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Review of Advances in Grading Systems for Asphalt Binders in Hot-mix Asphalt Pavements

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Abstract: This study is intended to review the traditional methods of grading of asphalt binders and the advances that have been made in this area. A critical look is taken at the adequacy or otherwise of the traditional penetration method of grading still being employed in the country. Some of the basic characteristics of asphalt cement in use in the country were quantified using penetration grading system through experimental tests in a laboratory. The research carried out in this study shows that the conventional method of grading asphalt cement as is still being practiced in Nigeria is archaic. It is recommended that current methods based on viscosity and Superpave tests should be employed since many advantages accrue from these more advanced methods of grading.

Key words: Asphalt binder, HMA, grading, superpave, asphalt binder modifiers

INTRODUCTION

Asphalt, one of the two principal constituents of Hot-Mix Asphalt (HMA), functions as a relatively inexpensive, waterproof, thermoplastic and viscoelastic adhesive. It acts as the glue that holds the mineral aggregates together. One of the characteristics of asphalt is its vers atility. Besides its popular use as a road construction and maintenance material, it is also used in several other areas as indicated in Fig. 1.

Although, a solid or semi-solid at ordinary temperatures, asphalt may be liquefied by applying heat (asphalt cement), dissolving it in solvents (cut-back), or emulsifying it (emulsion). Asphalt binders of the various grades are most commonly characterized by their physical properties, which directly describe how it will perform as a constituent in asphalt mixtures. The challenge in physical property characterization is to develop physical tests that can satisfactorily characterize key asphalt binder parameters and how these parameters change throughout the life of an HMA pavement or any other facility in which asphalt is used.

Rather than refer to an extensive list of its physical properties, asphalt binders are typically categorized by

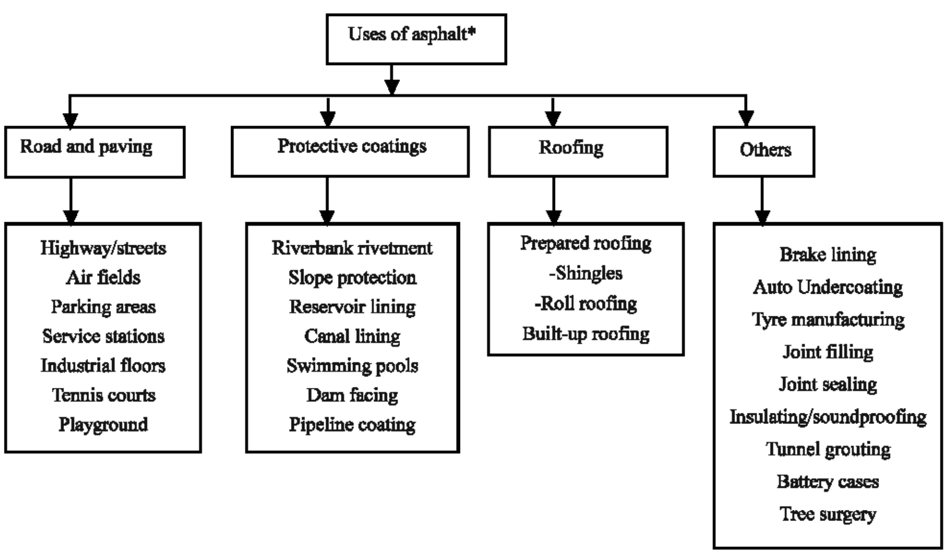

Fig. 1: Some uses of asphalt, Source: Adedimila (2005)

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one or more shorthand grading systems. These systems range from simple (penetration grading) to complex (Superpave performance grading) and represent an evolution in the ability to characterize asphalt binders.

The objective of this research is to review the traditional methods of grading or classifying asphalt binders and the advances that have been made in this area. A critical look will be taken at the adequacy or otherwise of the traditional penetration method of grading still being employed in the country for construction specification. The results of some laboratory experiments carried out on samples of asphalt cement obtained from different asphalt plants in the country will be reported and discussed.

PRODUCTION AND CLASSIFICATION OF ASPHALTS

In the simplest terms, asphalt binder is the residue left over from petroleum refining. Thus, asphalt binders are produced mainly by petroleum refiners and to a lesser extent, by formulators who purchase blending stock from refiners. The composition of the 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.

The American Petroleum Institute (API) classifies crude oils by their API gravity. API gravity is an arbitrary expression of a material's gravity or density at 15.5°C (60°F). API gravity can be used as a rough estimate of asphalt yield with lower API gravity crude oils producing more asphalt (Table 1). Although, mathematically API gravity has no units (Eq. 1), it is nevertheless referred to as being in "degrees". The formula used to obtain the API gravity of petroleum liquids is (Wikipedia, 2007):

Table 1: API gravities of some typical substances

Substance	Typical API gravity
Water	10
Asphalts	5-10
Gasoline	55
Low API gravity crude oil	< 25 (yields high percentages of asphalt)
High API gravity crude oil	> 25 (yields low percentages of asphalt)

Source: WSDOT (2003)

$$\text{Degrees API gravity} = \frac{141.5}{\text{Specific Gravity}} - 131.5 \quad (1)$$

Conversely, the specific gravity of petroleum liquids can be obtained from the API gravity value as follows:

$$\text{Specific Gravity at } 60°\text{F} = \frac{141.5}{\text{API Gravity} + 131.5} \quad (2)$$

Thus, heavy oil with a specific gravity of 1.0 would have an API gravity of 10 degrees API. Crude oil is classified as light, medium or heavy, according to its measured API gravity. Light crude oil is defined as having API gravity higher than 31.1°API. Medium oil is defined as having API gravity between 22.3°API and 31.1°API. Heavy oil is defined as having API gravity below 22.3°API (Wikipedia, 2007).

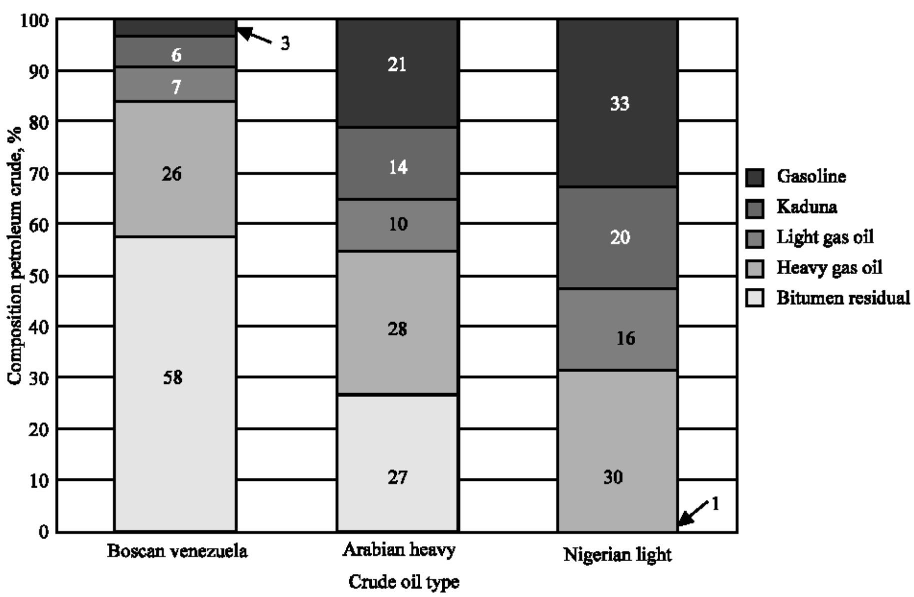

Fig. 2: Typical composition of some crude oils, Source: WSDOT (2003)

Figure 2 shows the composition of three very different crude oils. The high percentage of the bitumen residuals in the Boscan Venezuela and the negligible amount in Nigerian Light are evident in Fig. 2. This accounts for the dependence on importation of crude oils for the production of bitumen at the Kaduna refinery, or outright importation of bitumen into the country.

PHYSICAL PROPERTIES OF ASPHALT

The earliest physical tests were empirically derived. Some of these tests (such as the penetration test) have been used for the better part of the 20th century with good results. Later tests (such as the viscosity tests) were first attempts at using fundamental engineering parameters to describe the physical properties of asphalt binders. Ties between tested parameters and field performance were still quite tenuous. Superpave binder tests were developed in the 1980s and 1990s, with the goal of measuring specific physical properties of asphalt binders that are directly related to field performance by engineering principles. These tests are generally a bit more complex but seem to accomplish a more thorough characterization of the tested asphalt binder.

CONVENTIONAL METHODS OF GRADING AND SPECIFICATIONS OF ASPHALT CEMENTS

There are three conventional methods of grading asphalt cements. These three methods are:

- Grading by penetration at 25°C.
- Grading by absolute viscosity at 60°C.
- Grading by absolute viscosity of aged asphalt residue after the rolling thin film oven test (RTFOT) procedure.

These three methods of grading and the associated ASTM specifications of asphalt cements are presented and discussed in this stuyd.

Grading by penetration at 25°C: The method of grading of asphalt cements by standard penetration at 25°C is the first systematic method developed and is still used by a few highway agencies in the world. The penetration grading system, developed in the early 1900s, is used to characterize the consistency of semi-solid asphalts. Penetration grading quantifies the following asphalt concrete characteristics (WSDOT, 2003):

Table 2: Aashto m 20 and astm d 946 penetration grades

Penetration grade	Comments
40-50	Hardest grade
60-70	Typical grade used in Nigeria and the U.S.
85-100	Typical grade used in the U.S.
120-150	Recommended for cold climatic condition
200-300	Softest grade. Used for cold climates such as northern Canada (Roberts *et al*., 1996)

- Penetration depth of a 100 g needle applied for 5 sec at 25°C (77°F).
- Flash point temperature.
- Ductility at 25°C (77°F).
- Solubility in trichloroethylene
- Thin-film oven test (accounts for the effects of short-term aging).
    - Retained penetration.
    - Ductility at 25°C (77°F).

Penetration grading's basic assumption is that the less viscous the asphalt, the deeper the needle will penetrate. This penetration depth is empirically (albeit only roughly) correlated with asphalt binder performance. Therefore, asphalt binders with high penetration numbers (called "soft") are used for cold climates while asphalt binders with low penetration numbers (called "hard") are used for warm climates.

Penetration grades are listed as a range of penetration units (one penetration unit = 0.1 mm) such as 120-150. The standard grades by this method include 40/50, 60/70, 85/100, 120/150 and 200/300 asphalts, which have penetrations of 40-50, 60-70, 85-100, 120-150 and 200-300, respectively. The Asphalt Institute recommends the use of a 120/150 or 85/100 pen. 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, a 85/100 or 60/70 pen. asphalt is recommended. For hot climatic condition with a mean annual air temperature of 24°C or greater, the use of a 40/50 or 60/70 pen. asphalt is recommended (Asphalt Institute, 1991). A summary of penetration grades specified in AASHTO M 20 and ASTM D 946 (1994a) are listed in Table 2.

ASTM D946 (1994a) provides a specification for penetration-graded asphalt cements. Table 3 shows the specification for 60/70 and 85/100 pen asphalts as examples. According to this specification, 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

Table 3: Requirements for 60/70 and 85/100 penetration asphalt cements

	Penetration grade			
	60/70		85/100	
Test	Min	Max	Min	Max
Penetration at 25°C, 0.1mm	60	70	85	100
Flash point (Cleveland open cup),°C	232	-	232	-
Ductility at 25°C, cm	100	-	100	-
Solubility in trichloroethylene (%)	99.0	-	99.0	-
Retained penetration after TFOT (%)	52	-	47	-
Ductility at 25°C after TFOT, cm	50	-	75	-

Source: ASTMD (1994)

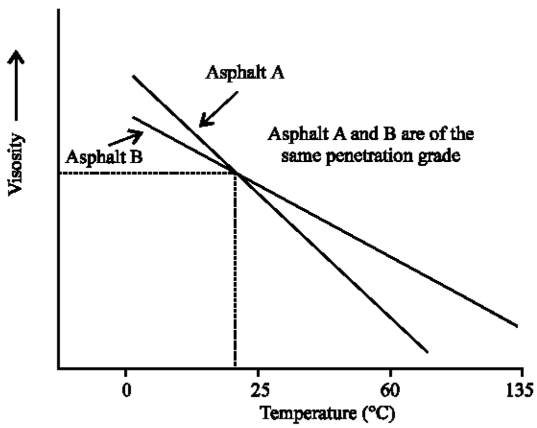

Fig. 3: Variation in viscosity of two penetration-graded asphalts at different temperatures, Source: Mang (2001)

the asphalt cements. Two asphalts may be of the same penetration grade and yet have substantially different viscosities at 60°C. This problem is illustrated in Fig. 3.

Thus, it is clear that specifying the penetration grade alone will not ensure that the asphalt used will have the appropriate viscosities at the expected service temperatures. Other requirements in the specification are, Minimum flash point temperature, minimum ductility at 25°C, minimum solubility in trichloroethylene and penetration and ductility at 25°C of the asphalt after aging by the TFOT procedure.

The key advantages and disadvantages of penetration grading are listed in Table 4.

Grading by absolute viscosity of original asphalt: Since, penetration is an empirical test, grading by penetration was thought to be unscientific. Considerable efforts were made in the 1960s to grade asphalts using fundamental units and incorporating a rational scientific viscosity test. Early attempts were made to grade asphalts by viscosity at 25 and 20°C. However, problems were encountered in measuring viscosity at such low temperatures (Table 4). With some reluctance, the temperature for grading asphalt by viscosity was moved to 60°C, which represents approximately the highest temperature pavements may experience in most parts of the United States (Mang, 2001).

This scientific viscosity test started to replace the empirical penetration test (in the U.S.) as the key asphalt binder characterization. Viscosity grading quantifies the following asphalt binder characteristics (WSDOT, 2003):

- Viscosity at 60°C (140°F).
- Viscosity at 135°C (275°F).
- Penetration depth of a 100 g needle applied for 5 seconds at 25°C (77°F).
- Flash point temperature.
- Ductility at 25°C (77°F).
- Solubility in trichloroethylene.
- Thin film oven test (accounts for the effects of short-term aging):
    - Viscosity at 60°C (140°F).
    - Ductility at 25°C (77°F).

Viscosity grading can be done on original (as-supplied) asphalt binder samples (called AC grading) or aged residue samples (called AR grading). The AR viscosity test is based on the viscosity of aged residue from the rolling thin film oven test. With AC grading, the asphalt binder is characterized by the properties it possesses before it undergoes the HMA manufacturing process. The AR grading system is an attempt to simulate asphalt binder properties after it undergoes a typical HMA manufacturing process and thus, it should be more representative of how asphalt binder behaves in HMA pavements.

When asphalt is graded based on original (as-supplied) asphalt binder samples, it is designated as AC followed by a number which represents its absolute viscosity at 60°C in units of 100 poises. For example, an sAC-20 would have an absolute viscosity of 2,000±400 poises at 60°C. An AC-20 roughly corresponds to a 60/70 pen. Asphalt (Mang, 2001). Viscosity grading includes AC-2.5, AC-5, AC-10, AC-20, AC-30 and AC-40.

However, due to the possible effects of different temperature susceptibility and non-Newtonian behaviour, the conversion from a viscosity grade to a penetration grade may be different for different asphalts. Figure 4 shows the effects of different temperature susceptibility on the viscosity variation of two asphalts which have the same viscosity grade. Similar effects were noticed for penetration-graded asphalts in Fig. 3. In an effort to

Table 4: Advantages and disadvantages of the penetration grading

Advantages	Disadvantages
The test is done at 25°C (77°F), which is reasonably close to a typical pavement average temperature in tropical countries.	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 (140°F).	Shear rate is variable and high during the test. Since asphalt binders typically behave as a non-Newtonian fluid at 25°C (77°F), 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 (77°F).	Temperature susceptibility (the change in asphalt binder rheology with temperature) cannot be determined by a single test at 25°C (77°F).
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.

Source: Roberts *et al.* (1996)

Table 5: Requirements for AC-10 and AC-20 asphalt cements

	Viscosity grade			
	AC-10		AC-20	
Test on original asphalt	Spec. 1	Spec.2	Spec. 1	Spec.2
Absolute Viscosity at 60°C, poises	1000±200	1000±200	2000±200	2000±200
Kinematic Viscosity at 135°C, cSt	150	250	210	300
Penetration at 25°C, 0.1mm	70	80	40	60
Flash point (Cleveland open cup),°C	219	219	232	232
Solubility in trichloroethylene, min, %	99.0	99.0	99.0	99.0
Tests on residue from TFOT				
Viscosity at 60°C, max., poises	5000	5000	10000	10000
Ductility at 25°C, min, cm	50	75	20	50

Source: ASTM D 3381 (1994)

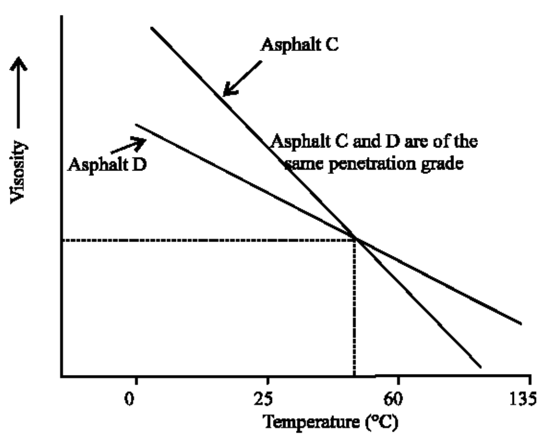

Fig. 4: Variation in viscosity of two viscosity-graded asphalts at different temperatures, Source: Mang (2001)

control this variation, the requirements for a minimum penetration at 25°C and a minimum viscosity at 135°C were added to the specification.

ASTM D3381 (ASTM, 2001) provides two different specifications for asphalt cements graded by absolute viscosity of the original asphalt at 60°C. Table 5 shows the requirements for AC-10 and AC-20 grade asphalts in the two specifications as examples. The main difference between these two specifications is that Spec. 1 requires lower temperature susceptibility than Spec. 2. Limits on temperature susceptibility are specified through a minimum required penetration at 25°C and a minimum required kinematic viscosity at 135°C. The other requirements which are similar to those in the specification of penetration-graded asphalts are:

- Minimum flash point temperature.
- Minimum ductility at 25°C.
- Minimum solubility in trichloroethylene.
- Required properties of the asphalt after aging by the TFOT procedure (by means of maximum viscosity at 60°C and ductility at 25°C).

GRADING BY ABSOLUTE VISCOSITY OF AGED ASPHALT RESIDUE

The third asphalt grading system is to grade asphalts according to their viscosity when placed on the road (after aging due to the heating and mixing process). This grading system has been adopted by several western states in the U.S. (Mang, 2001). Grading is to be based on the absolute viscosity at 60°C of the asphalt residue after the Rolling Thin Film Oven Test (RTFOT) procedure, which simulates the effects of the hot-mix plant operation.

Asphalt graded by this system is designated as AR (aged residue) followed by a number which represents the viscosity of the aged residue at 60°C in units of poises. For example, an AR-6000 would have an Aged Residue (AR) with an absolute viscosity of 6000±1500 poises. An AR-6000 would roughly correspond to an AC-20 or a

Table 6: Requirements for ar-4000 and ar-8000 asphalt cements

Test on residue from rtfot	Viscosity grade AR-4000	AR-8000
Absolute Viscosity at 60°C, poises	4000±1000	8000±2000
Kinematic Viscosity at 135°C, min., cSt	275	400
Penetration at 25°C, min., 0.1mm	25	20
% of original penetration, min.	45	50
Ductility at 25°C, min., cm	75	75
Test on Original Asphalt		
Flash point (Cleveland open cup), min,°C	227	232
Solubility in trichloroethylene, min., %	99.0	99.0

Source: ASTM D 3381 (1994)

Table 7: Advantages and disadvantages of viscosity grading

Advantages	Disadvantages
Unlike penetration depth, viscosity is a fundamental engineering parameter.	The principal grading (done at 25°C (77°F)) may not accurately reflect low-temperature asphalt binder rheology.
Test temperatures correlate well with: 25°C (77°F) - average pavement temp. 60°C (140°F) - high pavement temp. 135°C (275°F) -HMA mixing temp.	When using the AC grading system, thin film oven test residue viscosities can vary greatly with the same AC grade. Therefore, although asphalt binders are of the same AC grade they may behave differently after construction.
Temperature susceptibility (the change in asphalt binder rheology with temperature) can be somewhat determined because viscosity is measured	The testing is more expensive and takes longer than the penetration test
at three different temperatures (penetration only is measured at 25°C (77°F)).	Testing equipment and standards are widely available.

Source: Roberts *et al.* (1996)

60/70 pen. Asphalt (Mang, 2001). Other viscosity gradings include AR-1000, AR-2000, AR-4000, AR-8000 and AR-16000.

ASTM D3381 (1994b) provides a specification for asphalt cements graded by viscosity of aged residue after the RTFOT process. Table 6 shows the specification for AR- 4000 and AR-8000 grade asphalts as examples.

According to, this specification, temperature susceptibility is specified through requiring a minimum penetration at 25°C and a minimum kinematic viscosity at 135°C of the residue after the RTFOT. Similar, to the requirements in the specifications for the other 2 grading systems, there are requirements on:

- Ductility at 25°C of the aged residue.
- Minimum flash point of the original asphalt.
- Minimum solubility in trichloroethylene of the original asphalt.

Another requirement in this specification is a minimum percent of retained penetration after the RTFOT, which can serve as a check on the composition and aging characteristics of the asphalt.

Table 7 lists key advantages and disadvantages of the viscosity grading system.

SUPERPAVE SYSTEM

Superpave system was a bold step by the U.S. government to make significant advancement in the design, materials efficiency, performance and maintenance of the nation's highway system. This bold step and determination commenced about 2 decades ago and have witnessed huge success. The outcome of extensive research programmes has led to new methods of asphalt binder characterization away from the traditional ways. Thus, though Nigeria as a nation is yet to embrace this new system, it is worth taking a look into.

The asphalt research program of the Strategic Highway Research Program (SHRP) is the largest SHRP program at $53 million (FHWA, 1998) and it had three primary objectives (NECEPT, 2001):

- Investigate why some pavements perform well, while others do not.
- Develop tests and specifications for materials that will out-perform and outlast the pavements being constructed today.
- Work with highway agencies and industry to have the new specifications put to use.

The final product of this research program is a new system referred to as "Superpave", which stands for SUperior PERforming asphalt PAVEments. Superpave, in its final form consists of three basic components:

- An asphalt binder specification. This is the Performance Grading (PG) asphalt binder specification.
- A design and analysis system based on the volumetric properties of the asphalt mix. This is the Superpave mix design method.

- Mix analysis tests and performance prediction models.Test development and evaluation in this area was concluded in 2004.

Each one of these components required new specifications and performance standards as well as new testing methods and devices. As of late 2001, most states (48) in the U.S. have adopted or would adopt the Superpave PG asphalt binder specification and 39 states either have adopted or would adopt the Superpave mix design method (NHI, 2000).

Superpave performance grading: Asphalt binders appropriate for pavement construction have been traditionally graded based on resistance to penetration and/or viscosity measures. Although, in common use throughout the U.S., these traditional grading systems are somewhat limited in their ability to fully characterize asphalt binder for use in HMA pavements. Therefore, as part of the Superpave research effort new binder tests and specifications were developed to more accurately and fully characterize asphalt binders for use in HMA pavements. The current grading system in the United States is known as the Performance Grading (PG) system (WSDOT, 2003). Performance grading tests and specifications are specifically designed to address HMA pavement performance parameters such as aging, rutting, fatigue cracking and thermal cracking.

Superpave Performance Grading (PG) is based on the idea that an HMA asphalt binder's properties should be related to the conditions under which it is used. For asphalt binders, this involves expected climatic conditions as well as aging considerations. Therefore, the PG system uses a common battery of tests (as the older penetration and viscosity grading systems do) but specifies that a particular asphalt binder must pass these tests at specific temperatures that are dependant upon the specific climatic conditions in the area of use. In Superpave grading system, asphalt binders are graded based on the temperature range over which the binder retains certain desirable characteristics. These desirable characteristics include adequate flexibility to resist cold temperature cracking and sufficient rigidity to resist warm temperature rutting.

Superpave performance grading is reported using two numbers-the first being the average seven-day maximum pavement temperature (°C) and the second being the minimum pavement design temperature likely to be experienced (°C). Thus, a PG 58-22 is intended for use where the average seven-day maximum pavement temperature is 58°C and the expected minimum pavement temperature is -22°C. The maximum temperature establishes the upper temperature limit for the binder to retain adequate rigidity to resist rutting while the minimum temperature establishes the lower limit for the binder to retain sufficient flexibility to resist thermal cracking. It should be noted that these numbers are pavement temperatures and not air temperatures.

Table 8 shows how the Superpave PG system addresses the general limitations of specific penetration, AC and AR grading systems.

Performance grading uses fundamental physical and mechanical properties rather than index properties. The criteria remain constant but the test temperature changes from lowest 1-day temperature to highest 7-day temperature. Physical properties of the binders are measured at various temperatures both before and after laboratory aging. The laboratory aging is conducted to simulate field conditions imposed during the HMA production process as well as from long-term environmental exposure.

Table 8: Advantages of superpave over other grading systems

Limitations of penetration, AC and AR grading systems	Superpave binder testing and specification features that address prior limitations
Penetration and ductility tests are empirical and not directly related to HMA pavement performance.	The physical properties measured are directly related to field performance by engineering principles.
Tests are conducted at one standard temperature without regard to the climate in which the asphalt binder will be used.	Test criteria remain constant, however, the temperature at which the criteria must be met changes in consideration of the binder grade selected for the prevalent climatic conditions.
The range of pavement temperatures at any one site is not adequately covered. For example, there is no test method for asphalt binder stiffness at low temperatures to control thermal cracking.	The entire range of pavement temperatures experienced at a particular site is covered.
Test methods only consider short-term asphalt binder aging (thin film oven test) although long-term aging is a significant factor in fatigue cracking production and construction.	Three critical binder ages are simulated and tested: 1. Original asphalt binder prior to mixing with aggregate. 2. Aged asphalt binder after HMA 3. Long-term aged binder.
Asphalt binders can have significantly different characteristics within the same grading category.	Grading is more precise and there is less overlap between grades.
Modified asphalt binders are not suited for these grading systems.	Tests and specifications are intended for asphalt "binders" to include both modified and unmodified asphalt cements.

Source: Roberts *et al.* (1996)

ASPHALT BINDER GRADING IN NIGERIA

The asphalt cements used in virtually all road construction and maintenance activities in Nigeria are the 60/70 and 85/100 pen bitumen. This is largely because their characteristics are very suitable for the prevailing temperature range in the country-being a tropical country.

The 60/70 and 85/100 pen asphalt cement grade used in the country are exclusively imported into the country from countries such as Venezuela, Ivory Coast, Italy, South Africa, etc. Each consignment of bitumen brought into the country always comes with certificate of quality assurance of the product. Basically, the certificate indicates the basic tests that were 'expectedly' carried out on the bitumen consignment, the test methods, the results and specifications. The basic tests, as indicated from sample copies of these certificates include, but sometimes not limited to the following:

- Flash Point°F (Cleaveland Open Cup).
- Flash Point°F (Cleaveland Open Cup).
- Density @15°C and @25°C.
- Softening Point (°C).
- Penetration at 77°F (25°C) 100g, 5s.
- Solubility in Trichloroethylene, %.
- Retained penetration after thin-film oven test, %.
- Loss on heating for 5 h (% m m^{-1}).
- Drop in penetration percentage, % (0.1 mm).

The test results contained in the certificates are expected to conform to appropriate Federal Ministry of Works (FMW) specifications (Table 9). These tests indicate that the asphalt cements imported into the country are graded by the conventional method of grading by penetration at 25°C.

Table 9: Quality of asphalt cement

Property	Asphalt cement 80-100 PEN	60-70 PEN
Specific Gravity @ 25°C	1.0-1.05	1.0-1.06
Softening Point R and B (°C)	45-52	48-56
Penetration @ 25°C---0.1mm	80-100	60-70
Ductility @ 25°C---0.1mm	100	100
Loss on Heating for 5 hours at 163°C		
% by weight---max	0.5	0.2
Solubility in CS2, % by Wt---min	99	99
Drop in Penetration after heating		
% original---max	20	20
Flash point (Open Cup)°C min.	225	250
Ash. % by wt.---max.	0.5	0.5

Source: FMWH (1997)

RESULTS

In an attempt to verify the basic characteristics of asphalt cement in use in the country, some basic laboratory experiments were carried out on samples of asphalt cement. The samples were obtained from different asphalt plant of various companies including RATCON (Ibadan); Julius Berger Nig. Ltd. (Lagos); FISCO Construction Ltd. (Ijebu-Ode); Lagos State Asphalt Plant (Isheri-Lagos) and Nigercat Construction Ltd (Warri). These tests were also to ascertain the veracity of the claims in the certificates of quality assurance that usually accompany every consignment of imported asphalt cement.

The tests, which were carried out in accordance with the recommended standards of the FMW include:

- Penetration at 77°F (25°C) 100 g, 5 s.
- Softening Point (°C).
- Solubility in Trichloroethylene, %.
- Flash Point°C (Cleaveland Open Cup).
- Loss on heating for 5 h (% by weight).

Other desirable tests could not be carried out due to equipment constraints. The tests on sample asphalt cements obtained from each company were conducted at Julius Berger Euro 65 laboratory in Lagos. The results of the tests are contained in Table 10.

Table 10: Results of laboratory experiments on asphalt cement

Test	Ratcon	Julius berger	Fisco	Lagos asphalt plant	Nigercat
Penetration	80, 90, 84, 83	80, 79, 81, 84, 86	60, 62, 60, 61, 60	122, 129, 117, 116	96, 99, 101, 98
	Avrg = 84.25	Avrg = 82	Avrg = 60.33	Avrg = 121	Avrg = 98.5
Softening Point,°C	42.0, 48.0	55.5, 57	44.0, 48.0	42.0, 40.0	52.0, 52.5
	Avrg = 45°C	Avrg =56.25°C	Avrg = 46°C	Avrg = 41°C	Avrg = 52.25°C
Solubility in					
trichloroethylene, %	71.8	85.3	94.2	82.1	93.3
Flash Point, °C	235	230	270	170	225
Loss on heating,					
% by weight	2.02	0.35	0.33	0.49	0.67
Specific gravity at 25°C	0.993	0.995	0.998	0.972	0.974

DISCUSSION

The results of the tests are evaluated using the recommended specifications in Table 9.

Penetration tests: Only the sample from FISCO falls within the 60/70 pen grade. Three out of the five samples (Ratcon, Julius Berger and Nigercat) are 80/100 pen grade while the sample from Lagos Asphalt plant falls within the 120/150 pen grade. Interestingly, all the companies believe their asphalt cements are 60/70 pen grade. This indicates likely problems of rutting, flushing and slipperiness of pavement surface during hot weather.

Softening point tests: The only 60/70 pen grade sample (FISCO) fell out of the specification range of 48-56°C. Samples from Julius Berger and Lagos Asphalt Plant also fell outside the specification range. However, the sample from Lagos Asphalt Plant is on the lower side, which indicates an early attainment of undesirable level of softness of the pavement built with such asphalt. Only RATCON and Nigercat samples (80/100 pen grade) barely fell within the specification range of 45-52°C.

Solubility tests: All the samples fell short of the recommended value of 99, indicating rather impure bitumen.

Flash point tests: Values for all the 60/70 and 80/100 pen grades samples were above the recommended minimum values of 250 and 225, respectively. The exception was the sample from Lagos Asphalt Plant which has a value of 170°C and therefore constitute some potential fire hazard during the production of asphalt concrete.

Loss on heating: Samples from RATCON and Nigercat (80/100 pen grade) had values higher than the recommended maximum value of 0.5. Sample from FISCO (60/70 pen grade) also had value higher than the recommended maximum value of 0.2. Only the sample from Julius Berger (80/100 pen grade) had value below the recommended maximum.

Specific gravity: All the samples fell below the recommended values. One of the implications of this is that rather incorrect results will be derived from quality control experiments carried out on bitumen and asphalt concretes (since these incorporate specific gravity of bitumen as one of the parameters in the analysis of results).

CONCLUSION

Asphalt binders can be characterized by chemical and physical properties. Chemically, asphalt is a mixture of polar and non-polar complex organic molecules. The microstructure of these molecules tends to govern asphalt's physical behaviour. Since, chemical knowledge and testing is limited, asphalt is most commonly described by its physical attributes. Over the years many tests have been developed to fully characterize asphalt's physical attributes. To date, these tests have reached an apogee with the Superpave binder tests. Superpave tests measure specific asphalt binder physical properties that are directly related to field performance by engineering principles. Thus, theoretically they offer the best and most complete asphalt binder characterization. They are also the most complex and the most expensive.

Using the tests highlighted above, asphalt binders are classified for use (graded) based on their physical properties as measured through testing. The most common asphalt binder classifications are: penetration grade, viscosity grade and performance grade (from Superpave). At present in Nigeria, the only asphalt binder classification is penetration grading. This grading is reflected in General Specifications for Roads and Bridges (FMWH, 1997).

In addition, there is lack of quality assurance on asphalt binders used in the country, in the form of comprehensive laboratory and in-situ tests. As already highlighted, the importers of bitumen and the government-appointed inspectors rarely bother to carry out recommended (independent) tests on imported bitumen.

The developed countries have made significant progress in improving the quality of asphalt cement and bituminous binders used for their road works. This is attested to by the research into and development of Superpave Performance Grading, Asphalt Binder Modifiers and Foamed (Expanded) asphalt. However, till date, no attempt is being made to incorporate these advances in Nigeria. As such, the country is unable to benefit from such ground-breaking, performance-improving advancement.

RECOMMENDATIONS

It is clear from the foregoing research work that the conventional method of grading asphalt cement as is still being practiced in Nigeria is archaic. It is also clear that many advantages accrue from the more advanced methods of grading. As a way of making progress and reaping better performances from our bituminous pavements, the following recommendations are proffered:

- The government of Nigeria through the Ministry of Transportation (Highway Department) should initiate moves to upgrade from the conventional grading of asphalt by penetration to more advanced and better performing methods.
- The General Specifications (Roads and Bridges) Volume II (FMWH, 1997) should then be revised to incorporate the advanced grading methods.
- More stringent cross evaluation should be put on the quality control of bitumen imported into the country. This should be in the form of comprehensive laboratory and in-situ tests on representative samples of imported bitumen. This would ensure that only quality bitumen is imported into the country.

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