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Adapting of Performance Grading System for Local Asphalt Cement

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Abstract

The General Specifications for Roads and Bridges (SCRB) don't adopt the performance grading (PG) based system suggested by Superpave program to evaluate the currently used asphalt cements for paving works. The air temperature data used in this study covers approximately 20 years time period (1982-2002) for seven Iraqi cities (Kirkuk, Mosul , Rutba , Baghdad , Kut , Najaf , and Basrah) which represent climatically unique regions in Iraq. The currently used asphalt cements with penetration grades (40-50) and (60-70) were tested by both of conventional test methods and Superpave methods to determine the equivalent performance grade for each type of the penetration graded asphalt and to evaluate the capability for these two types of asphalt cement to satisfy the required performance of pavement for each region of country. The paper results indicate the following for the required PG asphalt binders:

Region	Performance Graded (PG) Asphalt Binder
North governorates	70-16
Middle governorates	70-10
West governorates	64-10
South governorates	76-4

The Daurah asphalt cements with penetration grade (40-50) are equivalent to PG 70-16, PG70-10 and PG76-4 while asphalt with penetration grade (60-70) is equivalent to PG 64-10. The rotational viscosity , dynamic shear rheometer and creep stiffness versus penetration relationships have been developed to estimate the some Superpave asphalt binder tests based on penetration values.

Key words: Performance grade , asphalt cement , Superpave binder tests, and physical properties.

تبني نظام تصنيف الأداء للإسفلت الأسمنتي المنتج محلياً

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الخلاصة

المواصفات العامة للطرق و الجسور (SCRB) لا تتبنى نظام تصنيف الخرسانة الإسفلتية العالية الجودة (Superpave) في تقييم الإسفلت الأسمنتي المستخدم لإعمال التبليط. تم جمع بيانات دراجات الحرارة للهواء المستخدمة في هذه الدراسة خلال فترة (٢٠) سنة تقريباً من ١٩٨٢ و لغاية ٢٠٠٢ و تشمل سبع مناطق من العراق وهي (كركوك و موصل و رطبة و بغداد و كوت و نجف و البصرة) والتي تمثل مناطق مختلفة من حيث المناخ. تم اجراء الفحوصات التقليدية لنماذج الإسفلت المصنفة حسب فحص الاختراق (٤٠-٥٠) و (٦٠-٧٠) و من ثمه تم تحديد خواص الاسفلت حسب طرق (Superpave) لغرض تحديد صنف الاداء المكافئ لكل نوع من الاسفلت و اعطاء صنف الاداء الملائم لكل منطقة من العراق. لقد بينت نتائج البحث ان تدرج الاداء المطلوب لمحافظات المناطق الشمالية و الوسطية و الغربية و الجنوبية هو PG64-10, PG70-16 PG70-10, PG76-4 على التوالي. الإسفلت ذو اختراق (٤٠-٥٠) والمنتج من مصفى الدورة مكافئ الى اصناف الأداء التالي (PG76-4,PG70-16,PG70-10) بينما الاسفلت ذي الصنف (٦٠-٧٠) مكافئ الى (PG 64-10). ثلاثة علاقات بين الاختلاق و لزوجة الدوران و القص المتحرك و صلادة الزحف تم تطوريها لتخمين فحوصات (Superpave) بالاعتماد على قيم الاختراق.

1.Introduction

Asphalt binders are most commonly characterized by their physical properties. An asphalt binder's physical properties directly describe how it will perform as a constituent in HMA pavement. 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.

The earliest physical tests were empirically derived tests. 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 asphalt binder physical properties. Ties between tested parameters and field performance were still quite tenuous. Superpave binder tests, developed in the 1980s and 1990s, were developed with the goal of measuring specific asphalt binder physical properties that are directly related to field performance by engineering principles **(Anderson et al., 1994)**. These tests are generally a bit more complex but seem to accomplish a more thorough characterization of the tested asphalt binder.

This subsection, taken largely from **Roberts et. al. (1996)**, describes the more common U.S. asphalt binder physical tests. Asphalt binder tests specifically developed or adopted by the Superpave research effort are noted by a " – *Superpave*" in their title. Sections that discuss Superpave tests also discuss relevant field performance information as well as the engineering principles used to develop the relationship between test and field performance.

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. Notice that these numbers are pavement temperatures and not air temperatures (these pavement temperatures are estimated from air temperatures) as reported in **(SHRP,1994)**. As a general rule-of-thumb, PG binders that differ in the high and low temperature specification by 90°C .

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 dependent upon the specific climatic conditions in the area of use. This concept is not new – selection of penetration or viscosity graded asphalt binders follows the same logic – but the relationships between asphalt binder properties and conditions of use are more complete and more precise with the Superpave PG system **(SHRP,1994)**.**Table 1** shows how the Superpave PG system addresses specific penetration, AC grading system general limitations.

Table 1: Prior Limitations vs. Superpave Testing and Specification Features (after Roberts et. al., 1996)

Limitations of Penetration, AC 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 and low temperature cracking.	Three critical binder ages are simulated and tested: 1. Original asphalt binder prior to mixing with aggregate. 2. Aged asphalt binder after HMA production and construction. 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.

The penetration grading system was developed in the early 1900s to characterize the consistency of semi-solid asphalts. Penetration grading quantifies the following asphalt concrete characteristics: Penetration depth of a 100 g needle 25^{o} C ,Flash point temperature , Ductility at 25°C,Solubility in trichloroethylene ,Thin film oven test (accounts for the effects of short-term aging that occurs during mixing with hot aggregate) :Retained penetration , Ductility at 25°C.

Penetration grading's 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. 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 grading advantages and disadvantages are listed in Table 2.

Table 2. Advantages and Disadvantages of the Penetration Grading (after Roberts et al., 1996)

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.Experimental Program

The experimental program included in this study was aimed to achieve the potential benefits of traditional tests to develop asphalt performance specification in Iraq. A number of traditional tests are performed in Kufa University to characterize the physical properties of asphalt cement. All Superpave asphalt binder tests have been performed in the Tehran University , college of Engineering , Islamic Iran Republic . These tests have been adapted to measure dynamic rheological properties of asphalt cement.

3. Material

For the purpose of this work , two asphalt cement penetration grades were considered (40-50) and (60-70) which are obtained from the Daurah refinery, south-west of Baghdad. The physical properties of fourthly samples of asphalt have been evaluated and compared with requirements of local specification of State Commission for Roads and Bridges **(SCRB/R9,2003**) based on the conventional penetration grading system.

Table 3: Physical properties of asphalt cement samples

	Penetration (0.10 mm)	Softening point (^oC)	Ductility (cm)	Flash point (^oC)	Loss on heating, mass loss(%)	Residue from thin film oven test	
						Retained penetration(%)	Ductility (cm)
ASTM Designation	D5	D36	D113	D92	D1754	D5	D113
Pen (40-50)							
A1	42	52	100	311	0.42	61	60
A2	43	51	100	274	0.46	63	77
A3	41	58	100	316	0.60	60	59
A4	48	46	100	280	0.33	65	76

A5	42	51	100	306	0.53	66	76
A6	46	43	100	288	0.37	63	72
A7	40	59	100	321	0.51	62	77
A8	43	51	100	303	0.53	66	70
A9	44	53	100	290	0.57	64	75
A10	49	47	100	320	0.50	66	76
A11	43	51	100	300	0.55	61	72
A12	47	44	100	270	0.44	67	71
A13	42	51	100	302	0.45	68	69
A14	50	44	100	290	0.42	67	75
A15	43	52	100	318	0.45	61	76
A16	47	45	100	304	0.47	64	72
A17	41	57	100	315	0.48	61	68
A18	50	47	100	285	0.35	60	70
A19	43	53	100	311	0.34	58	75
A20	45	51	100	292	0.49	66	71
SCRB specification	40-50	------	≥100	≥232	<0.75	≥55	≥25
Pen (60-70)							
B1	67	45	100	281	0.58	57	87
B2	69	40	100	284	0.51	62	89
B3	61	46	100	290	0.55	59	82
B4	63	45	100	293	0.53	64	90
B5	64	43	100	295	0.66	66	95
B6	66	44	100	277	0.47	60	93
B7	69	40	100	282	0.48	67	92
B8	61	46	100	292	0.52	55	86
B9	63	45	100	299	0.59	67	85
B10	64	43	100	266	0.63	61	88
B11	62	46	100	300	0.59	64	90
B12	70	41	100	285	0.49	61	86
B13	61	46	100	300	0.58	60	90
B14	63	45	100	293	0.55	63	94
B15	64	43	100	302	0.61	62	97
B16	66	44	100	274	0.63	55	92
B17	69	40	100	282	0.66	64	86
B18	61	48	100	290	0.54	59	85
B19	63	45	100	275	0.57	66	81
B20	65	44	100	270	0.61	56	91
SCRB specification	60-70	------	≥100	≥232	<0.80	≥52	≥50

(ASTM, 2000)

The results indicate that all asphalt samples satisfy the requirements of SCRB specifications

4.Superpave Asphalt Binder Tests

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. These tests and specifications are specifically designed to address HMA pavement performance parameters such as rutting, fatigue cracking and thermal cracking.

4.1 Rotational Viscometer (RV) Test

This test was conducted according to AASHTO T 316-06 " Standard Method of Test for Viscosity Determination of Asphalt ".The basic RV test measures the torque required to maintain a constant rotational speed (20 RPM) of a cylindrical spindle while submerged in an asphalt binder at a constant temperature. This torque is then converted to a viscosity and displayed automatically by the RV. To have adequate mixing and pumping capabilities, Superpave specification (AASHTO M320) requires the binder to have a rotational viscosity less than 3.0 Pa.s at 135 ^{o}C. If the rotational viscosity value is higher than 3.0 Pa.s for an asphalt binder , special handling procedure is required to ensure proper mixing and pumping capabilities while using that binder. The viscometer can also be used to develop temperature- viscosity charts by running the viscometer at both 135 ^{o}C and 165 ^{o}C to determine laboratory mixing and compaction temperatures.

4.2 Flash Point Test

A typical flash point test involves heating a small sample of asphalt binder in a test cup. The temperature of the sample is increased and at specified intervals a test flame is passed a cross the cup. However, all the procedure details can be found in ASTM D92.

4.3 Rolling Thin Film Oven Test (RTFOT)

The Rolling Thin Film Oven Test as described in ASTM D2872 was developed to simulate aging that occurs in asphalt plants during the manufacture of hot mix asphalt concrete. This test is a modification of the thin film oven test .Instead of the sample being placed in pans on a rotating shelf , the samples are poured into specially designed bottles. The bottles are placed into a vertically rotating rack in an oven maintained at 163 ^{o}C within 85 minutes. The residue from the rolling thin film oven test is subsequently tested to determine the effects of aging.

4.4 Pressure Aging Vessel (PAV)

The pressure aging vessel is a method of aging the asphalt to simulate the effects of long term aging in the field. The procedure of the test was explained in AASHTO R28. After the asphalt has been first aged in the rolling thin film oven , it is aged in the pressure aging vessel. The pressure aging vessel (PAV) was adopted by Superpave to simulate the effects of long-term asphalt binder aging that occurs as a result of 5 to 10 years HMA pavement service **(Bahia and Anderson, 1995)**. Prior to Superpave, the general concept of the pressure aging vessel had been used for many years in rubber product aging. The PAV is an oven-pressure vessel combination that takes RTFO aged samples and exposes them to high air pressure (2070 kPa) and temperature (90°C, 100° C or 110°C) depending upon expected climatic conditions for 20 hours.

4.5 Dynamic Shear Rheometer (DSR)

The dynamic shear rheometer (DSR) is used in the Superpave system for testing medium to high temperature viscosities (the test is conducted between 46° C and 82° C). The actual temperatures anticipated in the area where the asphalt binder will be placed determine the test temperatures used.

The basic DSR test uses a thin asphalt binder sample sandwiched between two plates. The lower plate is fixed while the upper plate oscillates back and forth across the sample at 1.59 Hz to create a shearing action. These oscillations at 1.59 Hz (10 radians/sec) are meant to simulate the shearing action corresponding to a traffic speed of about 90 km/hr (55 mph) (Roberts et al., 1996). Asphalt binders in the medium to high temperature range behave partly like an elastic solid (deformation due to loading is recoverable – it is able to return to its original shape after a load is removed) and a viscous liquid (deformation due to loading is non-recoverable – it cannot return to its original shape after a load is removed). By measuring G* and δ , the DSR is able to determine the total complex shear modulus as well as its elastic and viscous components .

4.6 Bending Beam Rheometer (BBR)

The bending beam rheometer is used in the Superpave system to test asphalt binders at low temperatures where the chief failure mechanism is thermal cracking. The BBR basically subjects a simple asphalt beam to a small (100-g) load over 240 seconds . Then, using basic beam theory, the BBR calculates beam stiffness (S(t)) and the rate of change of that stiffness (m-value) as the load was applied.

$$S(t)=PL^3/(4\ bh^3\ \delta\ (t)) \qquad \text{... (1)}$$

where:

S(t) = creep stiffness at time, t = 60 seconds

P = applied constant load (980 ± 20 mN), obtained using a 100 g load. Note that 100 g multiplied by the force of gravity (9.8 m/s^2) = 0.98 N, or 980 mN.

L = distance between beam supports, 102 mm

b = beam width, 12.5 mm

h = beam thickness, 6.25 mm

δ (t) = deflection at time, t = 60 seconds

The m-value is simply the rate of change of the stiffness at time, t = 60 seconds and is used to describe how the asphalt binder relaxes under load. Superpave specification (AASHTO M320) requires that the creep stiffness at the specified grade temperature must be less than or equal to 300 Mpa at 60 seconds and creep rate (m-value) greater than or equal to 0.300 at 60 seconds.

4.7 Direct Tension Tester (DTT)

The direct tension tester (DTT) is used in the Superpave system to compliment the BBR in testing asphalt binders at low temperatures. The DTT is used because creep stiffness, S(t), as measured by the BBR is not sufficient to predict thermal cracking in some asphalt binders that exhibit high creep stiffness (> 300 MPa). Recall that a high creep stiffness BBR test value implies that the asphalt binder will possess high thermal stresses in cold weather as a result of shrinkage. The assumption is that the asphalt binder will crack because of these high thermal stresses. However, some asphalt binders (especially modified asphalt binders) may be able to stretch far enough before breaking that they can absorb these high thermal stresses without cracking. The DTT identifies these asphalt binders. The DTT is only used for testing asphalt binders with a high BBR creep stiffness (300 – 600 MPa); asphalt binders with BBR creep stiffness values below 300 MPa are assumed satisfactory and the DTT is not needed. The DTT basically loads a small sample of asphalt binder in tension until it breaks.The failure strain is then calculated from the following equation:

$$\varepsilon_f = \frac{\Delta L}{L_e} \quad \ldots(2)$$

where: ε_f = failure strain

ΔL = change in length corresponding to the specimen's maximum loading

L_e = effective length

If a particular asphalt binder has a high BBR creep stiffness (indicating high thermal stress), it must have a minimum failure strain (indicating it will stretch rather than crack) to meet Superpave binder specifications.

5.Air Temperature

An extensive air temperature data are available from the Iraqi Metrological Organization (IMO) which has 24 stations across the country. These stations record daily climatic conditions for the regions on which they exist. The air temperature data used in this study covers approximately 20 years time period (1982-2002) for seven Iraqi cities (Kirkuk, Mosul , Rutba , Baghdad , Kut , Najaf , and Basrah) which represent climatically unique regions in Iraq.

Every year , the hottest seven –days period are identified and the average maximum air temperature for this seven-days period is calculated and then based on 20 years a mean and standard deviation are determined. Similarly , the one-day minimum air temperature of every year was identified and the mean and standard deviation are calculated.

Table 4 shows the summery of the calculated mean and standard deviation for the collected data. The latitude value for Mosul ,Kirkuk, Rutba , Baghdad , Kut , Najaf , and Basrah is 36.32 , 35.47 , 33.03 , 33.23, 32.67, 31.95, and 30.57 respectively.

Table 4 : Mean and standard deviation for maximum and minimum air temperature

Region	Maximum air temperature , (^oC)		Minimum air temperature , (^oC)	
	Mean	Standard deviation	Mean	Standard deviation
Mosul	45.149	1.982	-2.5	3.811
Kirkuk	45.663	1.969	-0.5	5.40
Rutba	41.600	0.962	-2.6	3.70
Baghdad	47.670	1.082	-2.1	1.74
Kut	44.563	2.073	-1.96	2.51
Najaf	48.479	1.155	-2.84	1.99
Basrah	49.082	1.283	1.36	1.74

6. Reliability

Reliability is the percent probability in single year that the actual temperature (seven-days average high or one-day low) will not exceed the design temperatures ***(Asphalt Institute, 2003)***. From statistics, 98 percent reliability is approximately two standard deviations from the mean value:

$$T_{Max\ at\ 98\%} = T_{Max\ at\ 50\ \%} + 2.055 \times \sigma_{high\ Temp} \qquad \ldots(3)$$

$$T_{Min\ at\ 98\%} = T_{Min\ at\ 50\ \%} - 2.055 \times \sigma_{low\ Temp} \qquad \ldots(4)$$

Where:

$T_{Max\ at\ 98\%}$= Maximum air temperature for 98 % reliability level.

$T_{Max\ at\ 50}$ = Maximum air temperature for 50 % reliability level.

$\sigma_{high\ Temp}$ = Standard deviation of high air temperature.

$T_{Min\ at\ 98\%}$= Minimum air temperature for 98 % reliability level.

$T_{Min\ at\ 50}$ = Minimum air temperature for 50 % reliability level.

$\sigma_{low\ Tem}$ = Standard deviation of low air temperature.

The data presented in **Table 5** show the high and low air temperatures for 98 percent reliability level for the five selected regions in Iraq.

Table 5 : High and low air temperature for 98 % reliability level

Region	High air temperature , (°C)	Low air temperature , (°C)
Mosul	49.22201	-10.331605
Kirkuk	49.7093	-11.597
Rutba	43.57691	-10.2035
Baghdad	49.89351	-5.6757
Kut	48.82302	-7.11805
Najaf	50.85253	-6.92945
Basrah	51.71857	-2.2157

7. Pavement Temperature

In Superpave , the high pavement design temperature at a depth of 20 mm is computed by the following equation **(SHRP,1994):**

$T_{20\,mm} = 0.9545\ [\ Tair - 0.00618\ lat^2 + 0.2289\ lat + 42.2] - 17.78$ …(5)

Where:

$T_{20\,mm}$= High pavement design temperature at a depth of 20 mm in °C.

T_{air}= Seven –days average high air temperature in °C.

Lat.= The geographical latitude of the project in degrees.

The low pavement design temperature simply can be assumed to be the same as the low air temperature .**Table 6** shows the maximum and minimum pavement temperature for the regions under consideration.

Table 6: Maximum and minimum pavement temperature

Region	High pavement temperature , (°C)	Low pavement temperature , (°C)
Mosul	70	-10
Kirkuk	70	-12
Rutba	65	-10
Baghdad	71	-6
Kut	70	-7
Najaf	72	-7
Basrah	73	-2

8.Performance Grade

Performance grades are delineated by 6 °C increments. The standard grades presented in the Superpave binder specification (**Asphalt Institute , 2003**) : PG64- 10,-16, -22, -28,-34,-40 ,PG 70-10,-16, -22, -28,-34,-40 , PG 76- 10,-16, -22, -28,-34.Based on the results obtained from the analysis of pavement temperature, the suggested PG grades of asphalt cements for paving works within the selected six regions of Iraq are presented in **Table 7** below for 98 % reliability level.

Table 7 :Local binder performance grades

Region	PG
North governorates	70-16
Middle governorates	70-10
West governorates	64-10
South governorates	76-4

9. Superpave Performance Grade (PG) Tests

The same two types of asphalt cement with penetration grade (40-50) and (60-70) that have been tested by conventional methods are also tested by using Superpave approach. All Superpave tests have been performed in the University of Tehran/ College of Engineering of Islamic Iran Republic to determine the performance grade for each one. These tests are performed according to AASHTO R29-02 " Standard Practice for Grading or Verifying the Performance Grade of an Asphalt Binder". The Superpave standard for the selection of PG graded asphalt binders are given in AASHTO M320-05 " Standard Specification for Performance –Graded Asphalt Binder" as reported in **Table 8**. In this specification , test results are specified on the unaged binder, the RTFOT residue and the PAV residue.

Table 8 : Performance Graded Asphalt Binder Specification (AASHTO M320-05)

Performance grade	PG 64-						PG 70-						PG-76				
	10	16	22	28	34	40	10	16	22	28	34	40	10	16	22	28	34
Average 7-day Maximum Pavement Design Temperature , °C	<64						<70						<76				
Minimum Pavement Design Temperature, °C	>-10	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34
ORIGINAL BINDER																	
Flash Point Temp, T48 : Minimum °C	230																
Viscosity , T316 Maximum , 3 Pa.s, Test Temp, °C	135																
Dynamic Shear , T315 $G^*/\sin\delta$, Minimum ,1.00 kPa Test Temp @ 10 rad/s , °C	64						70						76				
ROLLING THIN FILM OVEN (T240)																	
Mass Loss , Maximum , percent	1.00																
Dynamic Shear , T315 $G^*/\sin\delta$, Minimum ,2.20 kPa Test Temp @ 10 rad/s , °C	64						70						76				
PRESSURE AGING VESSELRESIDUE(R28)																	
PAV Aging Temperature, °C	100						100						100				
Dynamic Shear , T315 $G^*\sin\delta$, Minimum ,5000 kPa Test Temp @ 10 rad/s , °C	31	28	25	22	19	16	34	31	28	25	22	19	37	34	31	28	25
Creep Stiffness , T313 S, Maximum , 300 MPa, m-value , Minimum 0.300 Test Temperature @ 60s, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24
Direct Tension , T314 Failure Strain , Minimum,1.0% Test Temp @ 1.0 mm/min, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24

The results of Superpave binder tests for asphalt cement with two penetration grades (40-50) and (60-70) are shown in **Table 9** .Also, failure strain values at two test temperatures of 0 and -6 obtained by using direct tension test (AASHTO T314 method) are exceeded 1.0%. Therefore , these values will not be mentioned in **Table 9** below.

Table 9 : Superpave Binder Test Results for Penetration Grades (40-50) and (60-70)

Asphalt Condition	Original					RTFO Aged				PAV Aged						
Parameters	Flash Point	Viscosity at 135 °C	DSR , G*/sinδ, at @ 10 rad/s , test temperature °C			Mass loss	DSR , G*/sinδ, at @ 10 rad/s , test temperature °C			DSR , G*/sinδ, at @ 10 rad/s , test temperature °C			BBR, Creep Stiffness		BBR, m-value	
			64	70	76		64	70	76	31	34	37	0	-6	0	-6
Pen (40-50)																
A1	311	2.01	2.56	2.33	2.11	0.49	5.12	4.66	4.22	4352	3961	3587	225	315	0.37	0.31
A2	274	1.92	2.47	2.26	2.03	0.50	4.94	4.52	4.06	4199	3842	3451	214	288	0.39	0.31
A3	316	1.82	2.12	2.00	1.91	0.73	4.24	4	3.82	3604	3400	3247	200	280	0.40	0.32
A4	280	0.56	1.39	1.18	1.09	0.44	2.78	2.36	2.18	2363	2006	1853	88	125	0.49	0.40
A5	306	1.52	1.88	1.75	1.66	0.66	3.76	3.5	3.32	3196	2975	2822	171	240	0.50	0.4
A6	288	1.18	1.80	1.66	1.47	0.40	3.6	3.32	2.94	3060	2822	2499	130	182	0.39	0.33
A7	321	1.74	1.97	1.89	1.77	0.55	3.94	3.78	3.54	3349	3213	3009	195	273	0.36	0.30
A8	303	1.71	1.90	1.81	1.69	0.59	3.8	3.62	3.38	3230	3077	2873	190	266	0.42	0.33
A9	290	1.05	1.81	1.57	1.41	0.70	3.62	3.14	2.82	3077	2669	2397	116	165	0.53	0.43
A10	320	0.62	1.45	1.22	1.17	0.59	2.9	2.44	2.34	2465	2074	1989	86	125	0.58	0.46
A11	300	1.73	1.95	1.82	1.70	0.61	3.9	3.64	3.4	3315	3094	2890	191	270	0.39	0.31
A12	270	1.07	1.84	1.60	1.48	0.53	3.68	3.2	2.96	3128	2720	2516	119	167	0.55	0.44
A13	302	1.62	1.90	1.81	1.73	0.50	3.8	3.62	3.46	3230	3077	2941	180	252	0.51	0.40
A14	290	0.53	1.30	1.10	1.01	0.49	2.6	2.2	2.02	2210	1870	1717	70	98	0.64	0.51
A15	318	0.86	1.66	1.38	1.20	0.53	3.32	2.76	2.4	2822	2346	2040	95	133	0.60	0.48
A16	304	0.88	1.67	1.44	1.29	0.55	3.34	2.88	2.58	2839	2448	2193	111	160	0.59	0.49
A17	315	0.93	1.77	1.50	1.33	0.44	3.54	3	2.66	3009	2550	2261	119	170	0.58	0.46
A18	285	0.61	1.41	1.20	1.11	0.40	2.82	2.4	2.22	2397	2040	1887	97	136	0.57	0.45
A19	311	1.79	2.01	1.93	1.80	0.39	4.02	3.86	3.6	3417	3281	3060	201	286	0.38	0.30
A20	292	1.09	1.88	1.67	1.52	0.58	3.76	3.34	3.04	3196	2839	2584	130	182	0.53	0.42
Specification M320 (AASHTO,2007)	230 °C, min	3 Pa.s, max	1.00 kPa, min			1%, max	2.2 kPa, min			5000 kPa, max			300 MPa, max		0.30, min	
Pen (60-70)																
B1	281	0.38	1.04	0.62	0.31	0.51	2.28	1.24	0.62	1390	885	442	49	75	0.60	0.48
B2	284	0.33	1.05	0.63	0.31	0.54	2.50	1.26	0.62	1400	900	442	44	66	0.64	0.51
B3	290	0.57	1.59	0.95	0.47	0.78	3.18	1.9	0.94	2120	1357	671	69	105	0.50	0.40
B4	293	0.49	1.40	0.84	0.42	0.46	2.83	1.68	0.84	1900	1200	600	63	96	0.52	0.43
B5	295	0.39	1.06	0.63	0.31	0.69	2.28	1.26	0.62	1415	900	442	54	81	0.56	0.47
B6	277	0.39	1.06	0.65	0.31	0.42	2.22	1.3	0.62	1420	928	442	58	87	0.55	0.44
B7	282	0.35	1.05	0.63	0.31	0.58	2.27	1.26	0.62	1399	900	445	49	75	0.61	0.49
B8	292	0.73	1.84	1.10	0.55	0.62	3.68	2.2	1.1	2460	1571	790	80	120	0.45	0.36
B9	299	0.46	1.20	0.72	0.36	0.74	2.4	1.44	0.72	1650	1028	514	59	89	0.52	0.42
B10	266	0.40	1.08	0.64	0.32	0.62	2.16	1.28	0.64	1440	914	457	55	85	0.55	0.44
B11	300	0.55	1.54	0.92	0.46	0.69	3.08	1.84	0.92	2055	1314	657	67	104	0.51	0.41
B12	285	0.32	1.04	0.62	0.31	0.58	2.08	1.24	0.62	1390	885	442	55	83	0.56	0.45
B13	300	0.64	1.70	1.02	0.51	0.53	3.41	2.04	1.02	2270	1457	728	69	109	0.55	0.44

B14	293	0.46	1.22	0.73	0.36	0.51	2.44	1.46	0.72	1630	1042	514	61	96	0.52	0.42
B15	302	0.41	1.17	0.70	0.35	0.55	2.34	1.4	0.7	1560	1000	500	63	98	0.52	0.43
B16	274	0.35	1.03	0.61	0.30	0.57	2.26	1.22	0.6	1380	871	428	48	72	0.58	0.45
B17	282	0.33	1.06	0.63	0.31	0.46	2.23	1.26	0.62	1420	900	442	43	67	0.67	0.53
B18	290	0.55	1.31	0.78	0.39	0.42	2.62	1.56	0.78	1750	1114.	557	66	99	0.56	0.45
B19	275	0.49	1.28	0.78	0.38	0.41	2.56	1.56	0.76	1710	1114	542	64	96	0.55	0.44
B20	295	0.78	1.88	1.10	0.55	0.62	3.68	2.2	1.1	2460	1571	790	80	120	0.45	0.36
Specification M320 (AASHTO,2007)	230 ºC, min	3 pa.s, max	1.00 kPa, min			1%, max	2.2 kPa , min.			5000 kPa, max			300 MPa, max		0.30, min	

It is obvious from table above that the asphalt with penetration grade (40-50) is equivalent to 70-16, 70-10 and 76-4 while asphalt with penetration grade (60-70) is equivalent to PG 64-10. The rotational viscosity , dynamic shear rheometer (G^*/sin δ, at @ 10 rad/s , test temperature of 64) ,and creep stiffness (BBR) at test temperature of 0 º C versus penetration relationships are presented in Figures (1,2 and 3) below for two asphalt penetration grades AC(40-50) and AC(60-70).

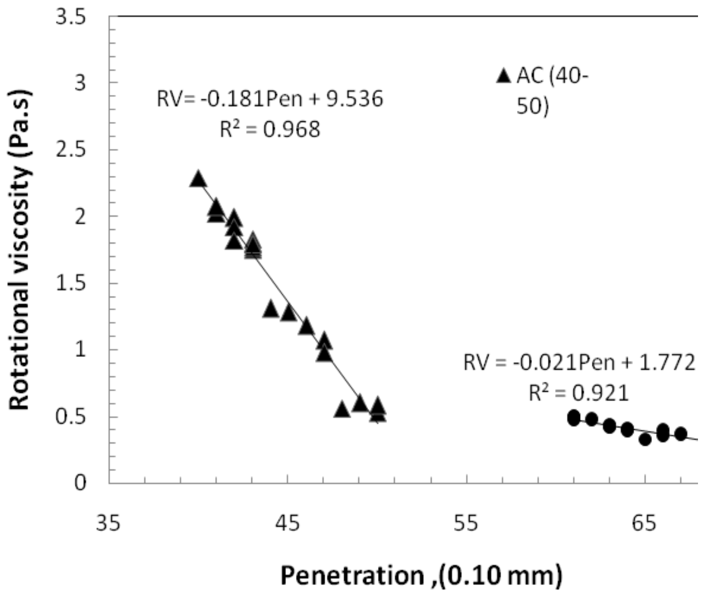

Figure1 . Relationship between Rotational viscosity and penetration

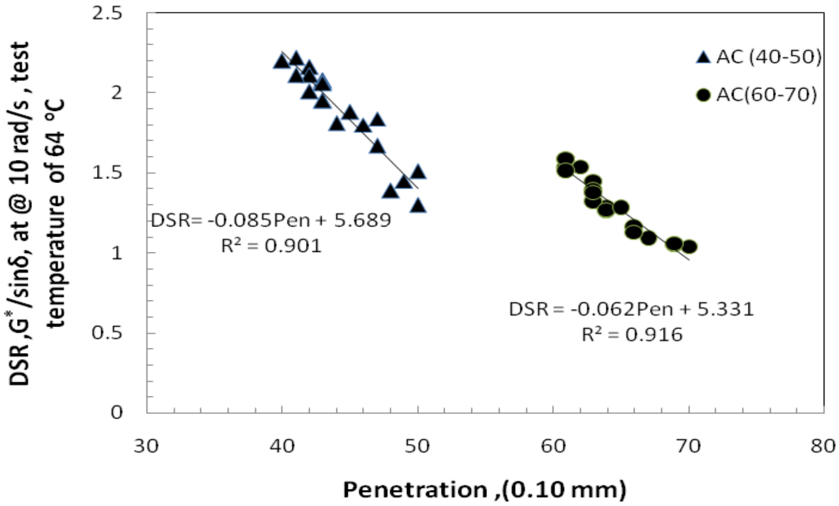

Figure 2 . Relationship between **dynamic shear rheometer (DSR)** ***and penetration***

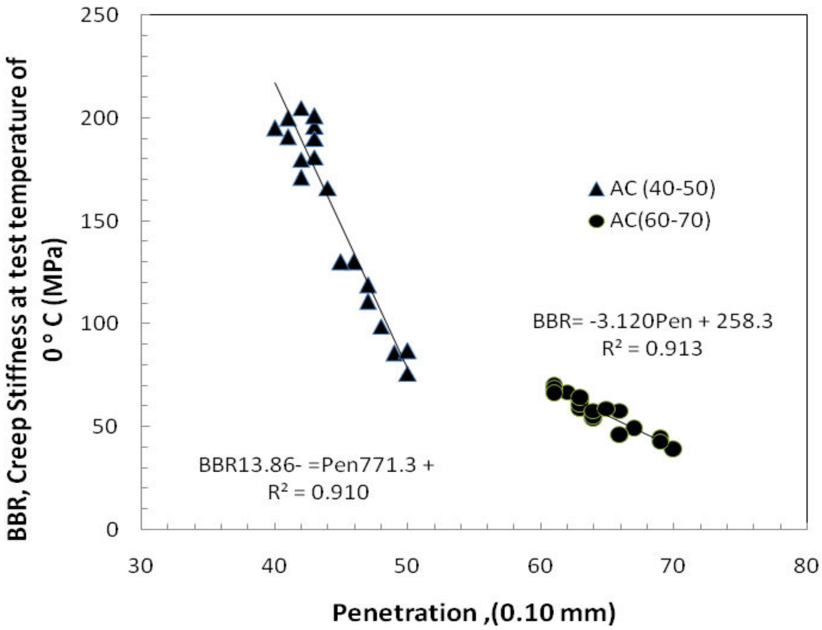

Figure 3 . Relationship between creep stiffness and penetration

The above figures can be used to estimate some Superpave asphalt binder tests based on penetration values.

10. Conclusions and Recommendations

Within the limitations of material and testing program used in this work , the following principal conclusions are made :

1. Performance grade (PG) can be distributed on Iraq regions based on Superpave criteria as follows:

Region	PG
North governorates	70-16
Middle governorates	70-10
West governorates	64-10
South governorates	76-4

2. The Daurah asphalt cements with penetration grade (40-50) are equivalent to 70-16, 70-10 and 76-4 while asphalt with penetration grade (60-70) is equivalent to PG 64-10.

3. It is recommended to prepare asphalt concrete mixtures in order to ensure that paving materials conform with the Superpave mix design requirements.

11.References

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