International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

Assessing The Impact of Bitumen Types on the Performance of Asphalt Concrete Road Construction in Uganda

Mpaata, Steven[1], Mugume Rodgers Bangi[2], Kyakula, Michael[3].
[1]MSc Student, Department of Building and Civil Engineering, Kyambogo University, Kampala, Uganda
[2]Engineer, Uganda National Roads Authority, Kampala, Uganda
[3]Senior Lecturer, Department of Building and Civil Engineering, Kyambogo University, Kampala, Uganda

***Abstract*:- The type of bitumen used in asphalt concrete construction affects the performance of the constructed road pavement. This paper presents the properties of the local binders and the binder temperature zoning for Uganda. Analysis of consistency properties such as penetration values, flash points and viscosity confirmed the binder classification. It was observed that the softening points for all the binders tested were less than the specified temperature ranges and thus paused a potential risk of mixture flow under service. This would happen when the pavement temperatures exceed the softening points obtained considering the areas of application. The variation of specific gravity in the pen grade binders indicated presence of increased asphaltenes mineral impurities that impact on the effective binder content. It was further noted that the performance grade (PG) 70-16 binder could not conform to short term ageing requirements. Intermediate temperature range test results conformed to fatigue damage requirements. Higher temperature range testing failed to meet rutting resistance. Binder temperature zoning based on super pave grading system was distributed in three zones i.e. PG70+3, PG64+7 and PG58+3.**

Key words: Bitumen, Pavement, Performance, Asphalt Concrete

1 BACKGROUND

Bitumen is a complex thermoplastic and viscous material produced through the fractional distillation of crude oils. It majorly comprises asphaltenes, resins, aromatics and saturates. Because of its complexity, it is very difficult to predict bitumen chemical properties – see for example Stiaan Van Zyl (2018). In Uganda, bitumen is majorly used in road construction as binder in asphalt concrete surfacing and in stone seal surfacing. The commonly available bitumen forms in Uganda include cut back, emulsion, penetration and polymer modified binders.

Roads in Uganda had generally been surfaced using stone chipping. However, recently, there has been and increasing trend of surfacing road pavements using asphalt concrete in order to achieve the desired performance and life of the pavement. Consequently, these newly constructed asphalt concrete paved roads have experienced pre-mature deterioration of the surfacing rising concerns in the design, materials used, methods of construction, construction equipment, traffic volume, traffic loading rates and laxity in supervision.

This research presents an assessment of the locally available bitumen types and their effect in the asphalt concrete road pavement construction in Uganda.

It should be noted that asphalt binders are accepted based on the consistency properties elaborated in the Ministry of Works and Transport, General Specifications for Roads and Bridge works. This specification largely relies on the provisions in BSi. (2009). London. *Bitumen and Bituminous Binders – Specifications for Paving Grade Binders.* It is noted that this specification relies largely on consistency properties for acceptance describing empirical tests. The specification does not elaborate on the physical properties like resistance of the binder to rutting and fatigue damage that are simulated in the laboratory testing procedures to predict pavement performance.

On a number of construction sites visited during this study, it was observed that there were no physical property testing equipment mobilized to ensure laboratory simulations can be done. On a few cases where these equipment were procured like the Expansion of the Entebbe International Airport, there were no trained staff to operate the equipment and yet precision in such testing is critical in the data to be obtained.

The pictures shown below were taken along newly completed road sections. In the first picture, performance grade (PG) 76-10 was used in the construction of the asphalt concrete surfacing. Before project acceptance by the Client, several section had developed cracks. In picture 2, PG 76-10 was replaced by Pen Grade 20/30 with average penetration value of 26 and fraas breaking point of -7^{O}C. The road section equally developed cracks before completion. Subsequently, in picture 3, PG 76-10 was replaced with Pen 20/30 binder. The eventual asphalt concrete surfacing developed longitudinal cracks.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023



Northern Corridor Route, Lot 1 Northern Corridor Route, Lot 2 Northern Corridor Route, Lot 3

2 RESEARCH APPROACH

In order to assess the impact of the bitumen types on the performance of asphalt concrete road pavement construction in Uganda, consistency and physical property testing was required to confirm the binder classification and also to be able to predict the binder performance during intermediate and high temperature ranges. Accordingly, for proper binder application, there was need to carry out a binder temperature zoning so that it is possible to design application temperatures in the various regions of the country.

2.1 Binder sampling

Asphalt binders were obtained from ongoing and completed road construction projects in accordance with procedures provided in BSi. (2004). 58: *Bitumen and Bituminous Binders – Sampling Bituminous Binders*. These samples were then tested to determine the consistency and physical properties.

2.2 Consistency property testing

The samples were tested to determine the penetration values, ductility, specific gravity, softening point, kinematic viscosity, mass change and flash and fire points. These tests were carried out in Central Materials Laboratory, Tanzania National Roads Agency, Dar Es Salaam, Tanzania.

The ductility tests were carried out in accordance with procedures provided in BIS to measure the ability of binders to maintain their elastic behaviour under traffic loading. The penetration tests at 25ºC were carried out in accordance with procedures provided in ASTM D5-86 to confirm the binder classification. Softening point tests were conducted on binders to measure their flow under elevated temperatures. This was done in accordance with procedures provided in ASTM D3461-14. Flash and fire points tests were carried out in accordance with procedures provided in ASTM D 36 to measure the safe handling or mixing temperatures. Specific gravity tests were carried out in accordance with procedures provided in ASTM D 70-18 to determine any presence of any increased asphaltenes mineral impurities present in the binder. Kinematic and rotational viscosity tests were conducted on binders in accordance with procedures provided in ASTM D 2170 and ASTM D 7741 respectively to study the mixing, flowability and pumping potential of binders. Mass change tests were carried out on virgin binders in accordance with procedures provided in AASHTO T 240 and ASTM D 2872 to measure the short term ageing potential that would affect elastic behaviour and durability requirements of binders.

2.3 Physical property testing

Dynamic shear rheometer testing was used to determine the physical properties of the binders. These tests were carried out in accordance with procedures provided in AASHTO T 320. High temperature range testing was carried out on virgin and rolling thin film oven aged binders to measure the resistance of the binders to rutting. Subsequently, intermediate temperature range testing on pressure aged vessel binders were carried out to determine the binder potential to fatigue damage resistance.

2.4 Binder temperature zoning

In Practice, there is no standard number of years that one can say are adequate to obtain very reliable data for temperature variations analysis in pavement design and most countries have adopted different periods based on local knowledge of weather variations. In some countries, like United States and Canada, the Strategic Highway Research Program researchers, used 20 years, Gulf Countries used 26 years and Sudan used 5 years in 18 states (Kobbail, 2005). In this study, four years were used to review the highest and lowest air temperature data obtained from the fourteen zones i.e. 2014, 2015, 2016 and 2017. This data was confirmed by indicative spot field measurements conducted between August and September 2018. Pavement temperatures were measured at 20mm below the pavement surface in the fourteen zones and were analyzed to form a regression equation that was used to predict pavement temperatures once air temperatures and latitudes were known. It was noted that these measured temperatures were not directly applied in binder temperature zoning but statistically analyzed/standardized to confirm the variation of individual data from the computed mean values. The model would then link the pavement design temperatures at 20mm depth to the air temperatures and the latitudes of each station.

Any adjustments to the determined binder temperature zones were made considering the traffic volume and loading rates as provided by Strategic Highway Research Program researchers (SHRP) based on Super Pave grading system presented in Table 2 below.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

Table 2:- High Temperature Binder adjustments based on Traffic Speed and Level (SHRP)

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	-	-	-
0.3 to < 3	+2	+1	-
3 to < 10	+2	+1	-
10 o < 30	+2	+1	-
> 30	+2	+1	+1

3 Results and discussions

3.1 Consistency property testing

Table 3.1 below presents the consistency property test results obtained for the binder grades tested. It provides average values computed from individual test results. In a general view, it can be observed that the samples tested complied with ductility, flash point and kinematic viscosity requirements.

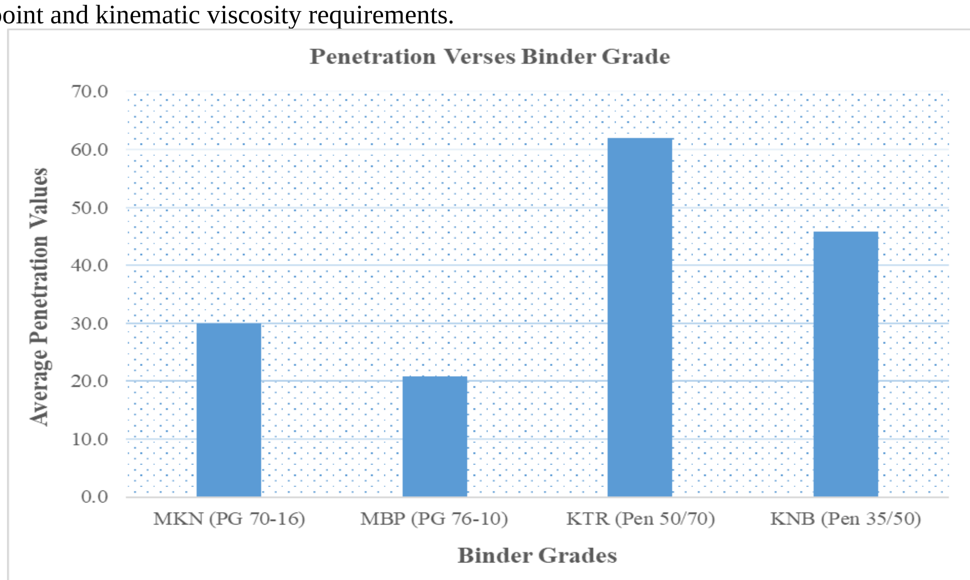

Figure 3.1: Penetration test results

The penetration test results presented in Table 3.1 and figure 3.1 above indicate that the binders conformed to binder classifications since the average penetration values obtained were within acceptable ranges. It was observed that performance graded binders had low penetration values implying that the binders were stiff.

Table 3.1:- Consistency Property Test Result

Binder Grades	Consistency Property Tests											
	Ductility (mm)	Spec. Min. (mm)	Average Penetration	Spec. range	Average Softening Point (°C)	Spec. Min. (°C)	Average Flash Point (°C)	Spec. Min.	Average Specific Gravity	Spec. range	Average Kinematic Viscosity (cP)	Spec.
MKN (PG 70-16)	140	75	30.0	20-30	46.7	55-63	335	Min. 240	1.020	0.97-1.02	735	Min. 530
MBP (PG 76-10)	140	75	20.8	20-30	54.8	55-63	318	Min. 240	1.018	0.97-1.02	1363	Min. 530
KTR (Pen 50/70)	140	75	62.0	50-70	41.9	46-54	316	Min. 230	1.028	0.97-1.02	432	Min. 295
KNB (Pen 35/50)	140	75	45.8	35-50	41.5	50-58	344	Min. 240	1.031	0.97-1.02	437	Min. 370

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

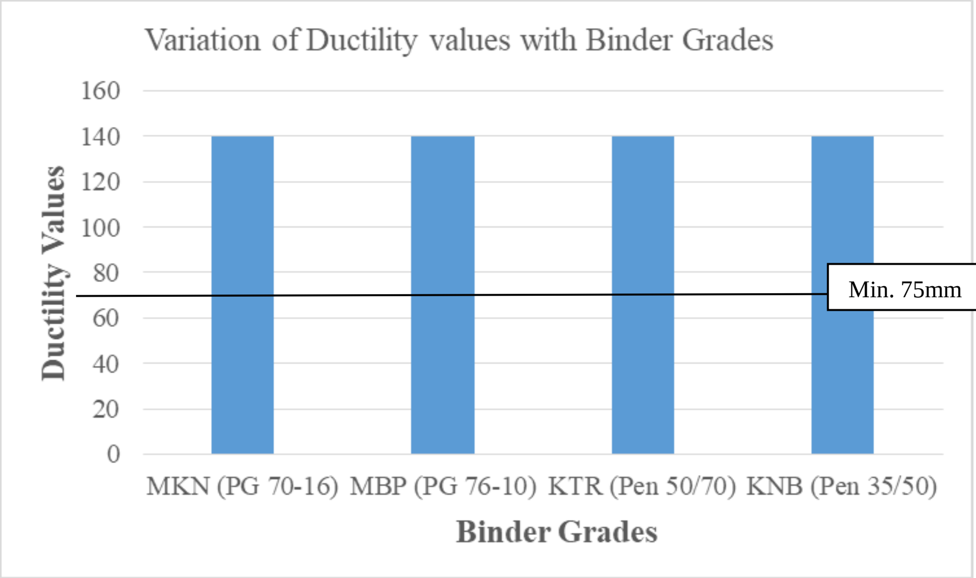

Figure 3.2: Ductility test results

Ductility test results obtained for the binders presented in figure 3.2 above were greater than the minimum specifications. This therefore implied that the binders can elongate and fill the voids making the mixture easily compacted and subsequently reducing the volume of voids in the mix.

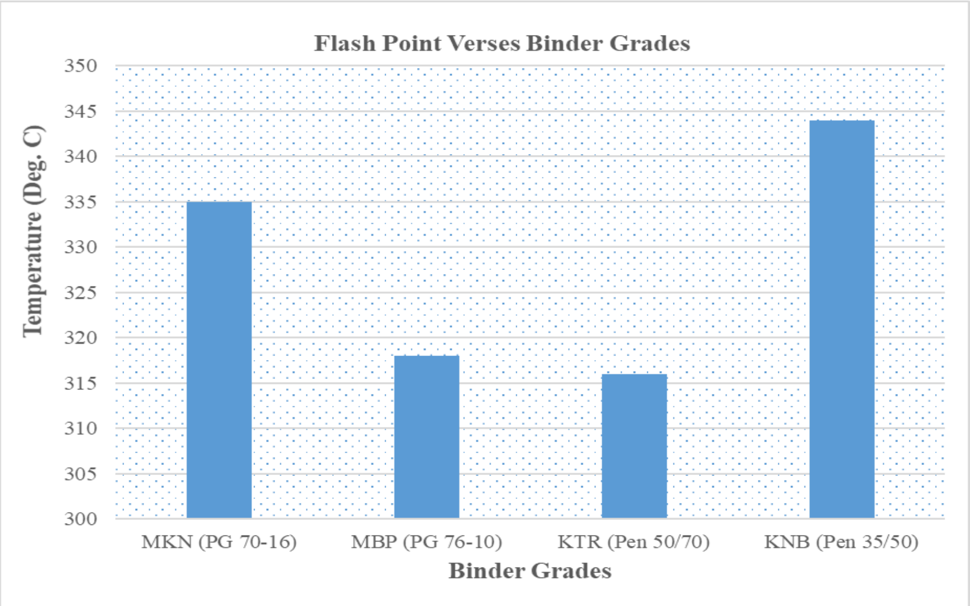

Figure 3.3: Flash point test results

The flash point test results obtained for all binders were higher than the minimum values – see Table 3.1 and figure 3.3 above. The binders can safely be handled during transportation, mixing and placing.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

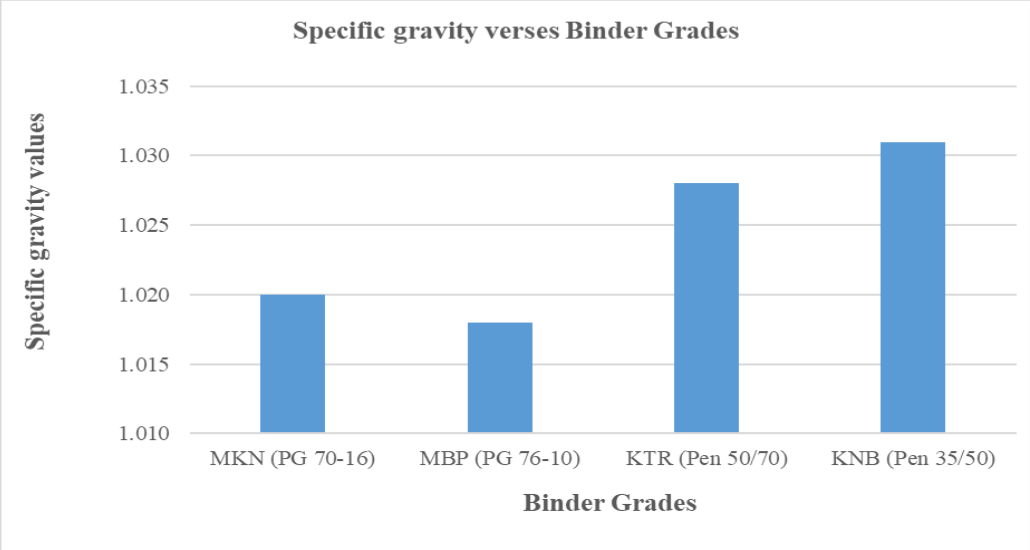

Figure 3.4: Specific gravity test results

The penetration graded binders (Pen 50/70 and Pen 35/50) gave specific gravity values greater than 1.02 (figure 3.4 above) – see BSi (2007). + A1. (2009) and BS. (2007). London. *Measurement of specific gravity and density of binders*. This implied that such binders contained increased asphaltenes mineral impurities that affect the effective binder content in the mixture. Low binder content in mixture reduces the packing potential of aggregates and thus severe secondary compaction under traffic leads to re-arrangement of aggregates causing surface cracks.

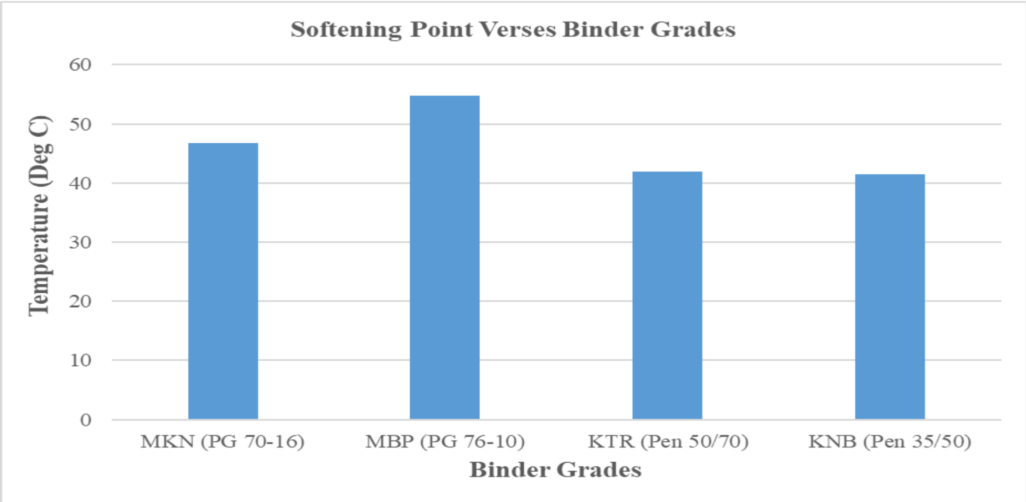

Figure 3.5: Softening point test results

As presented in Table 3.1 and figure 3.5 above, performance graded binders gave higher softening points as compared to penetration graded binders. This therefore implied that the performance graded binders were stiffer and could take up elevated pavement temperatures as compared to penetration graded binders. However, the softening points obtained for all the binders were lower than the specified ranges. This implied that when these binders are used in the mixture, there would be a probable risk of mix flow considering local temperatures in areas of application.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

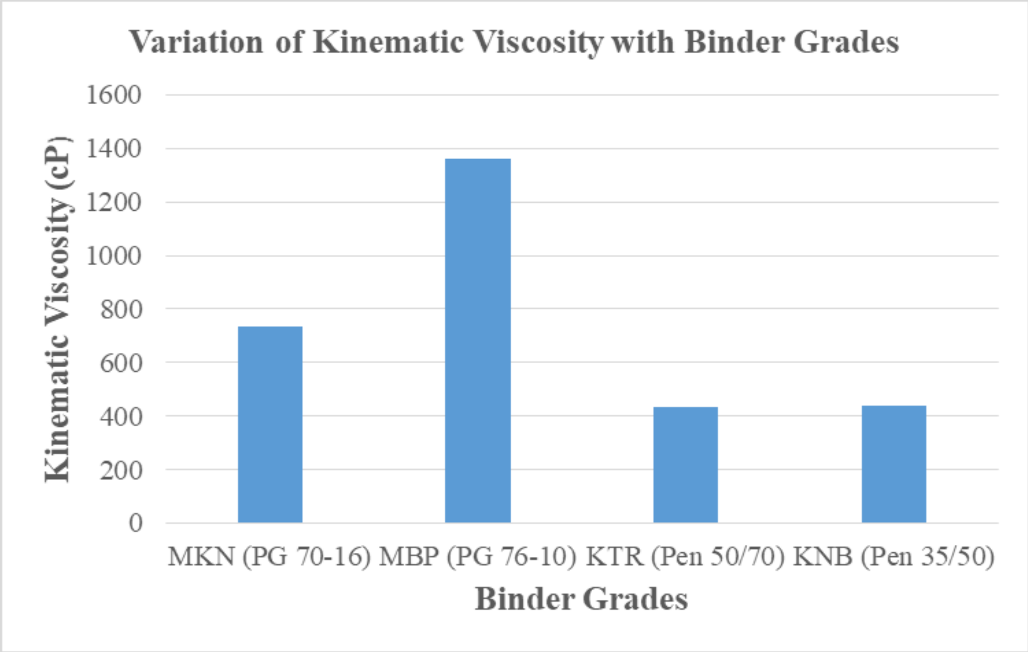

Figure 3.6: Kinematic Viscosity test results

The kinematic test results obtained for all binders complied with the general requirements. This therefore implied that the binders could easily be worked, pumped and mixed to form a uniform mixture thereby improving on the total volume of voids in the mixture.

3.2 Physical property test results

Table 3.2 below present a summary of the high and intermediate temperature range test results of the binders that predict performance.

Table 3.2:- Physical property test results

Binder Grades	Av. Mass Change (%) **Max. 0.5**	Av. Rotational Viscosity (Pa-s) **Max. 3.0**	Average DSR Un-aged (kPa) **Min. 1.0 kPa**	Average DSR - RTFO Aged (kPa) **Min. 2.2kPa**	Average DSR - PAV Aged (kPa) **Max. 5,000**
MKN (PG 70-16)	0.73	0.748	0.93	2.26	4,176
MBP (PG 76-10)	0.27	1.383	0.86	1.26	4,533
KTR (Pen 50/70)	0.01	0.443	0.82	1.93	4,417
KNB (Pen 35/50)	0.03	0.451	0.91	1.75	4,175

Generally, as observed from Table 3.2 above, the binders failed to meet the performance as determined by the dynamic shear rheometer (DSR) testing. The average mass change for performance graded binders (PG) 70-16 failed to meet the mass change requirements. The other binders – PG 76-10, Pen 50/70 and Pen 35/50 provided mass change test results that were acceptable.

Figure 3.7 below presents the variation of mass change with binder grades.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

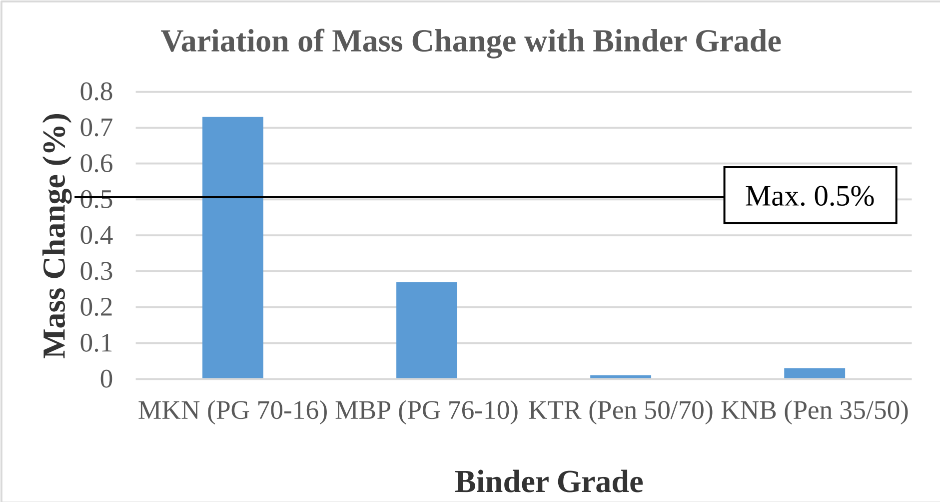

Figure 3.7: Mass change test results

All binder complied with mass change requirements other than Performance graded binder (PG) 70-16 which gave a mass change of over 0.72% (Table 3.2). This binder, PG 70-16 is susceptible to short term ageing and thus makes the eventual mixture lose its elastic behaviour. Once the elastic behaviour is lost, the mixture would suffer from cracking under traffic loading.

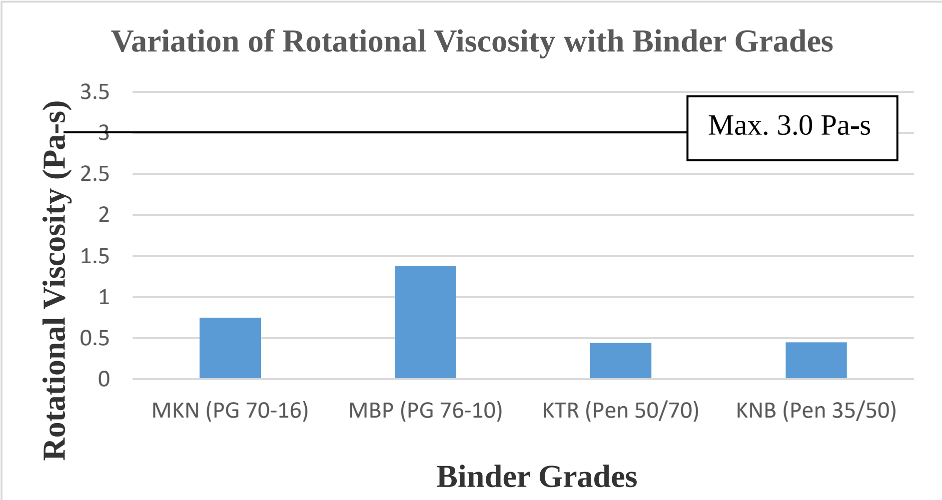

Figure 3.8: Rotational Viscosity Test results

All binders complied with the rotational viscosity requirements. This therefore implied that the binders could be easily worked, pumped and mixed with aggregates to form a uniform mixture that can easily be compacted and efficiently improve the aggregate interlock making the mixture dense.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

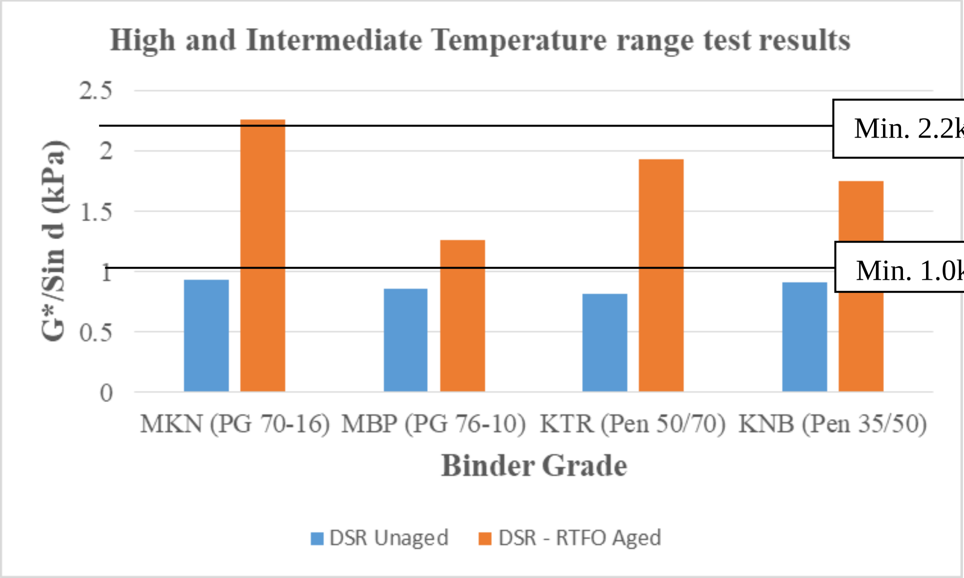

Figure 3.9: High temperature range test results for un-aged binders

The Dynamic Shear Rheometer (DSR) test results carried out on virgin binder presented in figure 3.7 above indicated that the binders failed to meet the performance requirements for high temperature range conditions. The relationship between the complex shear modulus and phase angles for un-aged binders were lower than 1.00 kPa for all the binders – see Table 3.2 above. The binders would be susceptible to early hardening potential under elevated temperatures. Similarly, the DSR test results carried out on the rolling thin film oven (RTFO) test asphalt residues gave marginal results for PG 70-16 binder. The other binders failed to meet the requirements for aged binder high temperature range test results. The binders would be susceptible to rutting potential under elevated temperatures. Formation of ruts along the wheel paths during service would be evident.

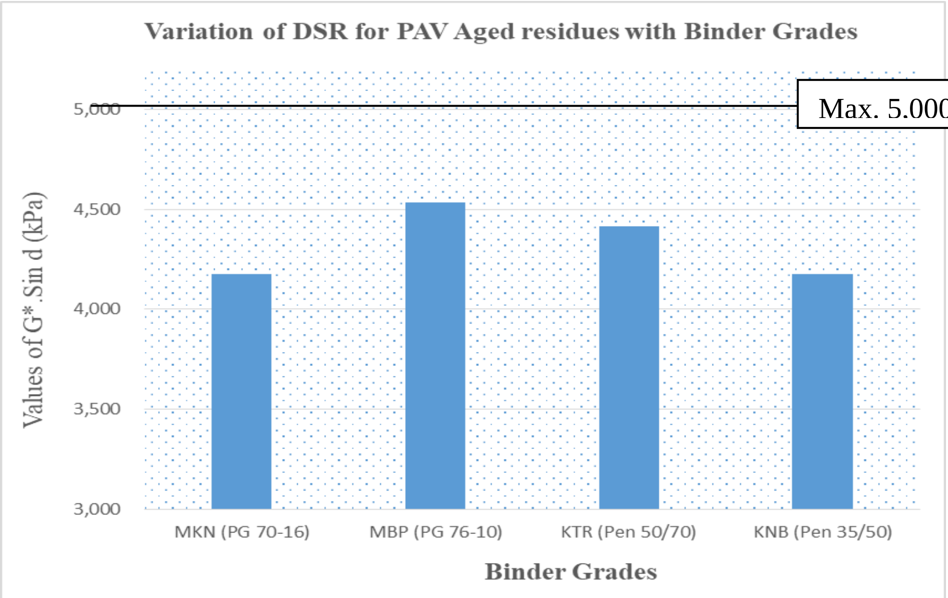

Figure 3.10: Intermediate range DSR test results for PAV aged residues

The test results obtained for intermediate temperature range test results for PAV aged binders (Table 3.2 and figure 3.10) were compliant to general requirements. This therefore implies that the binders would not suffer from fatigue damage under traffic loading. Reviewing previous studies such as in Thailand during the determination of performance grading system, it was observed that the relationship between the complex shear modulus and phase angles were about 3,000kPa. The relationship obtained between complex shear and phase angle gave complaint rutting resistance properties. This is elaborated in Charoentham, 2012. It is likely therefore that since the values obtained in this study were generally greater than 4,000kPa, there would be a probable risk in fatigue damage resistance (figures 3.10).

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

3.3 Binder temperature zoning

3.3.1 Temperature measurements

Based on historical data for air temperatures obtained from the meteorological Centre in fourteen zones, it was observed that the lowest air temperatures were measured in Kabale (6.8^{O}C) and the Maximum air Temperatures were recorded in Pakwach (40.3^{O}C). The maximum pavement temperatures were also measured in Pakwach (59.7^{O}C) and lowest pavement temperatures were recorded as 3^{O}C. Figures 5.1 presents the maximum air and pavement temperatures and figure 5.2 presents the minimum air and pavement temperatures.

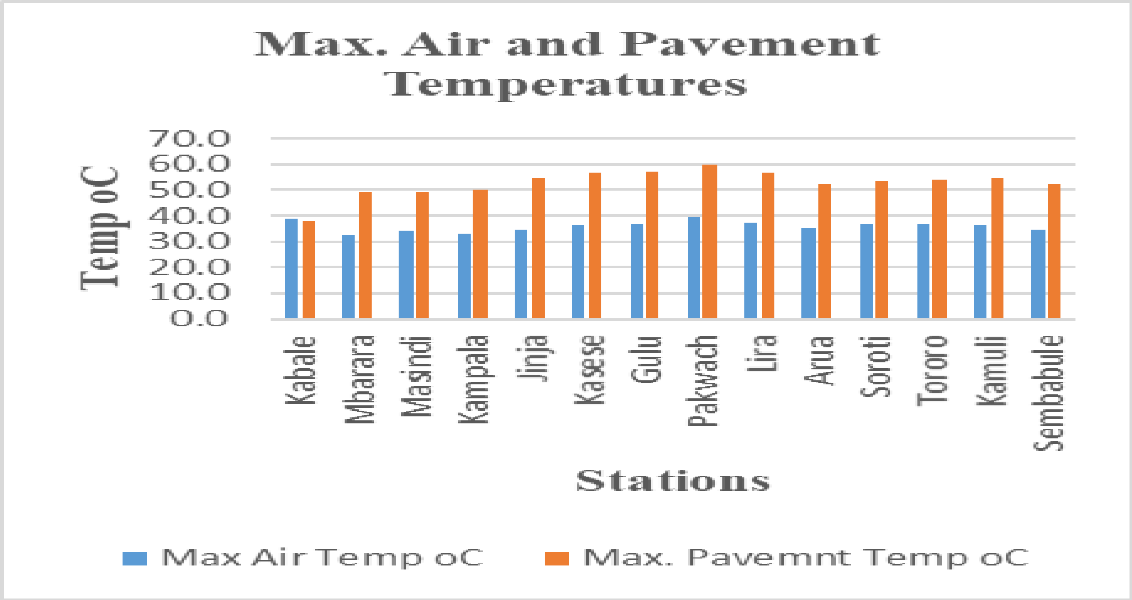

Fig. 3.11: Max Air and Pavement Temperatures

The average high pavement temperatures recorded in areas where the binders were obtained included 38.0^{O}C in Kabale, 50.3^{O}C in Kampala, 54.5^{O}C in Jinja and 54.5^{O}C in Kamuli (figure 3.11).

It was noted that Pen 35/50 binder used in Kampala had a softening temperature of 41.5^{O}C. A pavement temperatures of 50.3^{O}C was recorded. This temperature exceeded the softening point implying that there would be a risk of the mixture to flow under ambient conditions.
For Pen 50/70 used in Kamuli, Arua and Gulu township roads, the pavement temperatures recorded ranged between 52.3^{O}C and 57.4^{O}C. The softening point obtained for Pen 50/70 was 41.9^{O}C. Since the pavement temperatures exceed the softening point temperatures, there is a risk of mixture flow under traffic when the pavement temperatures exceed 41^{O}C.

Performance Grade (PG) 70-16 was applied between Mukono and Jinja whose measured paveemnt temperatures ranged between 50.3 to 54.5^{O}C. The average softening point for the binder was 46.7^{O}C. This implied that the binder was soft. The risk with this binder is that when the pavement is subjected to design traffic under ambient temperatures, the binder would flow causing rutting in the pavement.

PG 76-10 was applied in the areas of Mbarara and Ntungamo whose high pavement temperatures were recorded to be 49.3^{O}C. The softening temperatures obtained were 54.8^{O}C implying that under design traffic and ambient temperatures, the pavement would resist any deterioration due to local temperatures. The binder would retain its rigidity under pavement temperatures.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

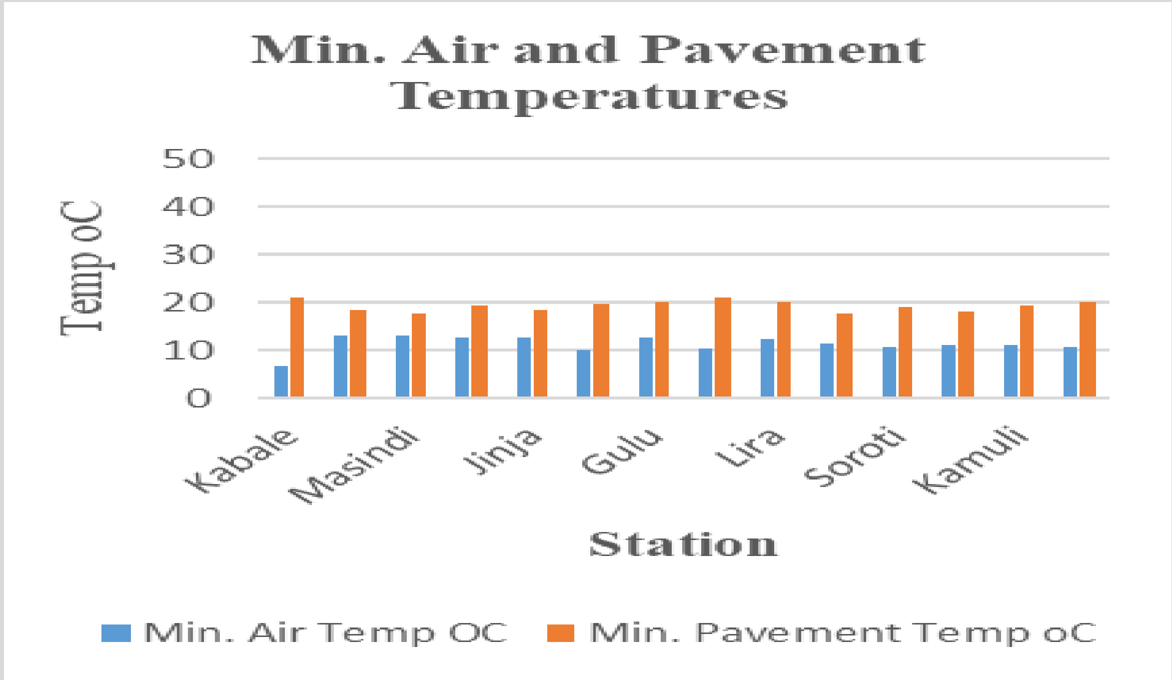

Fig. 3.12: Min. Air and Pavement Temperatures

The minimum pavement temperatures measured ranged between 3 to 13^{O}C. From this study, it was evident that there was no low pavement temperature risks.

Table 3.3: Air Temperatures, Pavement Temperatures measured at selected Stations in Uganda

Station/ Year	Average High Air Temperature ºC					Average Low Air Temperature ºC					Latitudes	Measured Max. Pavement Temp ºC	Meas. Min Pavement Temp ºC	Standard Deviation		Mean + 3*StDev	
	7 Day Max Air Temperature					1Day Minimum Air temperatures								Highest Temp	Lowest Temp	High	Low
	2014	2015	2016	2017	Max	2014	2015	2016	2017	Min.							
Kabale	28.4	28.8	29.5	29.5	29.5	7.8	7.5	6.8	7	6.8	-1.24857	**38.0**	21.0	0.54	0.46	31.13	8.17
Mbarara	32.8	33.5	33.7	33	33.7	13.8	13.4	13.3	13.2	13.2	0.6057	**49.3**	18.5	0.42	0.26	34.96	13.99
Masindi	34.9	34.8	36.7	35.8	36.7	14.2	13.0	13.8	14.6	13.0	1.6444	**48.9**	17.6	0.89	0.68	39.37	15.05
Kampala	33.0	34.3	33.2	34.0	34.3	12.8	14.2	16.0	16.4	12.8	0.31628	**50.3**	19.5	0.62	1.67	36.17	17.80
Jinja	33.8	36.0	34.2	34.7	36	13.5	12.8	13.2	12.6	12.6	0.43902	**54.5**	18.5	0.96	0.40	38.87	13.81
Kasese	35.1	37.4	36.7	36.5	37.4	13.5	13.5	12.0	10.1	10.1	0.1833	**56.7**	19.8	0.96	1.61	40.29	14.94
Gulu	36.8	38.4	37.6	37.6	38.4	16.4	12.7	14.4	12.7	12.7	2.77466	**57.4**	20.0	0.65	1.76	40.36	17.98
Pakwach	39.3	40.1	40.3	40.0	40.3	11.7	11.0	10.3	10.3	10.3	2.45716	**59.0**	21.0	0.43	0.67	41.60	12.31
Lira	39.0	36.8	37.6	36.0	39	14.3	13.8	12.5	12.5	12.5	2.23333	**56.6**	20.0	1.28	0.92	42.84	15.25
Arua	34.7	35.5	36.0	35.0	36	11.7	11.5	13.3	11.5	11.5	3.02013	**52.1**	17.8	0.57	0.87	37.71	14.12
Soroti	36.9	37.7	37.2	37.2	37.7	15.8	14.4	10.8	10.8	10.8	1.71464	**53.4**	19.0	0.33	2.55	38.69	18.44
Tororo	36.1	37.2	37.2	37.2	37.2	11.5	13.2	13.2	11.0	11.0	0.69299	**54.0**	18.0	0.55	1.14	38.85	14.43
Kamuli	36.7	37.4	36.5	37.2	37.4	11.2	12.6	13.2	11.2	11.2	0.9403	**54.5**	19.5	0.42	1.01	38.66	14.23
Sembabule	34.0	35.4	35.0	34.0	35.4	12.5	12.3	12.5	10.8	10.8	-0.07722	**52.5**	20.0	0.71	0.82	37.54	13.27

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

The air and pavement temperatures were analyzed, standardized and presented in Table 3.3 above. Usually every country has a degree of accuracy that they adopt. For the studies carried out in Sudan by the Strategic Highway Research Program, an accuracy of 2 was adopted. It was noted that measurements of temperatures for air and pavement were carried out for five years. In Uganda, there is no standardized level of accuracy. For purposes of this research, a factor of 3 was adopted and the standard deviations were multiplied by 3 and the product added to the mean value. A correlation regression was run and a strong correlation existed between high air temperatures and high pavement temperatures. Regression equation was developed to predict the Design Pavement Temperature at 20mm below surface given air temperatures and latitudes of a station. The Regression Equation developed to predict design pavement temperatures is presented below;

y = -21.75+2.13Air Temp – 0.35 Latitudes ……. Equation 3

Where;

Y – Pavement temperature at 20mm below the pavement surface

Lat – Latitudes

Table 3.4: Maximum and Minimum Pavement Temperatures

Station	High Temperature ºC	Low Temperature ºC	Latitudes	High Pavement Temperature ºC	Low Pavement Temperature ºC
Kabale	31.13	8.17	-1.24857	45.00	-3.8
Mbarara	34.96	13.99	0.6057	52.50	7.83
Masindi	39.37	15.05	1.6444	61.53	9.73
Kampala	36.17	17.80	0.31628	55.18	16.06
Jinja	38.87	13.81	0.43902	60.89	7.51
Kasese	40.29	14.94	0.1833	64.01	10.01
Gulu	40.36	17.98	2.77466	63.24	15.57
Pakwach	41.60	12.31	2.45716	66.01	3.61
Lira	42.84	15.25	2.23333	68.71	9.96
Arua	37.71	14.12	3.02013	57.53	7.26
Soroti	38.69	18.44	1.71464	60.07	16.93
Tororo	38.85	14.43	0.69299	60.76	8.75
Kamuli	38.66	14.23	0.9403	60.27	8.24
Sembabule	37.54	13.27	-0.07722	58.23	6.53

Table 3.4 above presents the high and low pavement temperatures that were used in the binder temperature zoning. Three temperature binder zones were concluded incorporating Performance Grade (PG) 70-3, PG 64+7 and PG 58+8 as presented in Table 3.5 below.

Table 3.5:- Binder Temperature Zoning for Uganda

Proposed Grade	PG 70	PG 64	PG 58
High Temperature ^{O}C	70	64	58
Low Temperature, ^{O}C	-3	+7	+8

The following conservative grading based on super pave grading system has been determined and presented in Table 3.6 below.

Table 3.6:- Conservative Binder Temperature Zoning for Uganda

Proposed Grade	PG 70	PG 64	PG 58
High Temperature ^{O}C	70	64	58
Low Temperature, ^{O}C	-10	-10	-10

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 02, February-2023

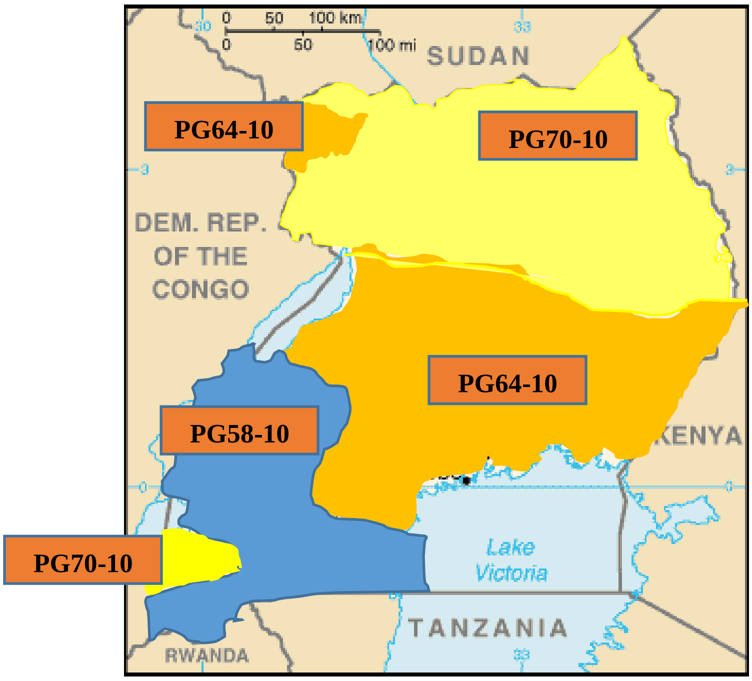

Figure 3.13: Binder Temperature Zoning

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

- The classification of penetration graded bitumen used on local market was found satisfactory. The performance graded binders were found to be stiffer than the penetration graded binders. All the binders complied with visco-elastic requirements of extension without failure under local conditions;
- It was noted that all penetration graded binders had probable traces of increased asphaltenes mineral impurities as implied from their specific gravity values;
- The laboratory in-service simulation of performance requirements indicated that most of the binders exhibited potential to short term and long term ageing. Therefore, most of the binders exhibited potential to high temperature range failure under traffic loading;

Based on the available data from the Meteorological Centre in the fourteen weather zones in Uganda, and the subsequent analysis based on the Strategic Highway Research Program based on Super pave grading system, the following was deduced;

- The lowest air temperatures ranged from 6.8°C in Kabale to 13.2°C in Mbarara. The highest temperatures ranged from 29.5°C to 40.3°C. The highest pavement temperatures ranged between 38°C in Kabale and 59°C in Pakwach;
- Based on data obtained from the Meteorological Centre, the highest air temperatures were recorded in Pakwach and lowest in Kabale;
- The study determined that the maximum pavement design temperature is 70°C and the minimum pavement design temperature is -3°C;
- The Binder Temperature zoning in Uganda was distributed in three Temperature binder zones such as Performance Grade (PG) 70-3, PG 64+7 and PG 58+8 with conservative values fixed at PG 70-10, PG 64-10 and PG 58-10.

4.2 Recommendations

- Air temperature measurement were obtained from fourteen zones. It is recommended that further survey involving each station within the sixteen zones be done separately and data analyzed to provide accurate air temperatures which indeed impact on the pavement temperatures;
- The study recommends pavement temperatures to be measured between January and March where maximum air temperatures are recorded each year so that the maximum ever pavement temperatures in any year can be captured;
- Further research by varying the test frequencies and temperatures to simulate the various field conditions will be key in enabling development of bitumen master curves;

- A robust testing regime and acceptance criteria for bitumen binders should be enforced by extending the current consistency property testing that only elaborate on empirical values and precautionary handling properties to physical property testing that predict in-service performance using laboratory simulations;
- Chemical analysis of the local bitumen should be determined to analyze the amount of saturates, aromatics, asphaltenes and resins present since they form the colloidal structure and their relative compositions impact on the performance properties of the binders.

REFERENCES

[1] D. 2015. Standard Specification for Penetration-Graded A sphalt Binder for Use in Pavement Construction: Asphalt Binder Specifications. West Conshohocken, PA: s.n., p. 2.
[2] A.Charoentham, 2012. Development of a Performance Grading System for Asphalt Binders Used In Thailand. Asian Transport Studies, 2(2), 121-138.
[3] AASHTO, 2012. Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer
[4] AASHTO, 2016. Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test). AASHTO T 240, 1 January, p. 12.
[5] AASHTO, 2017. Standard Method of Test for Viscosity Determination of Asphalt Binder Using Rotational Viscometer. AASHTO T 316, 1 January, p. 6.
[6] Ahamad Shafeeq, Y. K. Y. T, 2016. Study on pre-mature failure of flexible pavement structures in developing countries. s.l., Japan Society of Civil Engineers.
[7] Asphalt Institue, 2005. Principles of Construction of Hot Mix Asphalt Pavements, Washington: Asphalt Institute Manual, series No. 22.
[8] Aspalt Institute, 2005. Guidance on AASHTO M320 Specification Limit for Rotational Viscosity. Lexington, Kentucky, Asphalt Institute.
[9] BS EN 12591:2011. Bitumen and bituminous binders - Specifications for paving grade bitumens. BSi, 2004. Bitumen and bituminous binders - Sampling bituminous binders 474(05), p. 23.
[10] Emile Horak, 2010. Forensic Investigation to Determine the Reasons for Premature Failure in an Asphalt Surface Layer. Road Materials and Pavement Design, 11(3).
[11] FHWA, 2011. LTPP Computed Parameter: Dynamic Modulus. Washington, FHWA Office of Research, Development and Technology.
[12] Kobbail, 2005. Determination of Sudan Temperature Zoning based on Superpave System. Technical Note, 1(1), pp. 1-9.
[13] M.F.C, van de Ven1, K. J. a. H. B, 2004. Concepts used for development of bitumen specifications. Sun City, Document Transformation Technologies.
[14] MoWT, 2010. General Specifications for Roads and Bridge works.
[15] TRL, 2002. A Guide to the design of hot mix asphalt in tropical and sub-tropical countries. Volume 1, p. 94.
[16] Wahabb H.A.A, 1998. Performance-based characterization of Arab asphalt. Building and Environment, 33(6), pp. 375-383.
[17] Zaniewski, 2004. Evaluation of Performance Graded Asphalt Binder Equipment and Testing Protocol, Morgantown: Asphalt Technology Program.
[18] Zou G., 2017. Evaluation of factors that affect rutting resistance of asphalt mixes by Orthogonal experiment design, Issue 10, pp. 282-288.
[19] Zyl S.V, 2018. Relationship Between the Age Related Performance of a Typical Bituminous Binder in South Africa and the Fatigue Performance of the Asphalt Mixture, Stellenbosch.