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Impact of Climate Change on Rheological Properties of Bitumen

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Abstract

The present work investigated the properties of the commonly used Butimen for road construction in Nigeria (60/70 pen.) for normal temperature and climate Effect. The laboratory tests conducted were penetration, softening point, viscosity, ductility test and flash and fire point test based on the ASTM standards. The result indicates a decrease in stiffness of bitumen with an increase in temperature, with a decrease in penetration of bitumen by 85.5% when tested between 25˚C to 43.2˚C and also the Ductility decreases with increase in temperature by 54.9% between 25˚C and 43.2˚C. The viscosity result shows a decrease in viscosity with an increase in temperature, therefore at higher temperature Bitumen is likely to flow.

Keywords

Bitumen, Climate Change, Ductility, Penetratio, Properties, Rheological, Viscosity

1. Introduction

Bitumen is an engineering material and is produced to meets variety of specifications based upon physical properties, it is the residual product from distillation of crude oil.Eurobitume, A. I. (2011) [1]. Bitumen has been widely used in Nigeria for the construction of flexible pavements for more than a century. Flexible pavements with bituminous surfacing are widely used all over the world. It has been well known and used since 6000 BC as a waterproofing and binder material of great quality. The Sumerians used it in the prosperous shipbuilding industry, whereas the Babylonians used it as a binder in the mixture production for castle construction (Babel Tower) [2]. Asphalt was also used by the Egyptians both to mummify the dead bodies and to waterproof tanks. Around 3000 BC, the Persians also used bitumen for road construction.

Several road pavements distresses are related to bitumen properties. Rutting and fatigue cracking is the major distresses that lead to permanent failures in pavement construction. Bitumen is a viscoelastic material; its rheological properties are very sensitive to climate change (temperature and water/snow) and rate of loading (Ali, Nuha, and Mohammed (2013) [3]). The resistance to rutting of asphalt surfacing depends on road temperature as well as traffic load. At high temperature, asphalt becomes more susceptible to deformation, and rutting is more likely to occur, particularly on highly trafficked roads and at low traffic speeds. Research has found that the majority of rutting in asphalt surfacing occurs on a few days of the year, when the temperature of the road surfacing exceed 45˚C (Willway, and Reeves (2008) [4]). In general, road pavement performance properties are mainly affected by the bitumen binder properties.

Since the signing of Kyoto protocol to limit global warming, climate change impact has been in the forefront of international Discuss. Even though climate change is a global phenomenan, its impact must be evaluated for specific systems, areas or regions kyoto protocol report (1998) [5]. In Transportation, climate change impacts are manifested in pavement production and vehicle operation. The effort to migitate the impact includes the use of clean energy and the use of innovative materials and technology to lower the production and operating temperatures of ashphalt. The properties of bitumen are heavily dependent on temperatures and to some extent on the exposure of bitumen to water. Unless efforts are made to curtail global warming, the performance of bitumen under varying temperature regimes might adversely affect the life span of flexible pavements. Rutting, revelling and cracking are the main distress features caused by the temperature gradient in asphalts; climate change can aggravate these. Rutting in asphalts develops gradually with increasing number of loads applicationSousa, et al 1991 [6].

Collier, Conway, and Venables, 2008 [7]: Gemeda and Sima 2015 [8] reports on regional climate projection of 2007 state that by 2050 the average temperature in African continent is expected to rise by 1.5˚C - 3˚C and, warming of Africa is very likely to be severe than other regions. Asphalt institute 2011 finds that Changes in temperature alters the Physical properties of Bitumen. Temperature across Africa is expected to rise by 2 - 6 within the next 100 years and rainfall variability is also expected to increase, resulting in regular flooding EA, A. 2018 [9]. Qiang Li, *et al.*, 2011 [10] conclude that quantity and intensity of precipitation, in the form of rain and snow, affects the quantity of surface water infiltrating into the subgrade and the depth of groundwater table, Poor drainage may reduce shear strength, or cause pumping or loss of support. Moisture (in the form accumulated water or rainfall) affects pavements in several phases of the pavement life cycle: Ab Rahim 2012 [11] studying on aging process of polymer modified Bitumen finds the bitumen plays a large part in determining many aspects of road performance because of their good adhesion to mineral aggregate and their physical properties.

Many researches have been carried in the area of modification of bitumen to enhance its stiffness. As such, there is a need for studies to be conducted on the reason why asphalt pavement fails, which is mostly characterized by rutting and fatique cracking.

This primary objective of this research is to investigate the effect of climate change on the rheological properties of bitumen. The secondary objective is to determine the extent of climate change in the study area and to explore the use of appropriate penetration grade bitumen for use as a climent resilient material and also to analyse the implication for road maintenance.

2. Materials and Methods

Since the main aim of this research is to see the influence of climate parameters on the rheological properties of bitumen, the first step is to obtain climate data over a period of time and to analyse them to see whether climate has a bearing on bitumen. Two climate parameters *i.e.* (Temperature and Rainfall) were collected for 77 years and 103 years respectively and statistically analysed in trenches of thirty (30) years. This is because thirty (30) years is the average weather condition.

The sample bitumen (60/70) Penetration grade was obtained from Dantata and Sawoe asphalt plant, this binder has been commonly been used in Nigeria. The softening point, flash and fire point test, pentration test, viscosity test, and ductility test were all conducted as per American Standard for Testing Material (ASTM).

To achieve the aim and objective of this research, a temperature of 1.4˚C was increment to the ambient temperature of 25˚C upto 43.2˚C to conduct penetration test and ductility test. For viscosity 1.4˚C is incremented to 55˚C up to 73.2˚C because viscosity cannot be conducted at a temperature lower than softening point of the (60/70) penetration grade bitumen of 54.5˚C. The result obtained for penetration, ductility and viscosity were computed and analysed as shown in **Table 1**.

3. Results and Discussion

3.1. Climate Change

Temperature

Temperature records obtained are analysed in trenches of thirty (30) years as shown in **Figures 1-3**. In **Figure 1** the Probability Density Function has a_0 long left tail but the right tail is around 41˚C. There is a 36% probability of occurrence and the mean values of temperature will 33˚C. **Figure 2** shows the Probability Density Function for the second trench of temperature with a somewhat left tail shorter than the Probability Density Function for **Figure 1**, However, the body of the Probability Density Function is wider than Figure 4.1 indicating a wide range of temperature up to 41˚C. The mean Temperature for **Figure 2** is about 33˚C with Probability of occurrence of 28% but much higher temperature is increasingly likely to occur and may have a longer duration. The

Probability Density Function for the third trench is shown in Figure 1. In this case, the frequency of occurrence of the mean temperature is 32% but the range of the temperature has narrowed to 26˚C to 41˚C compared to Figure 4.1 and Figure 4.2, which has 14˚C to 41˚C and 22˚C to 41˚C respectively (Figures 4-8 and Table 2).

Table 1. Shows code/standard for test types.

Test type	Test standards
Softening point test	ASTM d-36 standard
Flash and fire Point test	ASTM d-9218 standard
Penetration apparatus	ASTM d-5 standard
Viscosity test	ASTM d-2170 standard
Ductility test	ASTM d-113 -99 standard

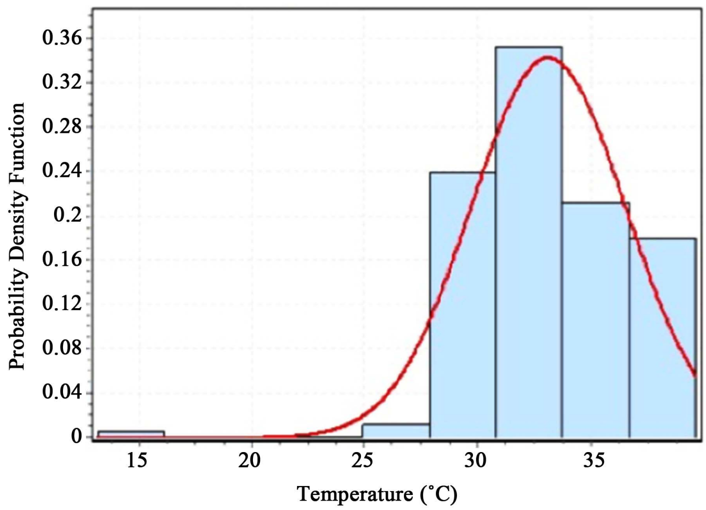

Figure 1. Temperature intensity first 30 years trench.

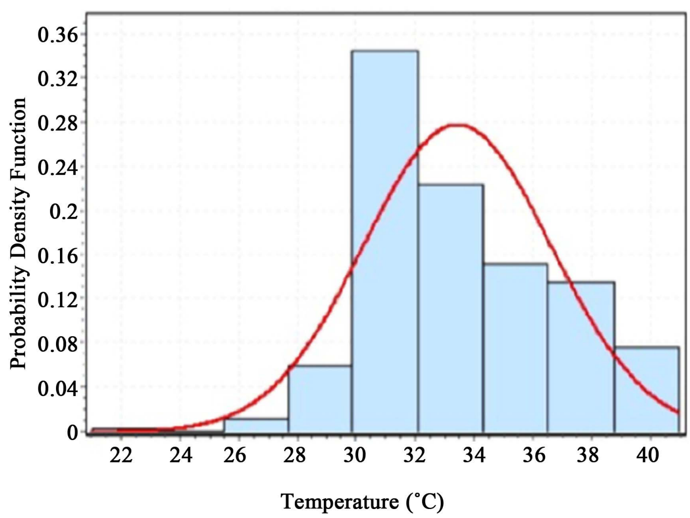

Figure 2. Temperature intensity second 30 years trench.

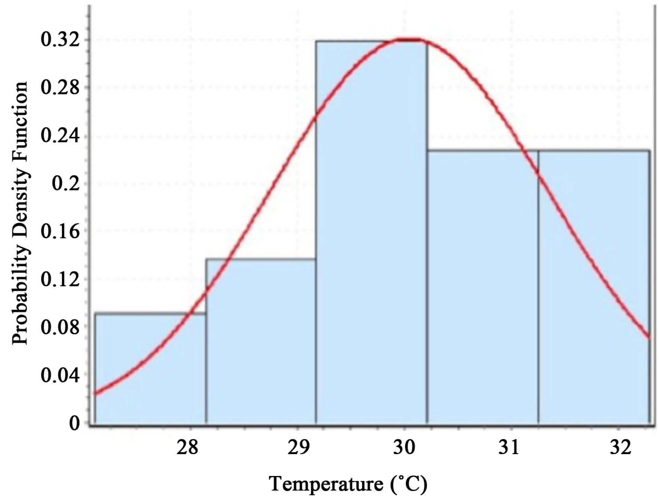

Figure 3. Temperature intensity third 30 years trench.

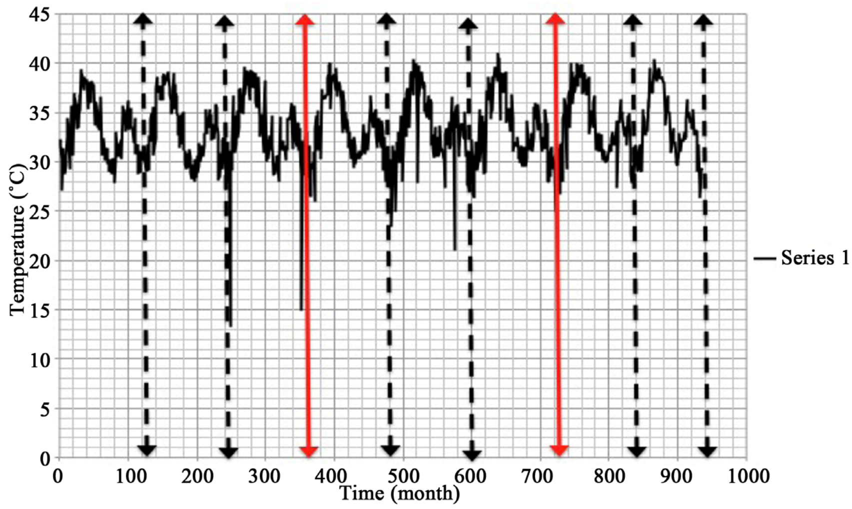

Figure 4. Temperature graph for two 30 years trenches.

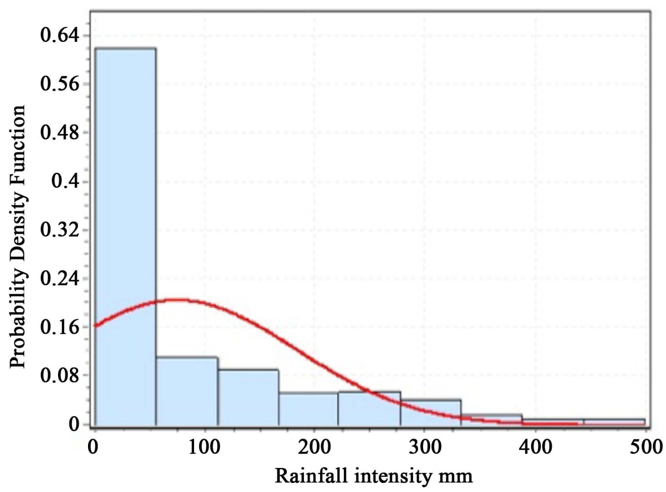

Figure 5. Rainfall intensity first 30 years trench.

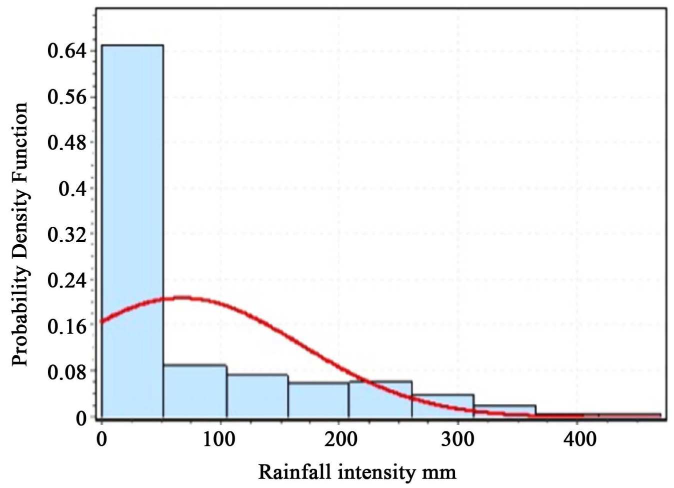

Figure 6. Rainfall intensity second 30 years trench.

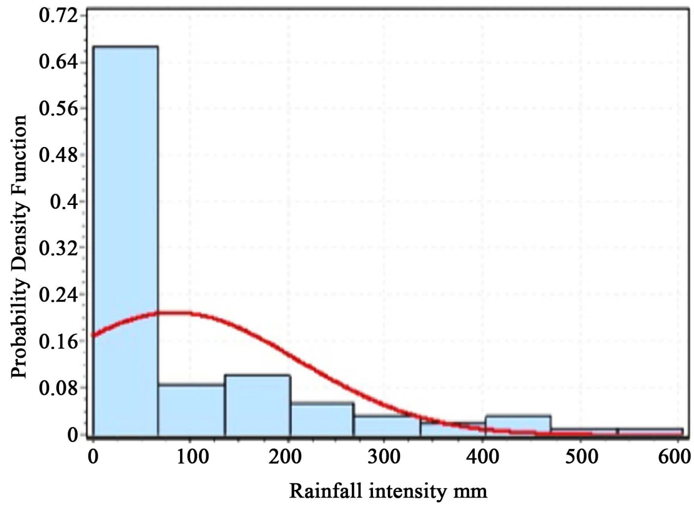

Figure 7. Rainfall intensity third 30 years trench.

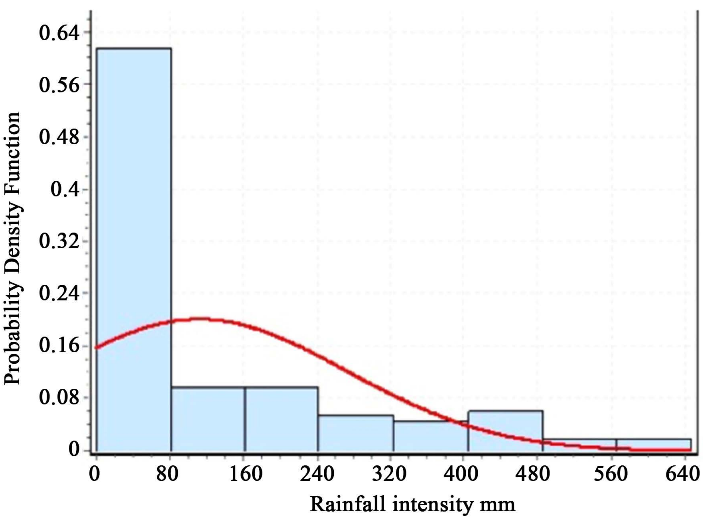

Figure 8. Rainfall intensity fourth trenches.

Table 2. Discriptive statistics of temperature in 30 years tranches.

Under Normal Distribution	1	2	3
Skewness	−0.65173	0.21892	−0.62852
Excess kurtosis	3.7768	−0.30439	−1.0044

From Table 3 the kurtosis is heavily tailed towards the right this means that kurtosis has positive excess kurtosis and this will return to a large extreme event of flooding. Looking at it from Figure 9 rainfall distributions are so random over an interval of ten (10) years because average rainfall was recorded. In General rainfall increase over time and is evidence of climate change, Similarly from Table 3 the skewness of the distributions has positive value and this clearly indicates that the distributions are skewed towards the right and therefore mean exceed mode value.

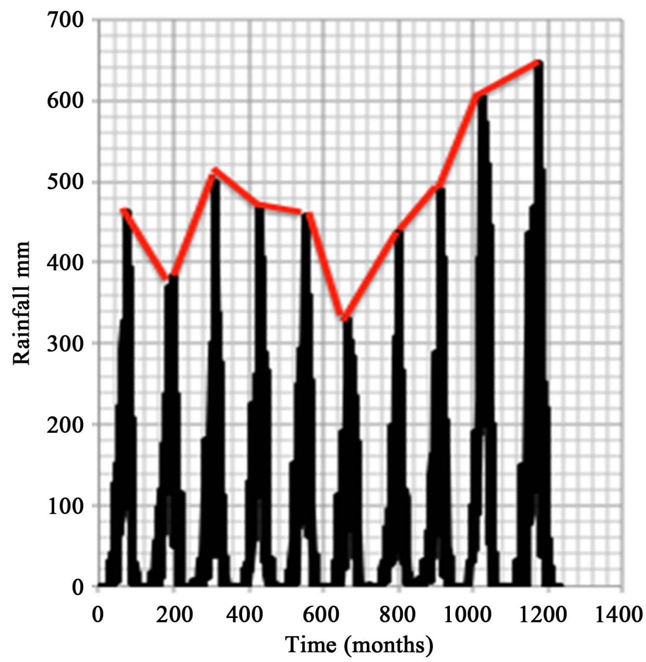

Figure 9. Rainfall graph for three 30 years trenches.

Table 3. Descriptive statistics of rainfall in 30 years tranches.

Under Normal Distribution	1	2	3	4
Skewness	1.4053	1.568	1.8492	1.4053
Excess kurtosis	0.94431	1.7235	2.9398	0.94431

3.2. Flash and Fire Point Test

The average flash and fire points are 148˚C and 279˚C respectively as seen in Table 4. In this test temperature required is very high. As such temperature is not likely to change.

Table 4. Flash and fire point of bitumen.

N/0	Flash point (˚C)	Fire point (˚C)
1	148	280
2	147	285
3	149	272
AVERAGE	148	279

3.3. Softening Point Test

The average softening point of the samples used is 54.5˚C as shown in **Table 5**. Temperature records obtained for the Kano region shows that the maximum temperatures are 24.77% lower than the softening point of 60/70 bitumen used.

Furthermore, the increment of 1.4˚C on the sample up to 43.2˚C is still lower than the softening point by 20.73%. Thus the softening point is not likely to be adversely effected by climate change.

3.4. Penetration Test

The penetration test is a measure of the hardness of bitumen ASTM D-2179 standard [12]. The results of this study are shown in **Table 6** Penetration tests are normally carried out in the laboratory under control condition usually 25˚C. Therefore, the Penetration results at ambient temperature; temperature is used as the control. The result of the Penetration test at 25˚C establishes the sample as a 60/70 penetration grade bitumen with average penetration of 60.67 mm ASTM D5 standard. The difference in penetration between the ambient temperatures of 25˚C and the mean temperature of 33.49˚C is 65.5% with (115 mm) while the difference in penetration between the ambient and the maximum temperature recorded, 43.2˚C is 82.03% *i.e.* (337.30 mm). This is important because any change in temperature could lead to a more than proportionate change in penetration of bitumen. This can accentuate the rutting of pavement and consequently their failure.

3.5. Ductility Test

The ductility of bitumen material is the distance in centimeters to which it will elongate before breaking when a briquette specimen of the materials is pulled at a specified speed and at specified temperature in the simplest definition is a measure of the tensile strength of bitumen ASTM D113-99 standard [13]. The results for this study shown in **Table 7**, Ductility test is normally carried out in the laboratory under control condition usually 25˚C. Recall that temperature change due to climate is 1.4˚C over a thirty years climate regime and this has been incremented to the ambient temperature of 25˚C. The results of the ductility test at 25˚C are deemed ok by ASTM D113 [6] for 60/70 Penetration grade Bitumen. The difference in ductility between the ambient temperatures of 25˚C

Table 5. Softening point of bitumen.

Softening Point		
1 (˚C)	2(˚C)	Average (˚C)
54	55	54.5

Table 6. Penetration of bitumen.

Temperature	1	2	3	Average (mm)
25	57	65	60	60.67
26.4	72	85	80	79
27.8	88	76	80	81.30
29.2	84	120	105	100.00
30.6	126	87	91	101.30
32	165	146	140	150.30
33.4	176	194	158	176
34.8	207	196	196	199.67
36.2	248	230	246	241.30
37.6	244	252	238	244.67
39	256	255	246	252.30
40.4	275	308	300	294.30
41.8	326	317	316	319. 67
43.2	355	343	314	337.30

Table 7. Ductility of bitumen subject to change in temperature.

Temperature	1	2	3	Average (cm)
25	100	100	100	100
26.4	78	78.5	78	78.20
27.8	69	69	68	68.67
29.2	53	54	54	53.67
30.6	50	51	49	50
32	48	47.5	47.5	47.67
33.4	46	46	47	46.30
34.8	46	46	46	46.00
36.2	45	45.5	45	45.20
37.6	44.5	44.5	45	44.67
39	44.5	44.5	44.5	44.5
40.4	44	44	44	44
41.8	44	44	45	44.30
43.2	43	43	42	42.67

and the mean temperature of 33.49˚C is 53.7% with (53.7 cm) while the difference in ductility between the ambient and the maximum temperature recorded, 41˚C is 54.9% *i.e.* (44.1 cm). This is important because any change in temperature could lead bitumen to fail in tension. This can accentuate fatique cracking of pavement and consequently their failure (**Figure 10**).

3.6. Viscosity Test

Asphalt pavements are laid at a high temperature of about 160˚C ASTM D-2179 standard [14]. This research is aimed at assessing the impact of climate change on the rheological properties of bitumen and the viscosity of bitumen cannot be related to the ambient temperature because bitumen 60/70 has a softening point of 54.5˚C which is 31.95% higher than the maximum temperature recorded in Kano, (41˚C). Quite clearly the viscosity decrease with an increase in temperature, 1.4˚C is incremented to 55˚C to 73.2˚C. As seen in **Table 8**, Viscosity result shows a decrease in resistance to flow with an increase in temperature; this shows that at a higher temperature the sample is likely flowing.

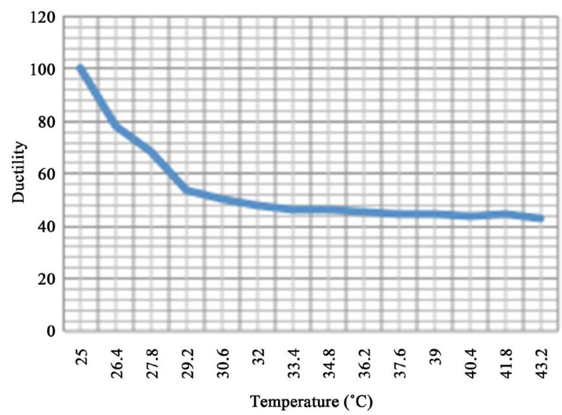

Figure 10. Ductility graph of bitumen subject to change in temperature.

Table 8. Viscosity result of bitumen subject to change in temperature.

Temperature	Seconds
55	370
56.4	360
57.8	189
59.2	120
60.6	79
62	74
63.4	69
64.8	64
66.2	58
67.6	54
69	52
70.4	52
71.8	48
73.2	46

4. Conclusions

The correlation between climate change and rheology of (60/70) penetration grade bitumen has been known. Nevertheless, the test condition needs to be further investigated in the future in order to get a correlation for all types of binders.

The (60/70) penetration grade bitumen is likely to flow under high, as such, there is a need for further research to be investigated on suitable materials that is low interms sustainability to climate change to modify our bitumen for more durability and to enhance stiffness of (60/70) grade bitumen.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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