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Adopting Viscosity Grading System for Proper Selection of Paving Asphalt in Sudan

Magdi M. E. Zumrawi[1]

[1]University of Khartoum, Department of Civil Engineering, Khartoum, Sudan

Abstract: ***Selection of proper asphalt binder is one of the most important factors considered in asphalt mixture design. This paper is aimed to overview the important role of adopting the viscosity grading system in performance and durability of flexible pavements in Sudan. The literature of the traditional grading systems with their respective advantages and disadvantages is intensively reviewed. An effort is made to verify the viscosity grading system is more realistic, reliable and practical than the old penetration grade. Twenty samples of asphalt cement, selected from penetration grades 60/70 and 85/100, were subjected to laboratory testing for measuring their consistency and safety properties. The results revealed that asphalt binders, from different sources used in the industry are highly temperature susceptible, though they have complied with the standards. Recommendations have been made to implement the viscosity grading system in order to improve the quality, performance and durability of bituminous pavements in Sudan.***

Keywords: Viscosity, penetration, grading, asphalt, temperature.

1. Introduction

The durability and performance of pavements are influenced to a great extent by the pavement materials and their inherent properties. In Sudan, most of the highways and urban roads paved with asphalt mixtures of which bitumen is an important and expensive ingredient. The construction sector should be interested in using the right type of bitumen for obtaining durable pavements, [1]. So we must use the bitumen which is best suited with Sudan climatic and traffic conditions, also whose physical characteristics are based on rational parameters rather than empirical. This can be achieved by adopting the viscosity grading system for selecting paving asphalt in Sudan.

Penetration grading system is the first standard method adopted by the American Society for Testing and Materials (ASTM) Committee D04 on road and paving materials in 1918. The viscosity grading system was introduced in 1960. Both methods are empirical methods, based on past experiences and observations. The latest grading system, the Superpave grading system, was introduced in 1998. Superpave grading system was developed as part of the Superpave research effort to introduce more accurate and fully characterized asphalt binders for use in hot mix asphalt (HMA) pavements. The penetration grading system is still used in Sudan while many countries have adopted the latest Superpave grading system.

The objective of this paper is to give an overview of the viscosity grading system for better selection of asphalt in Sudan. A critical look will be concentrated on the advantages resulted from adopting the viscosity grading system and the disadvantages of the old penetration grading system.

2. Literature Review

Asphalt is one of the two principal constituents of HMA. Asphalt functions as an inexpensive, waterproof, thermoplastic, viscoelastic adhesive. Asphalt binder is used to represent the principal binding agent in HMA. Asphalt binder includes asphalt cement as well as any material added to modify the original asphalt cement properties. The term "asphalt cement" is used to represent unmodified asphalt cement only. Asphalt binder is simply the residue left over from petroleum refining. Thus, asphalt binders are produced mainly by petroleum refiners. The composition of base crude oil from which asphalt is refined can vary widely and thus the asphalt yield from different crude oil sources can also vary widely.

Asphalt at ordinary temperatures, may be liquefied by applying heat (asphalt cement), dissolving it in solvents (cut-back), or emulsifying it (emulsion). Asphalt binder is a thermoplastic material and its consistency changes with the temperature. Temperature Susceptibility is the rate at which the consistency of an asphalt binder changes with temperature and is a very important parameter of asphalt cement, [2].

According to Kandhal [3] asphalt stiffness is dependent on temperature that stiffness of asphalt decreases as temperature is increased as shown in Figure 1. Kandhal [3] compared two asphalt types "A" and "B", asphalt "B" is stiffer than asphalt "A" at 25 ^{o}C whereas the situation is reversed at 60 ^{o}C. The plot of Figure 1 shows three temperatures at which the stiffness of asphalt has significance. The temperature of 135 ^{o}C is near the temperatures used for mixing and compacting asphalt mixtures during construction. It is useful to determine the stiffness (measured in terms of kinematic viscosity) of the bitumen to establish proper mixing and compaction temperatures for asphalt mixtures. The temperature of 60 ^{o}C is near the maximum bituminous pavement temperature on a hot summer day, when rutting is likely to occur. It is useful to determine the stiffness (in terms of viscosity) of the bitumen at 60 ^{o}C so that we can specify its minimum stiffness to ensure adequate resistance to rutting during hot weather. The temperature of 25 ^{o}C is near the average annual temperature of an asphalt pavement during a year. It is useful to determine the stiffness (in terms of penetration) of the bitumen at 25 ^{o}C so that we can specify its maximum stiffness (minimum penetration) to resist pavement raveling and/or fatigue cracking resulting from aged/brittle bitumen after 5-10 years in service.

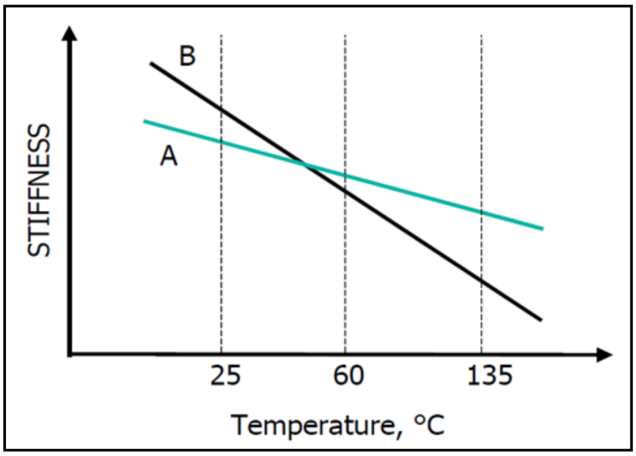

Figure 1: Temperature versus stiffness relationships of different asphalt binders (source [3])

Asphalt is available in variety of types and grades. To judge the suitability of asphalt binders are most commonly characterized by their physical properties rather than chemical properties, [4]. He reported, for engineering and construction purposes, normally three physical properties of asphalt are important; consistency, purity and safety. Apparao et al [4] described these properties as follows:

- **Consistency:** is the term used to measure asphalt degree of stiffness ability to flow. Asphalt is thermoplastic material which means it liquefy when heated and solidify when cooled and its state of solidness (stiffness) or liquidness (i.e., ability to flow) is very much temperature sensitive. Consistency of asphalt can be judged by some empirical tests such as penetration, softening point, ductility etc. and also by testing the fundamental property of asphalt such as viscosity.
- **Purity:** pure asphalt is completely soluble in solvents like carbon disulphide and carbon tetrachloride. Hence any impurity in asphalt in the form of inert minerals, carbon etc. could be quantitatively analyzed by dissolving the samples of asphalt in any of the above mentioned solvent.
- **Safety:** asphalt materials leave out volatiles at temperatures depending upon their grade. These volatiles catch fire causing a flash. The flash point of a material is the lowest temperature at which the vapour of a substance momentarily takes fire in the form of a flash under specified condition of test. The fire point is the lowest temperature at which the material gets ignited and burns under specified conditions of test.

Apparao et al [4] concluded that there is no point to grade bitumen on purity and safety aspects. It is the consistency property of bitumen by which it can be graded. Asphalt binders are typically categorized by one or more shorthand grading systems. These systems range from simple penetration grading and viscosity grading to complex Superpave performance grading and represent an evolution in the ability to characterize asphalt binders.

2.1. Penetration grading

The penetration grading system was developed in the early 1900s to characterize the consistency of semi-solid asphalts. Grading of bitumen by penetration test at 25 °C was adopted by the American Society for Testing and Materials (ASTM) Committee D04 on Road and Paving Materials in 1903.

In penetration grade, the bitumen is classified as per the values of penetration test. Figure 2 shows the schematic of the penetration test, in which a needle loaded with 100 grams is allowed to penetrate the bitumen maintained at 25 °C temperature in a water bath, for 5 seconds. The resulting penetration is measured in mm; 1 penetration unit = 0.1 mm.

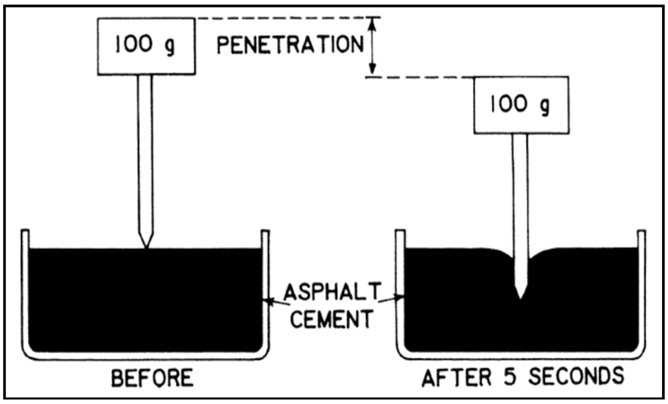

Figure 2: Schematic of penetration test

Penetration grading basic assumption is that the less viscous the asphalt, the deeper the needle will penetrate. This penetration depth is empirically correlated with asphalt binder performance.

ASTM Standard D946 [5] specified five penetration grades for bitumen: 40-50 (hardest bitumen grade), 60-70, 85-100, 120-150, 200-300 (softest bitumen grade). The Asphalt Institute recommends the use of 120/150 or 85/100 penetration asphalt in the asphalt concrete for cold climatic condition with a mean annual temperature of 7°C or lower. For warm climatic condition with a mean air temperature between 7 and 24 °C, 85/100 or 60/70 penetration asphalt is recommended. For hot climatic condition with a mean annual air temperature of 24°C or greater, the use of 40/50 or 60/70 penetration asphalt is recommended, [6].

ASTM D946 [5] provides a specification for penetration-graded asphalt cements as given in Table 1. According to the specification of ASTM D946 [5], the only requirement on the consistency of the asphalt cements is the penetration at 25°C. There is no requirement on the consistency at either a higher or lower temperature, and thus no requirement on the temperature susceptibility of the asphalt cements. The penetration grading system has advantages and disadvantages as listed in Table 2.

Table 1: Specification for penetration-graded asphalt cements, ASTM D946 [5]

Test	*Penetration Grade*									
	40/50		*60/70*		*85/100*		*120/150*		*200/300*	
	Min	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Penetration at 25°C, 0.1mm	40	50	60	70	85	100	120	150	200	300

Flash point (Cleveland open cup), °C	232	--	232	--	232	--	219	--	180	--
Ductility at 25°C, cm	100	--	100	--	100	--	100	--	100	--
Solubility in trichloroethylene, %	99.0	--	99.0	--	99.0	--	99.0	--	99.0	--
Retained penetration after TFOT, %	55	--	52	--	47	--	42	--	37	--
Ductility at 25 °C after TFOT, cm	--	--	50	--	75	--	100	--	100	--

Table 2: Advantages and Disadvantages of the Penetration Grading, [7]

Advantages	*Disadvantages*
The test is done at 25° C, which is reasonably close to a typical pavement average temperature.	The test is empirical and does not measure any fundamental engineering parameter such as viscosity.
May also provide a better correlation with low-temperature asphalt binder properties than the viscosity test, which is performed at 60° C.	Shear rate is variable and high during the test. Since asphalt binders typically behave as a non-Newtonian fluid at 25° C, this will affect test results.
Temperature susceptibility (the change in asphalt binder rheology with temperature) can be determined by conducting the test at temperatures other than 25°C.	Temperature susceptibility (the change in asphalt binder rheology with temperature) cannot be determined by a single test at 25°C.
The test is quick and inexpensive. Therefore, it can easily be used in the field.	The test does not provide information with which to establish mixing and compaction temperatures.

2.2. Viscosity grading

In the early 1960s an improved asphalt grading system was developed that incorporated a rational scientific viscosity test. This scientific test replaced the empirical penetration test as the key asphalt binder characterization. The viscosity grading system gave excellent performance results in the US for over twenty years. The viscosity grading system is more rational than the penetration grading system. Viscosity is defined as inverse of fluidity. Viscosity thus defines the fluid property of bituminous material. Viscosity is the general term for consistency and it is a measure of resistance to flow. Many researchers believe that grading of bitumen should be by absolute viscosity in instead of the conventional penetration units. Viscosity grading is based on a fundamental, scientific viscosity test, which is conducted at 60 °C (near the maximum pavement temperature during summer) and its measurement unit is poise. The test equipment for measuring viscosity both at 60 °C and 135 °C is simple as shown in Figure 3.

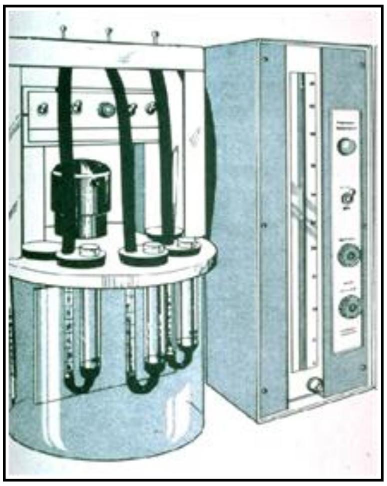

Figure 3: Vacuum capillary viscosity testing equipment, [3]

Viscosity grading can be done on original (as-supplied) asphalt binder samples (called AC grading) or aged residue samples (called AR grading). The AC grading is based on absolute viscosity at 60 °C in units of 100 poises. Six asphalt cement viscosity grades were established as AC-2.5 (softest), AC-5, AC-10, AC-20, AC-30, AC-40 (hardest). AC-2.5 means asphalt cement with a target viscosity of 250 poises at 60 °C (250 has been abbreviated to 2.5). Similarly, AC-5, AC-10, AC-20, AC-30, and AC-40 mean asphalt cements with target viscosity of 500, 1000, 2000, 3000, and 4000 poises, respectively. Low viscosity grades AC-2.5 and AC-5 are used in cold climate while high viscosity grades AC-10 to AC-40 are generally suitable for hot climate. Table 3 gives specification for viscosity grades, ASTM D3381, [8]. The AR Grading is based on residue from rolling thin-film oven test. ASTM D3381 [8] provides specification for viscosity grading on aged residue samples as given in Table 4.

The following advantages resulted from adopting the viscosity grading system for bitumen:

1. Unlike penetration grades, same viscosity grade bitumen gave similar rutting performance in hot weather.
2. Minimum penetration values were retained in the viscosity grading system to maintain acceptable performance (in terms of resistance to fatigue cracking) at yearly average service temperature of 25°C.
3. Minimum specified values of kinematic viscosity at 135°C helped to minimize the potential of tender mixes during construction.
4. Minimum specified penetration at 25°C and minimum specified kinematic viscosity at 135 °C established the maximum allowable temperature susceptibility (slope of temperature versus stiffness line).
5. Viscosity grades bitumen were suitable for a wide range of temperatures: 25 °C for raveling / fatigue cracking; 60 °C for rutting; and 135 °C for construction.
6. Since the viscosity values are measured at two temperatures, bitumen suppliers could provide to the users rational and accurate asphalt mixing and compaction temperatures (corresponding to bitumen viscosity of 170 and 280 centistokes, respectively).

Table 3: Specification for Viscosity Graded Bitumen (ASTM D3381 [8])

Test	*Viscosity Grade*					
	AC-2.5	*AC-5*	*AC-10*	*AC-20*	*AC-30*	*AC-40*
Viscosity at 60 °C, poises	250 ± 50	500± 100	1000 ± 200	2000 ± 400	3000 ± 600	4000 ± 800
Viscosity at 135°C, cst, min	125	175	250	300	350	400
Penetration at 25 °C, 0.1mm, min	220	140	80	60	50	40
Flash point, °C, min.	163	177	219	232	232	232
Solubility in Trichloroethylene, %, min.	99.0	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven						
Viscosity at 60 °C, poises, max	1,250	2,500	5,000	10,000	15,000	20,000
Ductility at 25 °C, cm, min.	100	100	75	50	40	25

Table 4: Specification for Viscosity Graded Bitumen (ASTM D3381 [8])

Tests on Residue from Rolling Thin-Film Oven	*Viscosity Grade*				
	AR-1000	*AR-2000*	*AR-4000*	*AR-8000*	*AR-16000*
Viscosity at 60 °C, poises	1000 ± 250	2000 ± 500	4000 ± 1000	8000 ± 2000	16000 ± 4000
Viscosity at 135 °C, cst, min.	140	200	275	400	550
Penetration at 25 °C, min.	65	40	25	20	20
% of original penetration at 25 °C, min.	--	40	45	50	52
Ductility at 25°C, cm, min.	100	100	75	75	75
Tests on original asphalt					
Flash point, °C, min.	205	219	227	232	238
Solubility in Trichloroethylene, %, min.	99.0	99.0	99.0	99.0	99.0

To compare the specification of each grading system, it is necessary to find the equivalent grade of other system. The following table shows the equivalent penetration grades of viscosity grades with their general application.

Table 5: Viscosity grade bitumen and equivalent penetration grade (source [10])

Viscosity grade (VG)	*General Applications*	*Equivalent Penetration grade*
VG 40	The area with high stress concentration like intersections of roads, truck parking, heavy traffic. It can be used in higher temperatures.	30-40
VG 30	It is the most suitable for use in hot and rainy weather condition.	60-70
VG 20	It is used in areas of cold climate and high altitude.	-----
VG 10	Used in spraying applications, and can be used in very cold regions. Also used for the manufacture of bitumen emulsion and modified bitumen.	85-100

3. Experimental Program

The quality of asphalt used for construction of flexible pavement is a vital concern to the highway professionals. The main objective of this study is to verify the important role of adopting the viscosity grading system in right selection of asphalt binder for design of HMA. To achieve this objective, intensive laboratory experiments were carried out to characterize the physical properties of asphalt cement. The tests performed to measure the consistency and safety characteristics of bitumen as per ASTM D3381 [8].

3.1 Materials Used

The asphalt binders used in construction of flexible pavements for Sudan's highways are imported from different sources such as Egypt, Saudi Arabia and Iran. The penetration grade 60/70 asphalt binder is currently used for road construction in Sudan. Twenty samples of asphalt cement were collected from the road contractors and the Sudanese Standards & Metrology Organization (SSMO). Thirteen samples (A1 to A13) were selected from grade 60/70 and seven samples (B1 to B7) from grade 85/100. The physical properties of asphalt samples have been evaluated and compared with the requirements of standard specification of ASTM [9].

3.2 Methodology

The study based on laboratory tests to measure the consistency and safety properties of twenty samples of asphalt binders. These samples were subjected to laboratory testing include consistency tests such as penetration, viscosity (kinematic) and softening point, ring and ball method. The cementitious property test of ductility and safety tests to measure flash and fire point using Cleveland open cup. The tests were performed in accordance to ASTM [9]. The samples of asphalt binders were classified using both penetration grading system and viscosity grading system.

3.3 Results and Discussion

The results of the experiments carried out for measuring the consistency and safety parameters of the asphalt cement samples are presented in Table 6. As shown in this table, the measured properties for the asphalt samples complied with the ASTM specifications. It can be noted that the penetration grade has no requirements in the specification for some properties such as fire point temperature, softening point temperature and viscosity. The viscosity values of the asphalt samples studied, for both penetration grades 60/70 and 85/100 are plotted in Figures 4 (a) & (b). These two figures demonstrate clearly that some asphalt samples, having same penetration grade show different viscosities.

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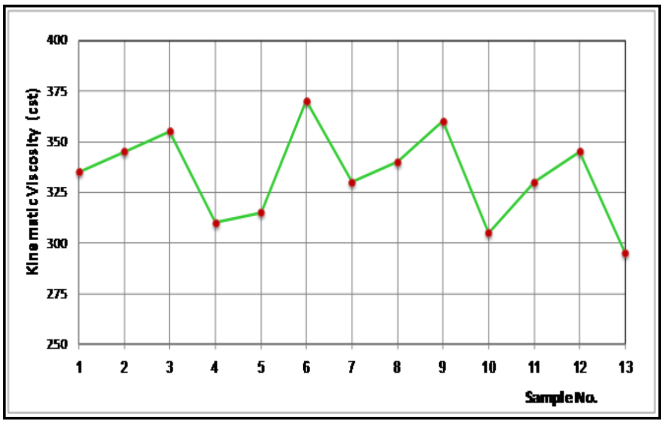
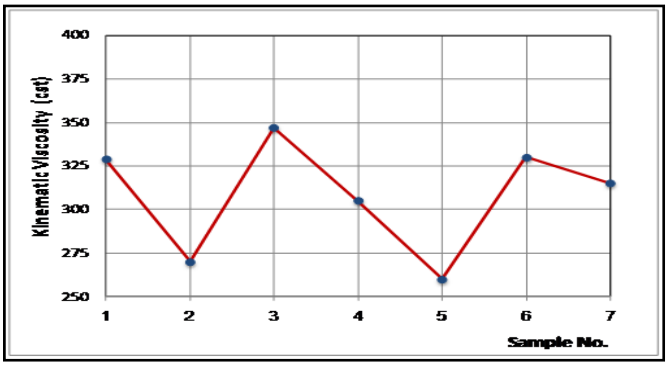
Table 6: Physical properties of asphalt cement samples

Sample	*Penetration,0.1mm*	*Ductility (cm)*	*Viscosity (cst)*	*Flash Point (°C)*	*Fire Point (°C)*	*Softening Point (°C)*
A1	62	103	335	311	315	52
A2	66	100	345	239	262	50
A3	67	87	355	248	267	48
A4	62	100	310	264	290	51
A5	68	100	315	281	295	49
A6	63	105	370	260	295	48
A7	64	106	330	276	290	49
A8	65	103	340	239	258	47
A9	59	100	360	292	354	51
A10	66	105	305	245	268	49
A11	61	101	330	276	295	53
A12	64	100	345	295	304	55
A13	66	102	295	243	304	48
B1	85	100	300	258	276	51
B2	80	88	305	248	276	49
B3	82	102	280	246	290	49
B4	97	104	250	225	280	47
B5	88	103	260	241	275	48
B6	85	101	265	242	285	49
B7	87	95	285	264	300	52



(a) Asphalt samples A1 to A13 [grade 60/70]



(b) Asphalt samples B1 to B7 [grade 85/100]

Figure 4: Kinematic viscosity values for asphalt samples of grade 60/70 and 85/100

The viscosity grading for the samples of grade 60/70 and 85/100 asphalt binders were identified and presented in Table 7 for comparison of the results. It can be observed that out of 13 samples, 9 samples belong to AC30 and 4 samples belong to AC20, though their penetration grade lies between 60/70. Similarly, for penetration grade 85/100, 4 samples belong to AC20 and 3 samples belong to AC10. It is clear from this observation that two asphalts may be of the same penetration grade and yet have substantially different viscosities. This problem is illustrated in Figure 5. In this figure the tests data were plotted in histograms to compare the results of the asphalt binders. The viscosity grading (AC10, AC20, and AC30) criteria for the asphalt binders are given in Table 3.

Table 7: The viscosity grading and the corresponding penetration grading for asphalt samples studied.

Sample	*Viscosity Grading*		*Penetration Grading*	
	Kinematic at 135°C, CTS	*Viscosity grade*	*Penetration, 0.1mm*	*penetration grade*
A1	335	AC-30	62	60 - 70
A2	345	AC-30	66	60 - 70
A3	355	AC-30	67	60 - 70
A4	310	AC-20	62	60 - 70
A5	315	AC-20	68	60 - 70
A6	370	AC-30	63	60 - 70
A7	330	AC-30	64	60 - 70
A8	340	AC-30	65	60 - 70
A9	360	AC-30	59	60 - 70
A10	305	AC-20	66	60 - 70
A11	330	AC-30	61	60 - 70
A12	345	AC-30	64	60 - 70
A13	295	AC-20	66	60 - 70
B1	300	AC-20	85	85 - 100
B2	305	AC-20	80	85 - 100
B3	280	AC-20	82	85 - 100
B4	250	AC-10	97	85 - 100
B5	260	AC-10	88	85 - 100
B6	265	AC-10	85	85 - 100
B7	285	AC-20	87	85 - 100

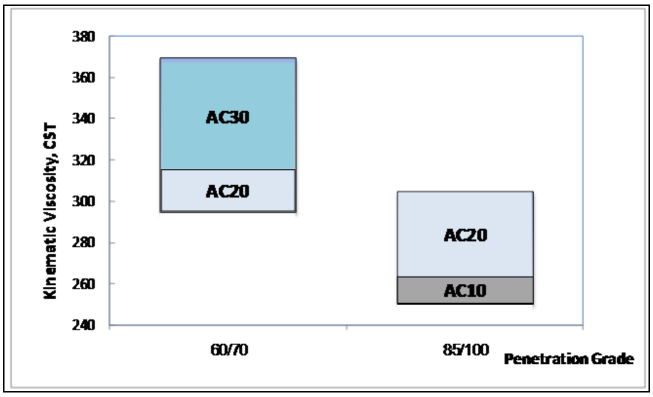


Figure 5: Comparison of the viscosity grading system with the penetration grading system for the samples tested

4. Conclusions

The quality of asphalt used for construction and maintenance of flexible pavements is an issue of vital concern to the highway engineers. The need to adopt a reliable asphalt grading system for long term performance and durable roads drew attention of professionals. This research has been undertaken to review the important role of adopting viscosity grading systems for selection of asphalt binder in Sudan. The results and the conclusions drawn as follows:

- The experimental results clearly demonstrated that asphalt cement of same penetration grade show different viscosity grades. Thus, any asphalt binder of same penetration grade may give different performance at high and low temperatures. For this reason, the existing penetration grading system of bitumen must be replaced by viscosity grading system for real improvement in the highway performance and durability.

- Obviously, the old penetration grading system is still being practiced in Sudan is archaic. It is also clear that many advantages accrue from the viscosity grading. The viscosity grading system is more realistic, reliable and practical than the penetration grading system. Since the testing procedure is carried out at three different temperatures; viscosity at 60 ºC and 135 ºC and penetration at 25 ºC, which relate to the properties of asphalt at high pavement temperature, mixing temperature and average pavement service temperature.
- Penetration test was developed in times of significantly lower pavement loading. Today there is a massive increase in pavement loading which contributes to increase in stresses applied to pavements and further heavy traffic and change in weather conditions. Therefore to cope up with the change, there is need to shift from penetration to viscosity grade. This change did not result in any significant price increase for paving bitumen in the US. The same is expected in Sudan.
- The complexity of testing, lack of instruments and knowledge, and high cost are some of the restraints to adopt the latest Superpave performance grading system. Moreover highway engineers would also need to be trained for its implementation. The adoption of Superpave performance grading system can be considered as a long-term goal or for use on very important, large projects if needed at the present time.

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Author Profile

Dr. Magdi M.E. Zumrawi was born in Omdurman, Sudan, 19 May 1963. He received the B.Sc. degree in Civil Engineering and M.Sc. degree in Road Technology from University of Khartoum in 1987 and 1991, respectively. He achieved Ph.D. in Highway and Railway Engineering, Chang'An University, Xi'an, in Sept. 2000. He is an associate Professor of Highway Eng. and his present occupation is Head, Civil Eng. Dept., Faculty of Eng., Khartoum University.