brookfield, 165°C, Pa.s	0.338		
G*/sin(d), 64°C	1.571	Minimum – 1.0 kPa	Pass
Phase Angle, delta	86.9	-	
G*/sin(d), 70°C	0.724	Minimum – 1.0 kPa	Pass
Phase Angle, delta	88.1	-	
Pass/Fail Temp	67.9	-	(T _{unaged}) 67.9°C
RTFO RESIDUE			
Mass Loss, %	0.55	Maximum – 1.0%	Pass
G*/sin(d), 64°C	3.700	Minimum – 2.2 kPa	Pass
Phase Angle	83.4	-	
G*/sin(d), 70°C	1.669	Minimum – 2.2 kPa	Fail
Phase Angle	85.4	-	
Pass/Fail Temp.	67.5	-	(T _{RTFO}) 67.5°C 67.9°C
PG High Temp	67.9	-	
PAV RESIDUE			
G*x sin(d), 25°C	3932	Maximum – 5000 kPa	Pass
Phase Angle	48.3	-	
Cr. St, - 18°C, Mpa	359	Maximum – 300 MPa	Fail
m-value, - 18°C	0.241	Maximum – 0.300	Fail
Cr. St, - 12°C, Mpa	205	Maximum – 300 MPa	Pass
m-value, - 12°C	0.302	Minimum – 0.300	Pass
Pass/Fail Temp.	-22.2	-	(T _{PAV}) -22.2°C 64-22
PG Grade	67.5 -22.2	-	
Physical Properties	NBRRI Sourced Bitumen	Penetration Grade 60/70 Specification	Status
Density @ 15°C, g/cm ³	1.0325	1.01/1.06	Pass
PEN @ 25°C, dmm	65	60 - 70	Pass
Softening point °C	52.7	49/56	Pass
Ductility @ 25°C cm	122+	100 minimum	Pass
Flash Point, °C	326	230 minimum	Pass

7. Performance Criteria

The rheological measurement of binder application in Nigeria would solely depend on testing binder using DSR to formulate the criteria for optimal performance. However, in rare cases, BBR could be considered. It should be noted that binder characteristics alone cannot guarantee optimal performance of asphalt, although adequate adherence to the appropriate criteria will contribute to the performance of asphalt layers. In addition, once we are sure that the gluing agent (binder) meets the needed criteria will complement the functions of other components of the layers to perform well in given traffic and environmental condition.

60/70 Bitumen DSR Properties

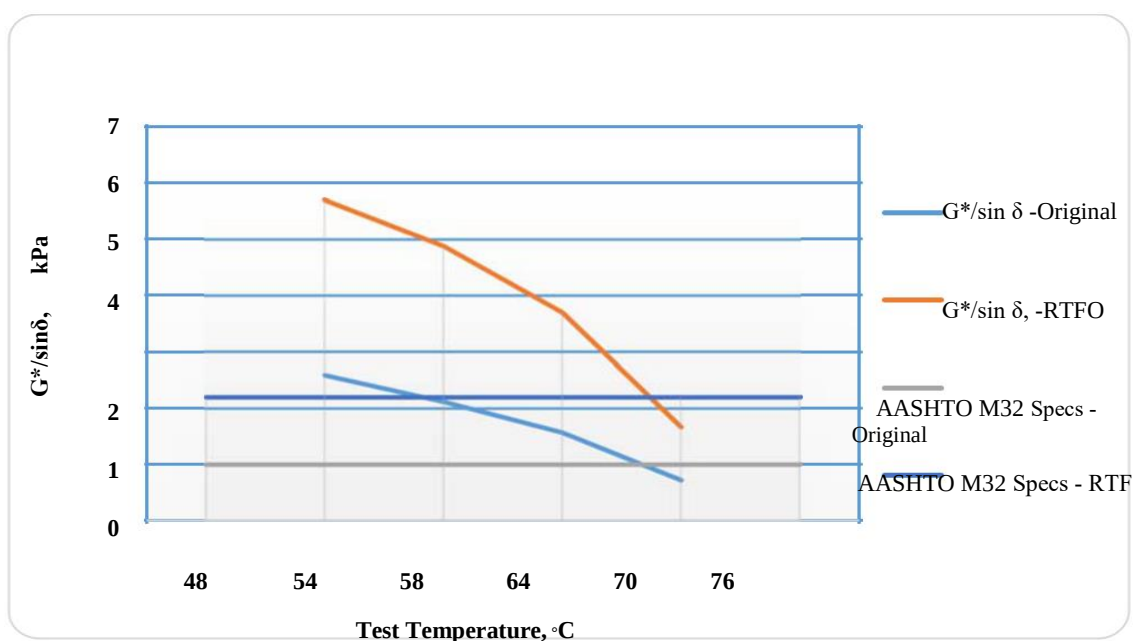


Figure 5 $G^*/\sin \delta$ for Original and RTFO-aged Bitumen Binders

7.1 Safety and Handling

Safety and handling of binder do not affect the performance of binder. However, it is imperative to consider safety, handling, and storage in the performance grading specification. Safety - flashpoint indicates how well the binder is pumped, sprayed, mixed with aggregates and the resulted asphalt concrete after compaction are all dependent on binder viscosity at elevated temperatures. The storage stability of modified binders can provide information on how well it will be compatible with a neat binder and indicate storage effects at the site.

7.2 Temperature

The maximum pavement design temperatures adopted for Nigeria are 52°C, 58°C, 64°C and 70°C. While the minimum temperature in Nigeria rarely falls below -10°C, the minimum temperatures adopted for grading purposes are considerable. The use of the DSR for this purpose is described in ASTM 7175: Standard Test Method for Determining the Rheological Properties of Asphalt Binder using a Dynamic Shear Rheometer. These tests will be carried out at the relevant intermediate temperature.

7.3 Low-Temperature Cracking

The resistance of the binder to (low) temperature fracture will be assessed by an upper limit of creep stiffness (to limit its brittleness) and its stress relaxation characteristics using the BBR as described in ASTM D6648[28]: The test is conducted on binder specimens at a low temperature.

7.4 Storage Stability

Storage stability will be assessed by the difference in complex shear modulus (G^*) at Temp. max carried out on an unaged binder in the top and bottom of the container, with a maximum value being assigned.

7.5 Safety

The flash point indicates the temperature to which the binder can be heated without danger of instantaneous flash in the presence of an open flame. The test is carried out on an unaged binder following ASTM D92[29]: Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester.

7.6 Pumping and Handling

To ensure that binders, especially modified ones, can be pumped and handled at elevated temperatures, a viscosity test is performed on the unaged binder at 165°C using a rotational viscometer as described in ASTM[30]: Standard method for viscosity determinations of unfilled asphalt using the Brookfield Thermosel apparatus.

8. Provisional Specification

The proposed trial implementation of performance grade specification in Nigeria presents four binder grades as shown in Table 87. Furthermore, the specification and its implementation would require determining specification parameter(s) and related compliance limits for fatigue resistance during its final stage.

SUPERPAVE MIX DESIGN MANUAL: BITUMEN SCALE DESIGN

Table 8 Performance Grade Specification for Nigeria

Test Property	Nigerian Performance Grade				Test Methods (ASTM)
	PG52-10	PG58-10	PG64-10	PG70-10	
Average 7-day Maximum Pavement Design Temperature °C	52	58	64	70	
Minimum Pavement Design Temperature °C	-10	-10	-10	-10	
Original Binder					
Flash Point Temp, minimum °C	≥ 230				D92-18
Viscosity Max. pa-s(3000Cp) Test Temperature	135				D4402
Storage stability at 180 °C	≤ 15				D7175
Dynamic Shear G*/sinδ, Minimum,1.00kPa Test Temperature @10rad/sec, °C	52	58	64	70	D7175
After RFOT Ageing					
Mass Loss, Maximum, %	must not exceed 1.00%				D2872
Ageing ratio G*RFOT/G*Original	≤ 3.0				D7175
Dynamic Shear G*/sinδ, Minimum,2.20kPa Test Temperature @10rad/sec, °C	52	58	64	70	D7175
After RFOT Ageing Plus PAV Ageing					
PAV Ageing Temperature	90	100			D6521 – 19a
Ageing ratio G*PAV/G*Original	≤ 6				D7175
Dynamic Shear G*/sinδ, Minimum,5000kPa Test Temp.@10rad/sec, °C					D7175
Physical Hardening	Report				
Creep stiffness S, Maximum,300Mpa m-Value, Minimum,0.30 Test Temperature@60 sec, °C					D6648
Direct Tension Failure Strain, Minimum,1.0% Test Temperature @1.0mm/min, °C					D6723

Hence it would be compulsory to report the frequency sweep at the intermediate temperatures on the original RFOT aged binder and PAV aged binder. Once we have sufficient data, compliance limits will be proposed for implementation. Modification of straight run would be required for the high traffic category.

9. Conclusions and recommendations

The conclusion and recommendation are made on the basis of test results and analysis conducted in this study as itemized below:

- Although four different grades were established based on the climatic zones, however for the purpose of implementation of this new performance grade system into the Nigerian Road sector it is expected that the Northern states should adopt PG70-22 while the southern states should adopt PG 64-22.
- The DSR and BBR test results obtained and according to SuperPave binder classification system, the 60/70 binder currently been used in the country is classified as PG 64-22. It is also noted that some 60/70 penetration grade bitumen did not meet the PG 64-22.
- To meet the desired PG 70-22 for the Northern states, there would be need for modification using polymer such as Styrene Butadiene Styrene (SBS), epolene EE2 Polymer.
- The BBR test was not conducted due to the fact that low temperature effect on pavements in Nigeria is seldom experienced.
- It is recommended that the road sector start to implement this new Grade of binder selection and the use of one single grade of 60/70 across Nigeria is not scientific and practically suitable.
- The next phase of this project would be to evaluate the aggregates criteria and mixture criteria for Performance Grade system complementing this effort made at this scale.

10. Acknowledgment

The management of Nigeria building and road research institute is well acknowledged for funding this project as part of an effort to revamp the Nigerian road specifications for the sustainable application. In addition, the management of ASCA bitumen, Julius Berger Nigeria Limited, is duly acknowledged for allowing the research team to utilize their lab for some experiments. Also, McAsphalt Canada is duly recognized for the collaborative effort they have rendered to the Institute via the utilization of their laboratory for this project. Finally, all contributions of the participants and members of this committee is gratefully acknowledged.

12. Reference

1. Echendu, A.J., *The impact of flooding on Nigeria's sustainable development goals (SDGs)*. Ecosystem Health and Sustainability, 2020. 6(1): p. 1791735.
2. Federal Ministry of Works, H., Mabushi, FCT, Abuja, *ROAD INFRASTRUCTURE & RELATED DEVELOPMENT IN NIGERIA-AN INVESTOR'S MANUAL*. 2013.
3. Anyanwu, C., B. Adebuseyi, and S. Kukah, *Highway maintenance in Nigeria: lessons from other countries*. 2003: Central Bank of Nigeria.
4. Clinton, E., O. Oluwaseun, and T. Zomatic, *Comparative study of the effect of the transport system on the economic growth of Nigeria*. J. Econ. Trade, 2017. 2(1): p. 30-43.

5. Nnanna, O., *Highway Maintenance in Nigeria: Lessons from Other Countries*. Central Bank (of Nigeria) Research Department Occasional Paper Series, CBN, Abuja, 2003.
6. Akinwale, A.A., *The menace of inadequate infrastructure in Nigeria*. African journal of science, technology, innovation and development, 2010. **2**(3): p. 207-228.
7. Mohseni, A., *LTPP Data Analysis: Improved Low Pavement Temperature Prediction:[tech brief]*. 1998, United States. Federal Highway Administration.
8. Solaimanian, M. and T.W. Kennedy, *Predicting maximum pavement surface temperature using maximum air temperature and hourly solar radiation*. Transportation Research Record, 1993: p. 1-1.
9. Shao, L., S.W. Park, and Y.R. Kim, *Simplified procedure for prediction of asphalt pavement subsurface temperatures based on heat transfer theories*. Transportation Research Record, 1997. **1568**(1): p. 114-123.
10. Bosscher, P.J., et al., *Relationship between pavement temperature and weather data: Wisconsin field study to verify superpave algorithm*. Transportation Research Record, 1998. **1609**(1): p. 1-11.
11. Marshall, C., R. Meier, and M. Welch, *Seasonal temperature effects on flexible pavements in Tennessee*. Transportation research record, 2001. **1764**(1): p. 89-96.
12. Hermansson, Å., *Simulation model for calculating pavement temperatures including maximum temperature*. Transportation Research Record, 2000. **1699**(1): p. 134-141.
13. Hermansson, Å., *Mathematical model for calculation of pavement temperatures: comparison of calculated and measured temperatures*. Transportation Research Record, 2001. **1764**(1): p. 180-188.
14. Committee, A.I.T.A., *Guidance on the Use of the MSCR Test with the AASHTO M320 Specification*. Asphalt Institute (AI), 2010.
15. Diefenderfer, B.K., et al. *Development and validation of a model to predict pavement temperature profile*. in *TRB 2003 Annual Meeting*. 2003. Citeseer.
16. Viola, F. and C. Celauro, *Effect of climate change on asphalt binder selection for road construction in Italy*. Transportation Research Part D: Transport and Environment, 2015. **37**: p. 40-47.
17. Delgadillo, R., K. Nam, and H. Bahia, *Why do we need to change $G^*/\sin\delta$ and how?* Road materials and pavement design, 2006. **7**(1): p. 7-27.

18. Ali Hussain, G.M., et al., *Asphalt binder performance grading for the Republic of Yemen based on superpave asphalt mix-design*. The Open Civil Engineering Journal, 2020. **14**(1).
19. Institute, A., *Performance graded asphalt binder specification and testing*. 1994: Asphalt Institute.
20. Mohseni, A., *LTPP seasonal asphalt concrete (AC) pavement temperature models*. 1998, United States. Federal Highway Administration. Office of Engineering
21. Khan, K.M., et al., *Development of Superpave Performance Grading Map for Pakistan*. Life Science Journal, 2013. **10**(7s).
22. Kennedy, T.W., et al., *Superior performing asphalt pavements (Superpave): The product of the SHRP asphalt research program*. 1994.
23. Kobbail, A., S. Osman, and R. Malkawi, *Determination of Sudan temperature zoning based on superpave System*. Journal of Building and Road Research, 2016. **8**(1).
24. Cominsky, R.J., et al., *The superpave mix design manual for new construction and overlays*. 1994: Strategic Highway Research Program Washington, DC.
25. Mirza, M.W., Z. Abbas, and M.A. Rizvi, *Temperature zoning of Pakistan for asphalt mix design*. Pakistan Journal of Engineering and Applied Sciences, 2011.
26. Roberts, F.L., et al., *Hot mix asphalt materials*. Mixture Design and Construction, 1996. **2**.
27. Khalil, N., H. Bahia, and C. Clopotel. *Developing a performance grading system for asphalt binders in Lebanon*. in *Sixth International Conference on Maintenance and Rehabilitation of Pavements and Technological Control (MAIREPAV6)*. 2009.
28. ASTM, A., *D6648-08 (2016), Standard Test Method for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)*, ASTM, Philadelphia, PA, 2016.
29. International, A., *ASTM D92-05a, Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester*. 2009, ASTM International West Conshohocken, PA, USA.
30. International, A.S.o.T.M., *ASTM D4402/D4402M-15, Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer*. 2015, American Society of Testing Materials (ASTM) International West Conshohocken



Figure 6 Axle Load data collection



Figure 7 Pavement Temperature testing



Figure 8 Traffic volume and speed data collection

Appendix B.

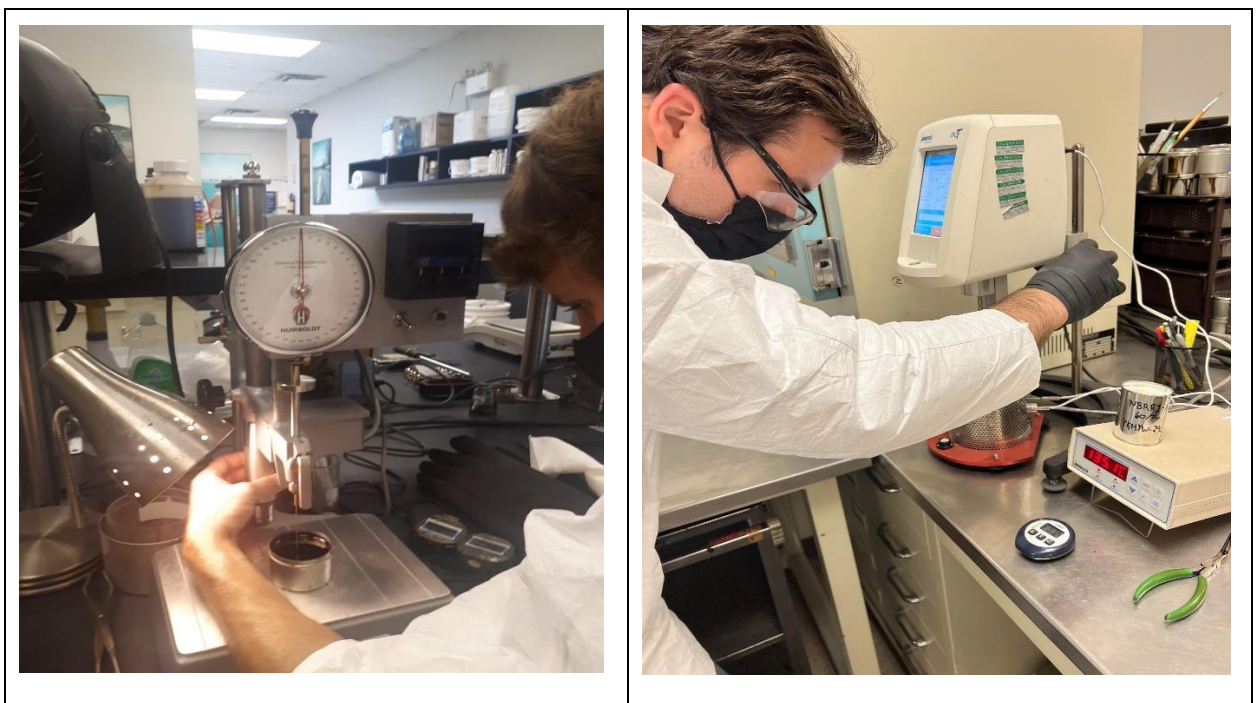


Figure 9 Bitumen testing

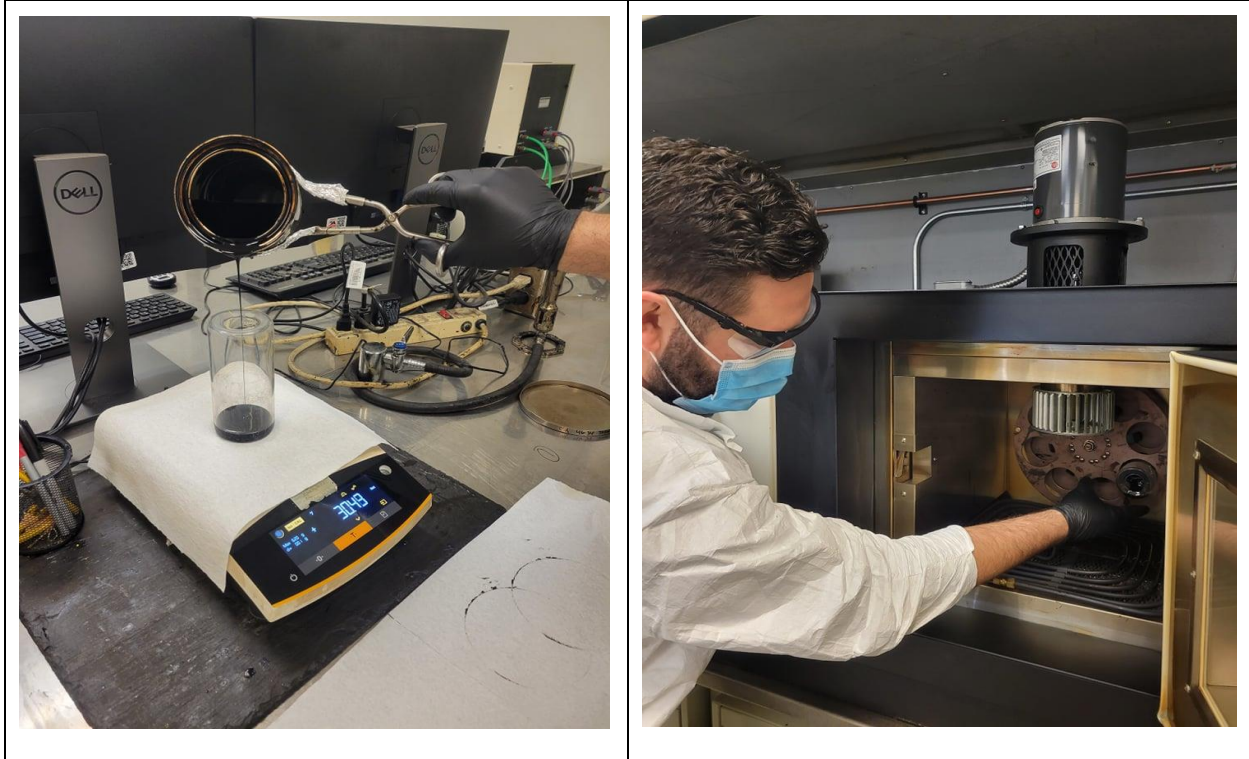


Figure 10 Aging of Bitumen

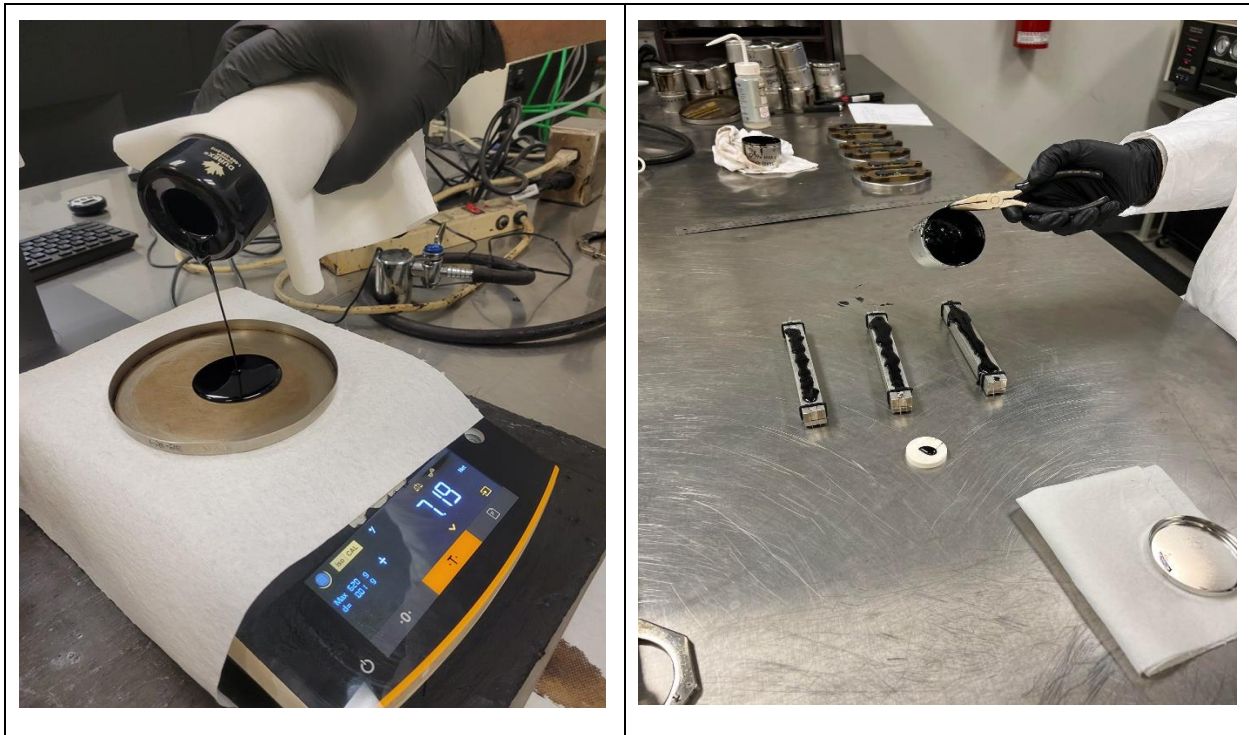


Figure 11 Measuring of Bitumen for PAV aging



Figure 12 DSR Testing of Bitumen

Appendix C.

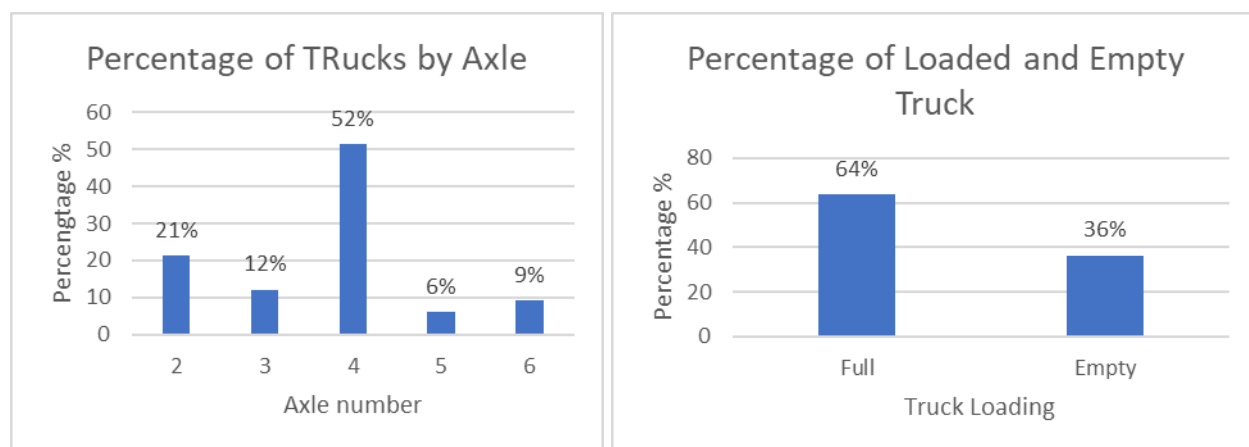


Figure 13 Lagos – Ibadan Road percentage of trucks by Axle, loaded and empty trucks percentage

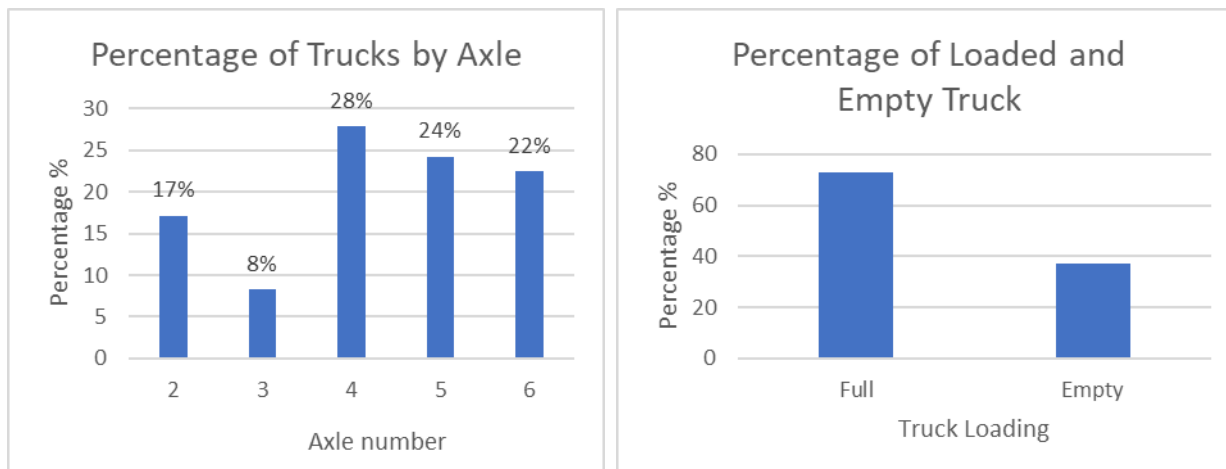


Figure 15 Warri – Pantani road percentage of trucks by Axle, loaded and empty trucks percentage

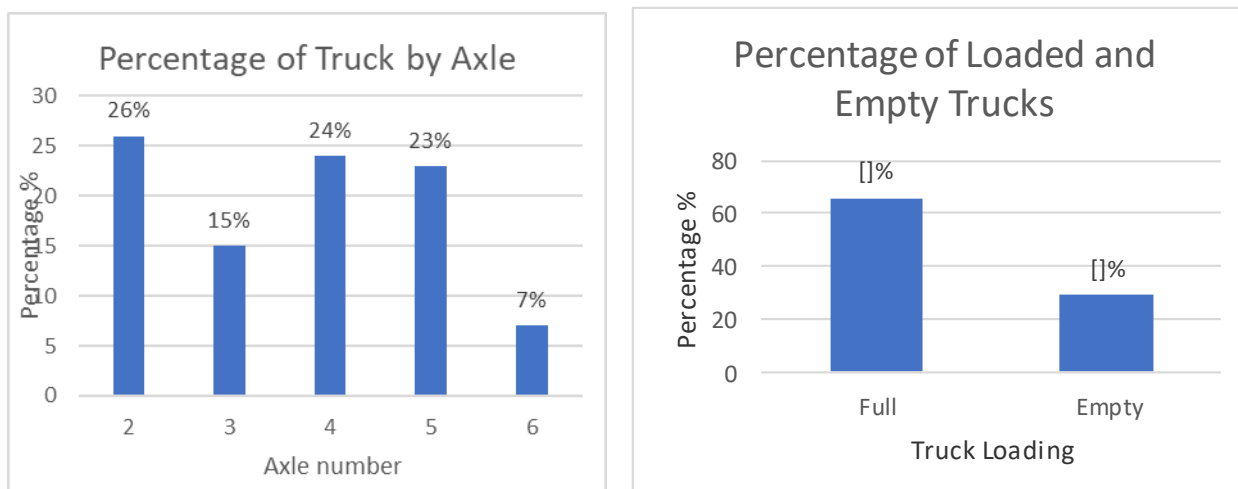


Figure 14 Enugu – Onitsha Road percentage of trucks by Axle, loaded and empty trucks.