THE TRANSITION TO A PG GRADING SYSTEM FOR ASPHALT CEMENT IN IRAQ

Prof. Hamed M. H. Alani, (Civil Eng. Dept.) / Baghdad Univ.
Dr. Amjad H. Albayati, (Civil Eng. Dept.) / Baghdad Univ.
Alaa S. Abbas, (Highway and Transportation Eng. Dept.) / Al-Mustansiriya Univ.

ABSTRACT

In Iraq, as well as many other developing countries the performance graded (PG) based System is not yet implemented to evaluate the currently used asphalt cements for paving works. It appears that not only the unavailability of test equipments is resulting in this delay but also the lack of clear understanding of what steps could be taken to incorporate this system. This research is an attempt to highlight the important aspects of a (PG) system that can be readily implemented without the need for expensive equipments. It includes the development of a Performance based System employing the conventional test methods and available nomographs from literature. It also, shows how climatic data, traffic data, and asphalt binder properties can be combined to propose a possible major improvement for the specifications of asphalts in Iraq.

To achieve the objective of this research, an extensive air temperature data for a period of 18 years was reviewed for five cities (Mosul, Kirkuk, Rutba, Baghdad, and Basrah) to establish the required PG asphalt binder for each city. Also, 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 city.

The results indicate that both the new proposed method and Superpave method give the same final performance grade, The asphalt with penetration grade 40-50 is equivalent to PG70-16 while that with penetration grade 60-70 is equivalent to PG64-16.

KEY WORDS: Asphalt cement, Superpave, Performance grade.

الخلاصه

في العراق وفي كثير من الدول النامية لم يطبق نظام تدرج الاداء (PG) لتقييم الاسفلت المستخدم في اعمال التبليط لغاية الان. لقد تبين ان الكلفة لم تكن وحدها سببا" في هذا التاخير بل النقص في فهم الخطوات التي يجب ان توخذ لتطبيق الفقرات الخاصة بهذا النظام . في هذا البحث تم القاء الضوء على الاقسام المهمة الخاصة بنظام تدرج الاداء والتي يمكن تطبيقها دون الحاجة الى المعدات المكلفة الثمن وذلك عن طريق استخدام الطرق التقليدية لفحص الاسفلت في العراق. لقد بين البحث كيفية استخدام نتائج هذه الفحوصات بطريقة غير مباشرة لتخمين الخصائص المتعلقة بالاداء بناءا" على مخططات بيانية (nomograph) وبين كيف يمكن للبيانات الخاصة بالطقس والبيانات المروية والخصائص الريولوجية او خصائص الفشل التي اشتقت من المخططات البيانية ان تشترك فيما بينها

لاقتراح تطوير لمواصفة الاسفلت في العراق.لتحقيق الهدف من البحث تم مراجعة بيانات الانواء الجوية العراقية وجمع المعلومات المتعلقة بدرجة حرارة الجو خلال فترة 18 سنة ولخمسة مدن عراقية (موصل، كركوك، رطبة، بغداد، والبصرة) وبناءا" على نظام تصنيف الخرسانة الاسفلتية العالية الجودة (Superpave) تم استنباط تدرج الاداء الخاص بكل منطقة. كذلك تم فحص الاسفلت السمنتي ذو درجة اختراق (40-50) و (60-70) باستخدام الطرق التقليدية و طريقة (Superpave) لحساب تدرج الاداء لكل نوع وتقييم مدى ملائمة هذين النوعين لكل منطقة.لقد بينت النتائج بان كلا الطريقتين (الطريقة المقترحة وطريقة Superpave) قد اعطت اقيام متماثلة لتدرج الاداء، الاسفلت السمنتي ذو اختراق (40-50) يكافي تدرج اداء PG70-16 والاسفلت السمنتي ذو اختراق (60-70) يكافي تدرج اداء PG64-16.

INTRODUCTION

Currently, the local specification for asphalt concrete paving works states two methods for asphalt cements grading, either based on viscosity or penetration of original asphalt. The two methods describe the physical properties of asphalt cements at standard test temperatures employing empirical means of testing which can not be related to field performance during service life. Another drawback of the above grading system is that long-term asphalt aging is not taken into consideration. The tests are performed on unaged or “tank” asphalt and on artificially short-term aged asphalt to simulate construction aging. No tests are performed to simulate in-service aging, which occurs when the asphalt reacts with the oxygen in the atmosphere by oxidation. Also, the current grading systems do not cover the temperature extremes that a pavement endures, binders that produce similar results at the temperatures used for penetration and viscosity testing may have very different results at other temperatures experienced by the pavement.

Since 1993, a new system for specifying asphalt materials and mix design have been developed in USA and widely used in the world, this system called Superpave (Superior Performing Asphalt Pavements). The Superpave performance grading (PG) for binder was developed to address the shortcomings of the previous asphalt grading systems. PG is reported using two numbers – the first being the average seven-day maximum pavement temperature (in °C) and the second being the minimum pavement design temperature likely to be experienced (in °C). Thus, a PG 64-16 is intended for use where the average seven-day maximum pavement temperature is 64°C and the expected minimum pavement temperature is -16°C.

The direct implementation of the Superpave approach required a direct measurement of the performance-related properties such as complex shear modules (G*) and phase angle (δ). In this approach, expensive and complex equipment are required, which is apparently out of reach of many pavement researchers and road laboratories at this time in Iraq as well as many other developing and developed countries. The best alternative to address the lack of reliable specification dose not keep the traditional testing specifications, but rather implementing components of performance grading that is attainable and less expensive. The concept of indirectly estimated performance-related properties based on available nomographs from literature could be used. That is to say, establishing a performance-grading framework in which grades are truly selected based on application conditions including pavement temperature and traffic. The criteria for accepting bitumen in such PG framework could be based on engineering properties which are performance related but derived from simple index properties such as penetration, softening point, or viscosity.

Although, the PG system has been adopted by the ASTM as well as AASHTO since 1999, it’s not yet implemented in Iraq to evaluate the currently used asphalt cements for paving works.

REVIEW OF LITERATURE

At present, there is no attempt existed or presented in the local literature dealing with implementation of Superpave performance grading requirements for local asphalt cements, therefore the review presented herein is limited to the foreign literatures.

According to Superpave requirements, Al-Abdul Wahhab et al. (1997) have evaluated different types of asphalt cements produced from the oil refineries in the Arabian Gulf countries. They found that the maximum pavement temperatures which can these types of asphalt cements sustain is 64°C while the temperature zoning indicated that more than 50 percent of the Gulf countries areas experience a maximum pavement temperature of 76°C. Therefore, The researchers suggest to modifiers for the asphalt binders in order to meet Gulf countries performance requirements in arid areas.

Asi (2007) tested the locally produced asphalt in Jordan with penetration grade 60-70. He found that the asphalt with this penetration grade is equivalent a performance grade PG64-16. He also developed a temperature zoning map for Jordan as shown in **Figure (1)**. It consists of three grade zones, PG64-10, PG64-16 and PG70-10. He conducted that the locally produced asphalt can be used without the need for modification in all parts of Jordan except Aqaba, Ruwaishied and Ghorsafi.

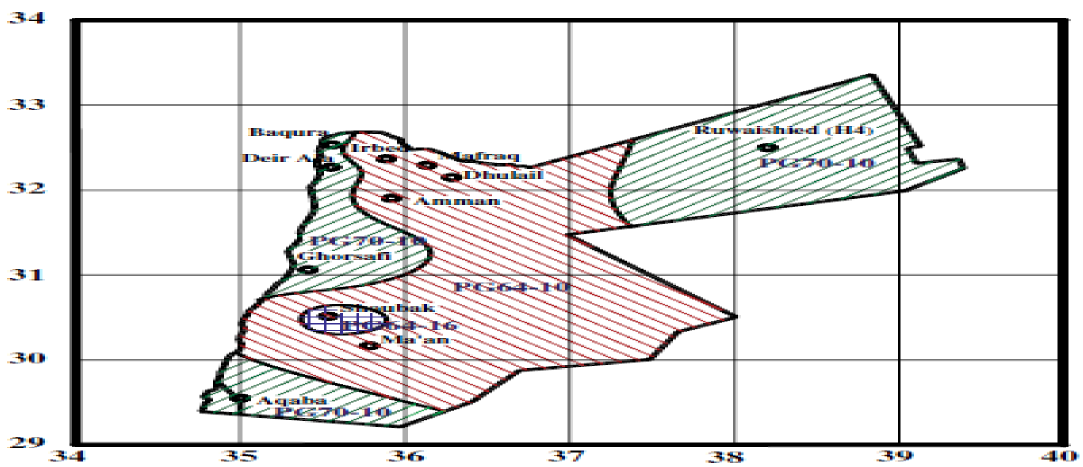

Figure (1) Jordan Temperature Zoning for Asphalt Binder (Asi ,2007)

The best alternative to address the lack of reliable specification dose not keep the traditional testing specifications, but rather implement components of performance grading that is attainable and less expensive. The concept of indirectly estimated performance- related properties based on available nonmograph from literature could be used. The first attempt for using this concept was made by van de Ven et al. (2004) in South Africa. They establishing a performance-grading framework in which grades are truly selected based on "application conditions" including pavement temperature and traffic. While the criteria for accepting bitumen in such PG framework could be based on engineering properties which are performance related but derived from simple index properties such as penetration, softening point or viscosity. Finally, the second attempt was made by Bahia and Vivanco (2005). They applied this concept to formulate PG specification in Chile.

THE BASIC PRINCIPLES OF PERFORMANCE GRADING SYSTEM

Performance grading could be defined as "a system in which fundamental mechanical properties that are related to pavement performance are used to select binders to minimize critical failures at critical conditions of pavement temperatures and traffic characteristics." The fundamental properties could be measured directly, but if not possible, could be derived numerically. The three basic elements for a performance grading system could therefore be listed as follows:

- It should be based on bitumen specific constitutive models. In others words, models describing stress-strain relationship under loading conditions experience in the field and that leads to failures.

- It should include the pavements` conditions as defined by temperature, traffic speed and traffic volume. It should also consider pavement structure in the sense that stresses and strains used in testing are within realistic ranges seen in pavements.
- It should include acceptance limits derived from experience and documented field performance to reduce, if not eliminate, initiating and progression of damage due to thermal or mechanical loading.

To achieve the first element, without direct measurements, it is necessary to define the model that can be used for getting the bitumen constitutive relationships based on Penetration and Softening Point. One of the well known alternatives is the Van der Poel nomograph (1954), (**Figure 2**), in which the creep stiffness can be estimated for a wide temperature range and loading times using Penetration Index (PI) which can be calculated by using the following equation:

$$PI=20-500A/ (1+50A) \qquad \text{equ. (1)}$$

Where:
PI = Penetration Index
A = Slop of the straight line plot between the logarithm of penetration and temperature, or

$$A=\log (\text{pen at } 25^0C) - \log 800 / (25- T_{R\&B}) \qquad \text{equ. (2)}$$

Where:
$T_{R\&B}$ = Ring and Ball softening point in ^0C

Although the nomograph is empirically derived, it is based on measuring the fundamental properties of a very large number of asphalts. In addition to the creep stiffness, failure properties are required. To estimate fatigue properties, a nomograph published by Shell (1978), (**Figure 3)**, for estimating the fatigue life of mixtures from PI of bitumen and mixture stiffness, can be used. To control brittleness of asphalt binders at minimum pavement temperature, the elongation at break estimated from chart developed by Heukelom (1973), (**Figure 4**), can be used. These three nomographs are numerical tools that can be used as initial substitutes to the dynamic shear rheometer, the bending beam rheometer, and the direct tension test, which are the main devices in the Superpave system and that are out of reach of many pavement technologists around the world.

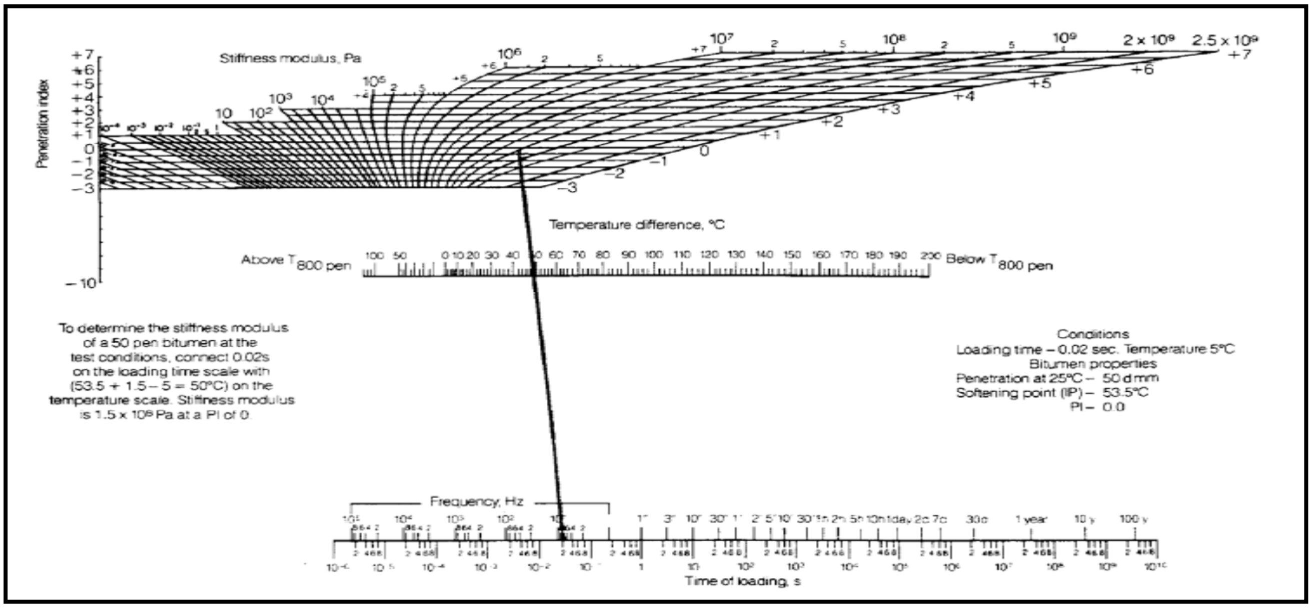

Figure (2) Creep Stiffness Nomograph (Van der Poel, 1954)

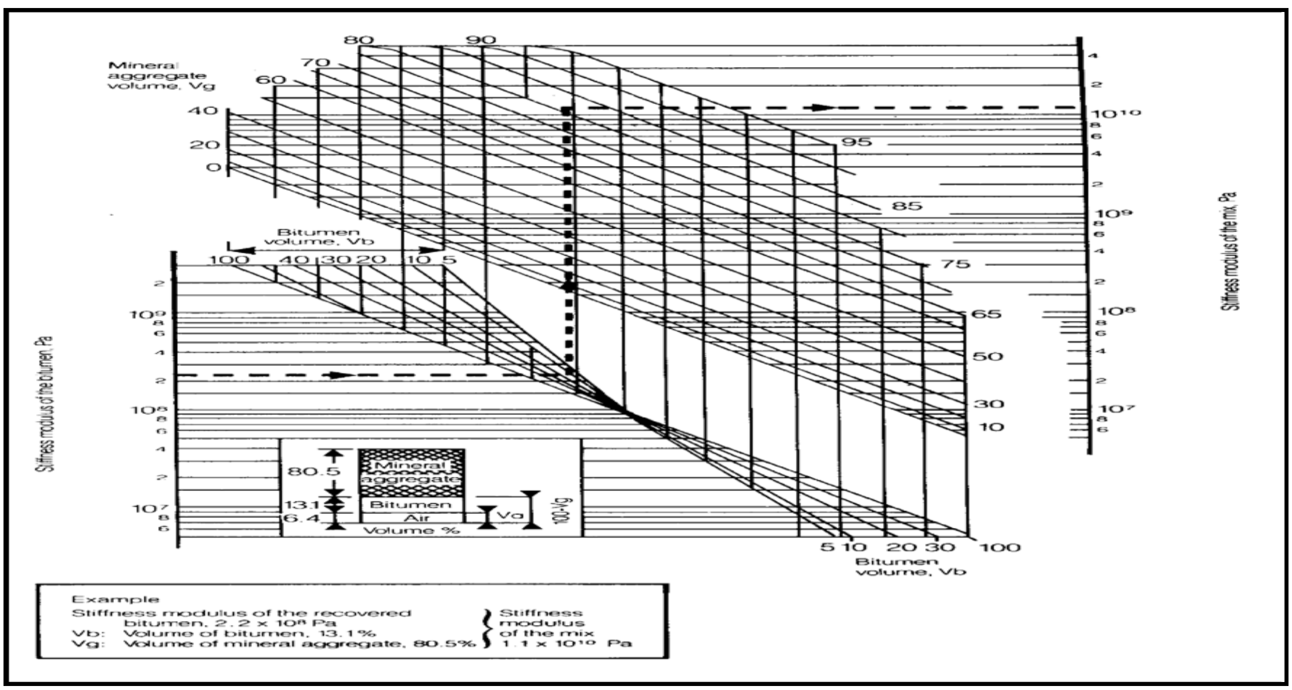

Figure (3) Nomograph for Stiffness Modulus of Mixes (Shell, 1978)

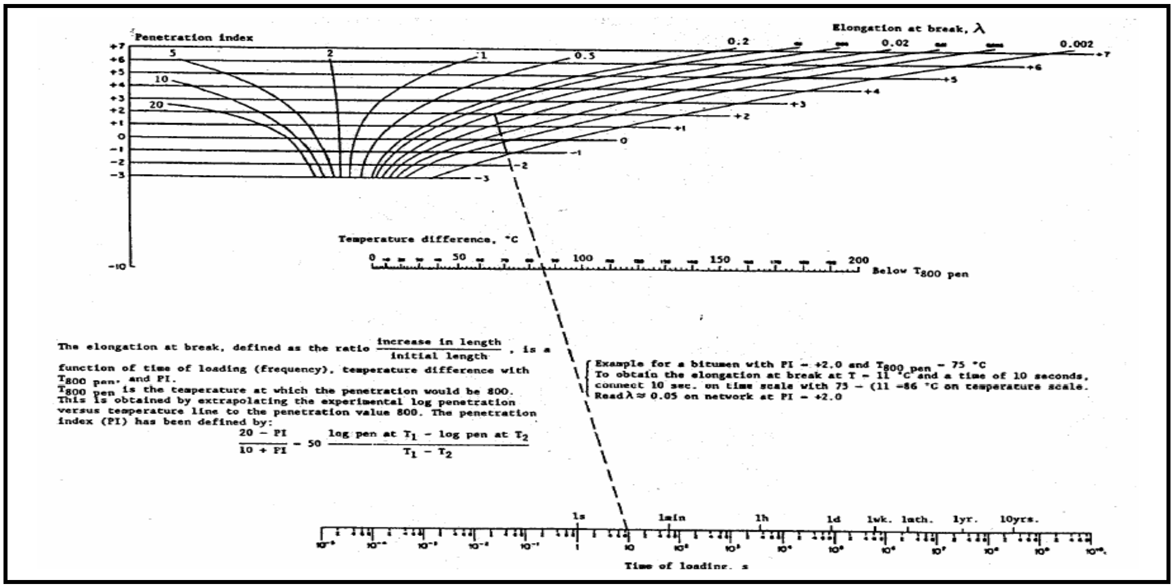

Figure (4) Estimating Elongation at Break (Heukelom, 1973)

To achieve the second element of performance grading system, the distribution of pavement temperature in various climatic conditions is necessary. These include the maximum and the minimum pavement design temperature, which can be based on weather data available from Iraqi Metrological Organization. These temperatures can be used to define the Performance Grades required for various regions in the country.

The air temperature data from the Iraqi Metrological Organization used in this research cover 18 years time period (1985-2002) for five Iraqi cities (Mosul, Kirkuk, Rutba, Baghdad and Basrah). Which represent climatically unique regions in Iraq. At each year, the hottest seven-day period is identified and the average maximum air temperature for this seven-day period was calculated and then based on 18 years a mean and standard deviation are determined. Similarly, the one-day minimum air temperature of each year was identified and the mean and standard deviation are calculated. The calculated mean and standard deviation for the five regions of Iraq are presented in **Table (1)** below**.** The latitude value for Mosul, Kirkuk, Rutba, Baghdad, Basrah, is 36.32, 35.47, 33.03, 33.23, 30.57 respectively (Iraq Metrological Organization, 1989)

Table (1) Mean and Standard Deviation for Maximum and Minimum Air Temperature

Region	Maximum Air Temperature °C		Minimum Air Temperature °C	
	Mean	Standard Deviation	Mean	Standard Deviation
Mosule	45.149	1.982	-2.5	3.8
Kirkuk	45.663	1.969	-0.5	5.4
Rutba	41.6	0.962	-2.6	3.7
Baghdad	47.5	1.077	-2.8	1.8
Basrah	48.594	1.103	1.8	1.8

Based on 98 percent reliability, temperatures can be determined based on the standard deviations for the high and low air temperature data. From statistics, 98 percent reliability is approximately two standard deviations from the mean value. The data presented in **Table (2)** shows the high and low air temperatures for 98 percent reliability level for the five regions of Iraq.

Table (2) High and Low Air Temperature for 98% Reliability level

Region	High Air Temperature ^{0}C	Low Air Temperature ^{0}C
Mosul	49	- 11
Kirkuk	50	- 12
Rutba	43	- 11
Baghdad	50	- 6
Basrah	51	- 2

These temperatures converted to pavement temperatures based on 98% reliability level. In Superpave, the high pavement design temperature at a depth of 20mm is computed by the following equation (SHRP, 1994)

$$T_{20mm}= 0.9545\ [T_{air} – 0.00618\ lat^2 + 0.2289\ lat + 42.2] – 17.78 \qquad \text{equ.(3)}$$

Where:

T_{20mm} = high pavement design temperature at a depth of 20 mm in °C.

T_{air} = seven- day 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. This method was originally recommended by SHRP researchers. **Table (3)** shows the maximum and minimum pavement temperature for the regions under consideration.

Table (3) Maximum and Minimum Pavement Temperature

Region	Maximum Pavement Temperature ^{0}C	Minimum Pavement Temperature ^{0}C
Mosul	70	-11
Kirkuk	70	-12
Rutba	64	-11
Baghdad	70	-6
Basrah	73	-2

The required PG for each city was established based on 6 ^{0}C increments. **Table (4**) shows the standard grades presented in the SHRP binder specification (Asphalt Institute, 2003). Therefore, based on this table and the results obtained from the analysis of pavement temperature, the suggested PG grade of asphalt cements for paving works within the five regions of Iraq is as that presented in **Figure (5)**.

Table (4) Superpave Binder Performance Grades (Asphalt Institute 2003)

	High Temperature Grade	Low Temperature Grade
PG	46	-34, -40, -46
PG	52	-10, -16, -22, -28, -34, -40, -46
PG	58	-16, -22, -28, -34, -40
PG	64	-10, -16, -22, -28, -34, -40
PG	70	-10, -16, -22, -28, -34, -40
PG	76	-10, -16, -22, -28, -34
PG	82	-10, -16, -22, -28,-34

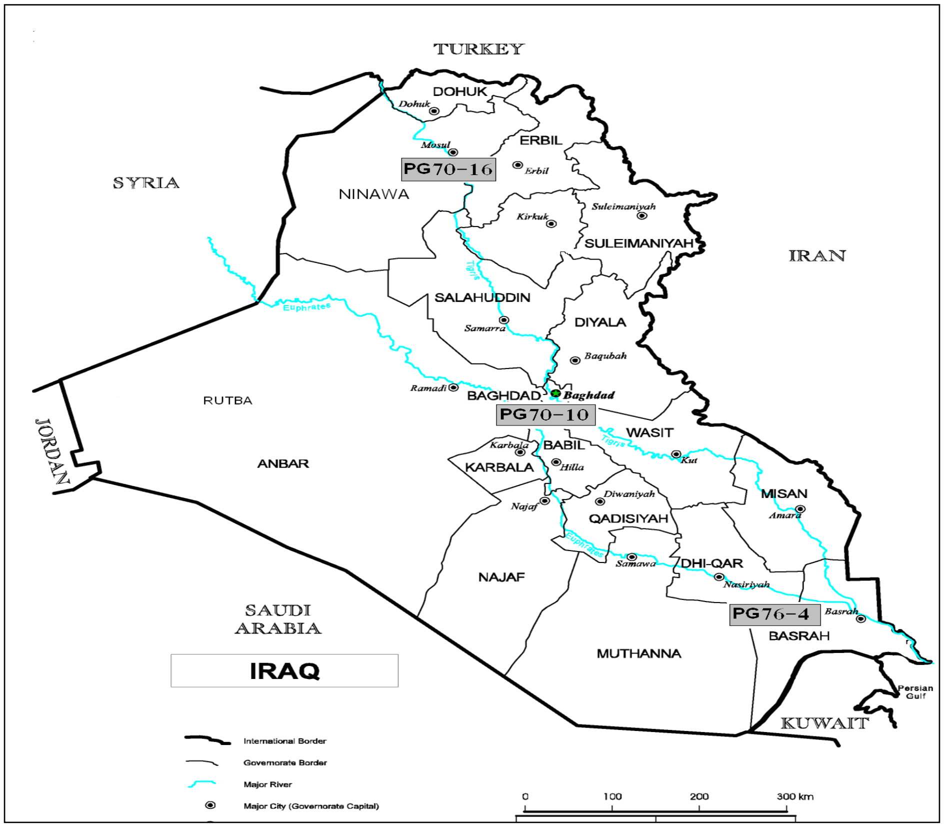

Figure (5) Temperature Zoning Map for PG Requirement in Iraq

To achieve the third element of a performance grading system, the performance related properties should be selected and the acceptable limits of asphalt cement should be defined. To estimate these limits, the conventional testing results (penetration and softening point) from previous studies for different asphalt types in Iraq can be used, these data are shown in **Table (5)**. The following sections explain how the properties and their limits were selected.

Table (5) Penetration and Softening Point Data

	Penetration 25 C^0	Softening point C^0	Source of Data
Pen 40/50			
A1	42	51	Albayati, A.H. (2006)
A2	47	49	Namir,G.A. (2002)
A3	45	52	Zaid,I. (2006)
A4	49	48	Abbas, F. (2005)
A5	47	49	Nahla, Y.A. (2005)
A6	42	49	Ahlam, K.R. (2007)
A7	43	54	Hanaa, K. (2004)
A8	42	51	Alazawy, A.M. (2006)
A9	43	48.5	Alekaby,K.H. (2005)
A10	45	52	Alaredi,H.A. (2006)
Pen 60/70			
B1	66	46.5	Alani, H.M.(1986)
B2	67	45	Albayati, A.H. (2006)
B3	67	47	Hanaa, K. (2004)
B4	69	45	Safar, M.M.(1992)
B5	62	46	Shakir, S. (1999)
B6	67	49.5	Taher, M. (1999)
B7	65	46	Asal, F.N. (2007)
B8	67	49.5	Magd Aldeen,A. (2003)
B9	63	45.5	Almudhadi, T.H.(2007)
B10	67	48.5	Aljumily, M.A. (2007)

- **For Workability**, The viscosity at 135ºC can be used. In performance specifications, the limits should remain the same for all grades since the contractors are expected to use the same heating and storage temperatures regardless of the binder source or grade, and regardless of pavement conditions. A range of 0.12 – 0.65 Pa.s, can be used which is based on the current specifications used in Chile (Bahia and Vivanco ,2005). The range is a better property than the maximum used in the current Superpave specifications. The minimum limit will control drain down and the maximum will ensure proper workability.

- **For Rutting Resistance**, It is proposed to use penetration and softening point to calculate the Penetration Index (PI) for the grades used currently in Iraq. The PI values are used for calculating the creep Stiffness at speed of traffic normally seen in the field by using the Van der Poel nomograph **(Figure 2)**. For a typical speed of 80 km/hr, and a pavement surface layer thickness of 20 mm, the loading time is estimated at 0.012 seconds based on **Figure (6).** To estimate an acceptable specification limit for rutting, the data in **Table (5)** can be used. The values of the PI's for such asphalts were calculated by using the equation (1), and used to estimate creep stiffness values from the Van der Poel nomograph. A loading time of 0.012 seconds, and the temperature of 64, 70 and 76ºC, which represent local performance grade, were used for all these asphalt cements. The results are shown in **Table (6).** Experience had to be used to derive acceptable limits for a PG framework. According to road engineers in Iraq it seems that the penetration grade of (40-50) has worked well for moderate traffic volume roads in moderate climate. The average results in **Table (6)** indicate that if the PG76 grade is a reasonable performance grade within which these binders should fit, then the estimated average stiffness value S(0.012) is >= 9 kPa for the unaged condition.It can therefore be assumed that for an asphalt to provide sufficient contribution to rutting resistance, the value of S(0.012), at maximum pavement design temperature, should be equal to or greater than 9 kPa. In other words, for other grades (PG64 and PG70) this stiffness minimum value should be met at 64 ºC and 70ºC respectively. Based on experience with RTFO aging the increase in G* values ranges between 1.8 and 2.5 times the unaged value (Bahia and Vivanco 2005). As a compromise between the high and low range mentioned, aged requirement after RTFO that is 2.5 times the unaged condition, which results in a limit for S(0.012) of greater than or equal to 22.5 kPa, should be used. This limit is based on the average estimated values that are shown in **Table (7)**.

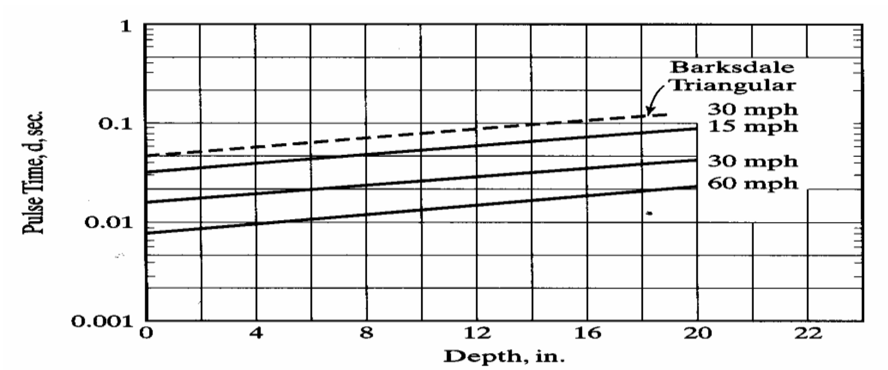

Figure (6) Speed-Loading Time Relationship (McLean, 1974)

Table (6) Asphalt Binder Stiffness at High Pavement Temperatures (Original Binders)

T=64 ^0C			
	T_{DIFF} ^0C	PI	S (N/M^2)
Pen 40/50			
A1	-13	-1.25	$3.5*10^4$
A2	-15	-1.477	$2*10^4$
A3	-14	-1.411	$3.5*10^4$
A4	-14	-1.253	$3*10^4$
A5	-15	-1.563	$2*10^4$
A6	-15	-1.689	$1.9*10^4$
A7	-10	-0.58	$4*10^4$
A8	-13	-1.321	$2.5*10^4$
A9	-15.5	-1.891	$2*10^4$
A10	-12	-0.94	$2*10^4$
Average Binder Stiffness			$2.64*10^4$
Pen 60/70			
B1	-17.5	-1.477	$3*10^4$
B2	-19	-1.89	$2*10^4$
B3	-17	-1.253	$2.5*10^4$
B4	-19	-1.792	$2.5*10^4$
B5	-18	-1.751	$3*10^4$
B6	-14.5	-0.613	$5*10^4$
B7	-18	-1.648	$2.8*10^4$
B8	-14.5	-0.613	$5*10^4$
B9	-18.5	-1.87	$3*10^4$
B10	-15.5	-0.87	$5.5*10^4$
Average Binder Stiffness			$3.4*10^4$

T=70 ^0C			
	T_{DIFF} ^0C	PI	S (N/M^2)
Pen 40/50			
A1	-19	-1.25	$2*10^4$
A2	-21	-1.477	$1.5*10^4$
A3	-20	-1.411	$1*10^4$
A4	-20	-1.253	$1.5*10^4$
A5	-21	-1.563	$2*10^4$
A6	-21	-1.689	$1.5*10^4$
A7	-16	-0.58	$2.5*10^4$
A8	-19	-1.321	$2*10^4$
A9	-21.5	-1.891	$1*10^4$
A10	-18	-0.94	$2*10^4$
Average Binder Stiffness			$1.67*10^4$
Pen 60/70			
B1	-23.5	-1.477	$2*10^4$
B2	-25	-1.89	$8*10^3$
B3	-23	-1.253	$1*10^4$
B4	-25	-1.792	$5*10^3$
B5	-24	-1.751	$1*10^4$
B6	-20.5	-0.613	$1.5*10^4$
B7	-24	-1.648	$8*10^3$
B8	-20.5	-0.613	$1.5*10^4$
B9	-24.5	-1.87	$5*10^3$
B10	-21.5	-0.87	$1*10^4$
Average Binder Stiffness			$1*10^4$

T=76 ^0C			
	T_{DIFF} ^0C	PI	S (N/M^2)
Pen 40/50			
A1	-25	-1.25	$6*10^3$
A2	-27	-1.477	$1*10^4$
A3	-26	-1.411	$9*10^3$
A4	-26	-1.253	$7*10^3$
A5	-27	-1.563	$2*10^4$
A6	-27	-0.689	$1*10^4$
A7	-22	-0.58	$1.2*10^4$
A8	-25	-1.321	$1.3*10^4$
A9	-27.5	-1.891	$7*10^3$
A10	-24	-0.94	$1.1*10^4$
Average Binder Stiffness			$9*10^3$
Pen 60/70			
B1	-29.5	-1.477	$5*10^3$
B2	-31	-1.89	$4*10^3$
B3	-29	-1.253	$8*10^3$
B4	-31	-1.792	$4*10^3$
B5	-30	-1.751	$4.5*10^3$
B6	-26.5	-0.613	$5*10^3$
B7	-30	-1.648	$4*10^3$
B8	-26.5	-0.613	$5*10^3$
B9	-30.5	-1.87	$4*10^3$
B10	-27.5	-0.87	$6*10^3$
Average Binder Stiffness			$4.95*10^3$

Table (7) Average Results for Asphalt Binder Stiffness at High Pavement Temperatures

	S(kpa) (Time of loading =0.012 sec)					
	64(^{0}C)		70(^{0}C)		76(^{0}C)	
	Original	Aged	Original	Aged	Original	Aged
Pen 40/50						
A1	35	87.5	20	50	6	15
A2	20	50	15	37.5	10	25
A3	35	87.5	10	25	9	22.5
A4	30	75	15	37.5	7	17.5
A5	20	50	20	50	10	25
A6	19	47.5	12	30	12	30
A7	40	100	25	62.5	13	32.5
A8	25	62.5	20	50	7	17.5
A9	20	50	10	25	5	12.5
A10	20	50	20	50	11	27.5
Average	26.5	66	16.7	41.75	9	22.5
Pen 60/70						
B1	20	50	20	50	5	12.5
B2	10	25	8	20	4	10
B3	20	50	10	25	8	20
B4	15	37.5	5	12.5	4	10
B5	20	50	10	25	4.5	11.25
B6	40	100	15	37.5	5	12.5
B7	18	45	8	20	4	10
B8	40	100	15	37.5	5	12.5
B9	20	50	5	12.5	4	10
B10	45	112.5	10	25	6	15
Average	24.8	62	10.6	26.5	4.95	12.37

- **For Fatigue Resistance**, To derive binder stiffness limits for fatigue, the nomograph published by Shell that shown in **Figure(3),** for estimating the fatigue life of mixtures from PI of binder and mixture stiffness can be used in a back calculation method. It is assumed that in a typical pavement structure strain levels of $1.0 * 10^{-4}$ mm/mm for stress controlled conditions and $5.0 * 10^{-4}$ mm/mm for strain controlled conditions are acceptable values that could be used. Specifying a minimum fatigue life of $1.0 * 10^{6}$ cycles, the mixture stiffness required to achieve this fatigue life is estimated at $7 * 10^{8}$ Pa. Using PI values and assuming a volume concentration of 13% binder in a typical asphalt mixture, the maximum allowable bitumen stiffness at 0.012 seconds loading time should be 50000 kPa. In this approximation it was assumed that PAV aging results in increasing the softening point by 20ºC for grades tested and to insure proper application of this change, the PI value for each binder was increased by 0.75 points. By using Van der Poel nomograph the values shown in **Table (8)** could be obtained. based on penetration 40-50 and PG76-4 with intermediate grade temperature 40^{0}C, a maximum limit of 50000 kpa could be also derived for fatigue resistance.

Table (8) Asphalt Binder Stiffness at Intermediate Pavement Temperatures

T=28 ^{0}C			
	T_{DIFF} ^{0}C	**PI**	**S (N/M^2)**
Pen 40/50			
A1	43	-0.5	$9*10^7$
A2	41	-0.727	$9*10^7$
A3	42	-0.661	$1*10^8$
A4	42	-0.503	$7*10^7$
A5	41	-0.813	$1*10^8$
A6	41	-0.939	$1.2*10^8$
A7	46	0.17	$8*10^7$
A8	43	-0.517	$9*10^7$
A9	40.5	-1.14	$1*10^8$
A10	44	-0.19	$6*10^7$
Average Binder Stiffness			$9*10^7$
Pen 60/70			
B1	35.5	-0.727	$7*10^7$
B2	34	-1.14	$6*10^7$
B3	36	-0.503	$5*10^7$
B4	34	-1.042	$5*10^7$
B5	35	-1.00	$5.5*10^7$
B6	38.5	0.137	$4.8*10^7$
B7	35	-0.898	$3*10^7$
B8	38.5	0.137	$4.8*10^7$
B9	34.5	-1.12	$8*10^7$
B10	37.5	-0.12	$5*10^7$
Average Binder Stiffness			$5.4*10^7$

T=31 ^{0}C			
	T_{DIFF} ^{0}C	**PI**	**S (N/M^2)**
Pen 40/50			
A1	40	-0.5	$1.3*10^8$
A2	38	-0.727	$1*10^8$
A3	39	-0.661	$9 *10^7$
A4	39	-0.503	$7*10^7$
A5	38	-0.813	$1*10^8$
A6	38	-0.939	$1.2*10^8$
A7	43	0.17	$2*10^7$
A8	40	-0.517	$5*10^7$
A9	37.5	-1.14	$5*10^7$
A10	41	-0.19	$4*10^7$
Average Binder Stiffness			$7.7*10^7$
Pen 60/70			
B1	35.5	-0.727	$4*10^7$
B2	34	-1.14	$4*10^7$
B3	36	-0.503	$4.5*10^7$
B4	34	-1.042	$5*10^7$
B5	35	-1.00	$5.8*10^7$
B6	38.5	0.137	$4.5*10^7$
B7	35	-0.898	$5.5*10^7$
B8	38.5	0.137	$4.5*10^7$
B9	34.5	-1.12	$6*10^7$
B10	37.5	-0.12	$3*10^7$
Average Binder Stiffness			$4.68*10^7$

T=34 ^{0}C			
	T_{DIFF} ^{0}C	**PI**	**S (N/M^2)**
Pen 40/50			
A1	37	-0.5	$7*10^7$
A2	35	-0.727	$6*10^7$
A3	36	-0.661	$12*10^7$
A4	36	-0.503	$6*10^7$
A5	35	-0.813	$7.5*10^7$
A6	35	-0.939	$7.5*10^7$
A7	40	0.17	$7*10^7$
A8	37	-0.517	$5*10^7$
A9	34,5	-1.14	$1*10^8$
A10	38	-0.19	$5*10^7$
Average Binder Stiffness			$6.4*10^7$
Pen 60/70			
B1	32.5	-0.727	$4*10^7$
B2	31	-1.14	$5*10^7$
B3	33	-0.503	$5*10^7$
B4	31	-1.042	$5*10^7$
B5	32	-1.00	$4.5*10^7$
B6	35.5	0.137	$3*10^7$
B7	32	-0.898	$4*10^7$
B8	35.5	0.137	$3*10^7$
B9	31.5	-1.12	$2.5*10^7$
B10	34.5	-0.12	$2.3*10^7$
Average Binder Stiffness			$3.8*10^7$

T=40 ^{0}C			
	T_{DIFF} ^{0}C	**PI**	**S (N/M^2)**
Pen 40/50			
A1	31	-0.5	$5*10^7$
A2	29	-0.727	$4*10^7$
A3	30	-0.661	$5.5*10^7$
A4	30	-0.503	$4*10^7$
A5	29	-0.813	$5*10^7$
A6	29	-0.939	$6*10^7$
A7	34	0.17	$5*10^7$
A8	31	-0.517	$5.5*10^7$
A9	28.5	-1.14	$6*10^7$
A10	32	-0.19	$4*10^7$
Average Binder Stiffness			$5*10^7$
Pen 60/70			
B1	26.5	-0.727	$1*10^7$
B2	25	-1.14	$1.5*10^7$
B3	27	-0.503	$1*10^7$
B4	25	-1.042	$2*10^7$
B5	26	-1.00	$1.8*10^7$
B6	29.5	0.137	$1*10^7$
B7	26	-0.898	$1.9*10^7$
B8	29.5	0.137	$1*10^7$
B9	25.5	-1.12	$1.8*10^7$
B10	28.5	-0.12	$1*10^7$
Average Binder Stiffness			$1.4*10^7$

- **or Thermal Resistance,** The main approach used in Superpave specification is followed for this type of pavement failure. The stiffness at 60 seconds loading time, at temperatures 10ºC higher than the minimum grade temperature, was estimated for both penetration grades (40-50) and (60-70). The shift in temperature is used to offset the effect of short loading time of 60 seconds compared to the loading time of a cooling cycle in the field, as used in the Superpave specifications. Also, the logarithmic creep rate (m (60)) should also be controlled. **Table (9)** shows the creep stiffness (S (60)) and creep rate (m (60)) at 6 ºC, 0 ºC and -6 ºC respectively. Using the properties of the penetration (60-70) and assuming that the bitumens of this grade performed well in cold climates in Iraq, the limits of S(60)=347000 kpa and m(60)=0.349 could be derived. Similar to the fatigue requirement the effect of long-term aging was considered by increasing the softening point by 20 ºC and PI increased by 0.75. To control brittleness of bitumen at minimum pavement temperature, the elongation at break (λ) from nomograph developed by Heukelom (shown in **Figure (4)**) could be used. The minimum strain at break should be more than 0.02 estimated by using a 60 second loading time and softening point of the PAV aged material (increasing softening point by 20 ºC and PI increased by 0.75).

Table (9) Asphalt Binder Stiffness at Low Pavement Temperatures

T= 6 ^{0}C						
	T_{DIFF} (^{0}C)	PI	S(N/M^2) (t=30sec)	S(N/M^2) (t=60sec)	m (60sec)	λ (60sec)
Pen 40/50						
A1	65	-0.5	$8*10^7$	$6*10^7$	0.415	0.059
A2	63	0.727	$9*10^7$	$7*10^7$	0.362	0.4
A3	64	-0.661	$1*10^8$	$7*10^7$	0.514	0.1
A4	64	-0.503	$9*10^7$	$6*10^7$	0.584	0.1
A5	63	-0.813	$1.5*10^8$	$1*10^8$	0.584	0.42
A6	63	-0.939	$1.5*10^8$	$1.2*10^8$	0.323	0.43
A7	68	0.17	$9*10^8$	$6*10^7$	0.584	0.1
A8	65	-0.517	$9*10^7$	$7*10^7$	0.584	0.05
A9	62.5	-1.141	$1*10^8$	$7*10^7$	0.514	0.02
A10	66	-0.19	$7*10^7$	$5*10^7$	0.485	0.1
Average				$7.3*10^7$	0.494	0.177
Pen 60/70						
B1	60.5	-0.727	$6*10^7$	$4*10^7$	0.585	0.1
B2	59	-1.14	$6*10^7$	$5*10^7$	0.678	0.15
B3	61	-0.503	$5*10^7$	$3.5*10^9$	0.514	0.18
B4	59	-1.042	$6*10^7$	$4.5*10^7$	0.415	0.2
B5	60	-1.00	$8*10^7$	$6*10^7$	0.415	0.2
B6	63.5	0.137	$5*10^7$	$3.5*10^7$	0.514	0.15
B7	60	-0.898	$6*10^7$	$4*10^7$	0.585	0.1
B8	63.5	0.137	$5*10^7$	$3.5*10^7$	0.514	0.15
B9	59.5	-1.12	$6*10^7$	$5*10^7$	0.687	0.21
B10	62.5	-0.12	$2.7*10^7$	$2*10^7$	0.432	0.1
Average				$4.1*10^7$	0.533	0.154

Table (9) Continued

T= 0 ^{0}C						
	T_{DIFF}(^{0}C)	PI	S(N/M^2) (t=30sec)	S(N/M^2) (t=60sec)	m (60sec)	λ (60sec)
Pen 40/50						
A1	71	-0.5	$2*10^8$	$1.5*10^8$	0.415	0.04
A2	69	0.727	$3*10^8$	$2*10^8$	0.321	0.22

A3	70	-0.661	$3*10^8$	$2*10^8$	0.321	0.1
A4	70	-0.503	$2*10^8$	$1.5*10^8$	0.415	0.1
A5	69	-0.813	$3*10^8$	$2*10^8$	0.585	0.2
A6	69	-0.939	$4.2*10^8$	$3*10^8$	0.585	0.2
A7	74	0.17	$1.5*10^8$	$1.3*10^8$	0.206	0.05
A8	71	-0.517	$2*10^8$	$1.5*10^8$	0.415	0.04
A9	68.5	-1.141	$3*10^8$	$2*10^8$	0.585	0.03
A10	72	-0.19	$1.5*10^8$	$1*10^8$	0.585	0.05
Average				$1.78*10^8$	0.443	0.103
Pen 60/70						
B1	66.5	-0.727	$1.5*10^8$	$1*10^8$	0.585	0.05
B2	65	-1.14	$2*10^8$	$1.5*10^8$	0.415	0.01
B3	67	-0.503	$1*10^9$	$8*10^7$	0.321	0.05
B4	65	-1.042	$1.6*10^8$	$1*10^8$	0.678	0.05
B5	66	-1.00	$1.5*10^8$	$1*10^8$	0.585	0.049
B6	69.5	0.137	$9*10^7$	$7*10^7$	0.362	0.075
B7	66	-0.898	$1.4*10^8$	$1*10^8$	0.485	0.048
B8	69.5	0.137	$1.5*10^8$	$1*10^8$	0.585	0.075
B9	65.5	-1.12	$2.5*10^8$	$1.8*10^8$	0.437	0.05
B10	68.5	-0.12	$8.5*10^8$	$6*10^7$	0.502	0.1
Average				$1.04*10^8$	0.495	0.0557

T= - 6 ^{0}C						
	T_{DIFF} (^{0}C)	PI	S(N/M^2) (t=30sec)	S(N/M^2) (t=60sec)	m (60sec)	λ (60sec)
Pen 40/50						
A1	77	-0.5	$3.5*10^8$	$3*10^8$	0.222	0.01
A2	75	0.727	$6*10^8$	$5*10^8$	0.263	0.048
A3	76	-0.661	$7.5*10^8$	$5*10^8$	0.585	0.015
A4	76	-0.503	$4*10^8$	$3*10^8$	0.415	0.015
A5	75	-0.813	$8*10^8$	$6*10^8$	0.415	0.049
A6	75	-0.939	$8*10^8$	$6*10^8$	0.415	0.01
A7	80	0.17	$4*10^8$	$2.9*10^8$	0.463	0.02
A8	77	-0.517	$3.8*10^8$	$3*10^8$	0.341	0.055
A9	74.5	-1.141	$6*10^8$	$5*10^8$	0.263	0.023
A10	78	-0.19	$2.5*10^8$	$2*10^8$	0.321	0.059
Average				$4.0*10^8$	0.3703	0.0304
Pen 60/70						
B1	72.5	-0.727	$4.5*10^8$	$3.5*10^8$	0.362	0.02
B2	71	-1.14	$3.5*10^8$	$3*10^8$	0.285	0.01
B3	73	-0.503	$4*10^8$	$3*10^8$	0.533	0.02
B4	71	-1.042	$5.2*10^8$	$4*10^8$	0.486	0.012
B5	72	-1.00	$5*10^8$	$4*10^8$	0.413	0.05
B6	75.5	0.137	$3*10^8$	$2.4*10^8$	0.413	0.023
B7	72	-0.898	$5*10^8$	$4.2*10^8$	0.323	0.015
B8	75.5	0.137	$3.5*10^8$	$2.8*10^8$	0.413	0.021
B9	71.5	-1.12	$5.5*10^8$	$4.4*10^8$	0.413	0.01
B10	74.5	-0.12	$4*10^8$	$3.4*10^8$	0.301	0.02
Average				$3.47*10^8$	0.394	0.020

The results of the previous analyses are shown in **Table (10)**. The table shows proposed system of performance grades based on the concept of using the index properties to derive engineering criteria that are performance related.

Table (10) Proposed Performance Grading for Iraq

High Temperature Grade (HT)		PG64	PG70		PG76
Low Temperature Grade (LT)		-16	-16	-10	-4
Performance Related Property	**Performance Criteria**				
For Workability					
Viscosity (pa-s)	0.12- 0.65	135 ºC			
For Rutting Resistance					
Estimated Creep Stiffness (Unaged)@ HT (kpa)	S(0.012)>=9	64	70		76
Estimated Creep Stiffness (RTFO-Aged) (kpa)	S(0.012)>=22.5	64	70		76
For Fatigue Resistance					
Estimated Creep Stiffness (PAV-Aged) ,(kpa)	S(0.012)<=50000	28	31	34	40
For Thermal Cracking Resistance					
Estimated creep stiffness (PAV-Aged), (kpa)	S(60)<=347000	-6	-6	0	6
Estimated Creep Rate (PAV-Aged)	m(60) >= 0.349	-6	-6	0	6
Elongation at break (PAV-Aged)	λ(60) >=0.02	-6	-6	0	6

TESTING LOCAL ASPHALT CEMENT BY CONVENTIONAL METHODS AND VERIFICATION OF CONCEPT

Two asphalt types with penetration grade (40-50) and (60-70) are tested using the conventional test methods (penetration and softening point). Both asphalt types are obtained from Daurah refinery, south-west of Baghdad. The tests are conducted on asphalt before aging and after aging with the RTFO and PAV, the results are shown in **Table (11)**. From this table it appeared that, the change in the softening point is less than the 20 ºC that is assumed previously in the analysis used to develop a PG framework. Since PAV represents only moderate long term aging (5-10 years), it is considered acceptable to continue the increasing of the softening point by 20 ºC to represent long term aging. As for the change in PI, an increase by 0.75 points is assumed. This table also shows that the change in PI value for both asphalt does not appear possible. Although sample size is small, it appears that it is necessary to conduct a laboratory aging procedure that would simulate long term aging. A test such as the PAV could be used.

Penetration and softening point values before and after aging are used in the nomographs mentioned previously to calculate the stiffness values in order to estimate rutting resistance, fatigue resistance, and thermal resistance. **Table (12)** includes the values of the selected parameters used in the proposed specification including S(0.012) of the unaged, RTFO-aged asphalts and PAV aged binders. The S(60), m(60) and λ(60) of the PAV-aged asphalts. The parameters are shown for both asphalt types at various temperatures representing the temperature grades selected for Iraq. In the last column of **Table (12)**, the estimated grades of the binders are listed, which indicate that the asphalt with penetration grade 40-50 is equivalent to PG70-16 while that penetration grade 60-70 is equivalent to PG64-16.

In the **Table (12)** the PAV properties are also estimated using a standard shift of 20 ºC increase in softening point of the unaged binders, and a standard increase of 0.75 in the PI values calculated for the unaged binders. This was done to compare the effect of using standard shift versus the measured values after PAV aging. The results shown in the table under (Estimated PAV) significant discrepancy compared to the values of the measured (Tested PAV). The results confirm that it is required that a long term aging procedure be used in a PG grading system with and without expensive rheology equipment.

Table (11) Conventional Testing Results for Different Performance Stages

	Original Asphalt	Short Term Aging (RTFO)	Long Term Aging (PAV)	Difference Between PAV and Original Asphalt
Pen 40-50				
penetration	45	27.45	15	-30
Softening Point	50.5	55	67	16.5
Penetration Index(PI)	- 1.3	- 1.27	- 0.180	1.12
Pen 60-70				
penetration	63	40	22	-41
Softening Point	45.3	49	57	11.5
Penetration Index(PI)	- 1.89	- 1.913	- 1.275	0.615

Table (12) Asphalt Grades According to Proposed Performance Classification System

Rutting Resistance								
	Original				RTFO			
pen	S(kpa) (Time of loading =0.012sec)				S(kpa) (Time of loading =0.012 sec)			
	>=9 kpa				>=22.5 kpa			
	58 ºC	64 ºC	70 ºC	76 ºC	58 ºC	64 ºC	70 ºC	76 ºC
40-50	90	40	20	8	22.5	100	50	20
60-70	40	10	6	3.8	100	25	15	9.5

Fatigue Resistance					
Tested in PAV					
pen	S (kpa)(t=0.012sec)				
	<=50000 kpa				
	25ºC	28ºC	31ºC	34ºC	40ºC
40-50	71200	58452	40840	24220	20760
60-70	57900	42000	30450	20722	15530

	Thermal Resistance									Grade
	Tested in PAV									
Pen	S (MPa)(t =60 sec)			m (60)			λ (60)			
	<=347000			>= 0.349			>=0.02			
	6 ºC	0 ºC	-6 ºC	6 ºC	0 ºC	-6 ºC	6 ºC	0 ºC	-6 ºC	
40-50	65	101	295	0.591	0.534	0.552	0.19	0.12	0.04	PG 70-16
60-70	45	98	290	0.432	0.423	0.452	0.21	0.94	0.085	PG 64-16

Table (12) Continued

Fatigue Resistance					
Estimated PAV					
pen	S (kpa)(t=0.012sec)				
	<=50000 kpa				
	25ºC	28ºC	31ºC	34ºC	40ºC
40-50	80800	60100	43760	31630	25500
60-70	67400	49900	36500	26600	18000

	Thermal Resistance									Grade
	Estimated PAV									
Pen	S (MPa)(t =60 sec)			m (60)			λ (60)			
	<=347000			>= 0.349			>=0.02			
	6 ºC	0 ºC	-6 ºC	6 ºC	0 ºC	-6 ºC	6 ºC	0 ºC	-6 ºC	
40-50	70	120	305	0.585	0.514	0.450	0.1	0.05	0.035	PG 70-16
60-70	50	110	300	0.447	0.415	0.384	0.15	0.081	0.054	PG 64-16

SUPERPAVE PERFORMANCE GRADE (PG) TESTS

The same two types of asphalt cement with penetration grade (40-50) and (60-70) that have been tested conventional methods are also tested using Superpave approach. All Superpave tests have been performed in the Ministry of Transportation lab. of Saudi Arabia except the Rotational Viscometer test was performed in the University of Baghdad lab. 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" on original (unaged binder), Rolling Film Oven aged residue (i.e. Rolling Film Oven Test RTFOT) and Pressure Aging Vessel (PAV) residue. While, The PG grades of asphalt binder was determined according to AASHTO M320-05 "Standard Specification for Performance -Graded Asphalt Binder". The results of Superpave binder tests for asphalt cement with penetration grade (40-50) are shown in **Table (13)** whereas, for asphalt cement with (60-70) penetration grade are shown in **Table (14)**. It is obvious from these tables that the asphalt with penetration (40-50) is equivalent to PG70-16 while asphalt with penetration (60-70) is equivalent to PG64-16.

Table (13) Summary of Superpave Binder Test Results for Penetration (40-50)

Asphalt	Parameters	Specification M320 (AASHTO,2007)	Temperature Measured		Measured Parameters	Pass/ Fail
Original	Flash Point Temperature	230 °C, min.	-		320 °C	Pass
	Viscosity at 135 °C	3 pa.s, max.	-		0.516 pa.s	Pass
	DSR, G*/sinδ at 10 rad/s	1.00 Kpa, min.	**58**		4.2361 Kpa	Pass
			G*=4.2320	δ=87.5		
			64		2.0113 Kpa	Pass
			G*=2.0108	δ=88.8		
			70		1.0619 Kpa	Pass
			G*=1.0617	δ=89.2		
			76		0.5604 Kpa	Fail
			G*=0.5603	δ=89.7		
RTFO Aged	Mass Loss	1%, max.	-		0.446	Pass
	DSR, G*/sinδ at 10 rad/s	2.2 Kpa, min.	**58**		9.6342 Kpa	Pass
			G*=9.6118	δ=86.1		
			64		4.9117 Kpa	Pass
			G*=4.9062	δ=87.3		
			70		2.2655 Kpa	Pass
			G*=2.2646	δ=88.4		
			76		1.4025 Kpa	Fail
			G*=1.4023	δ=89.3		
PAV Aged	DSR, G*sinδ at 10 rad/s	5000 Kpa, max.	**31**		4270 Kpa	Pass
			G*=3548.3	δ=56.2		
	BBR, Creep Stiffness	300 Mpa, max.	**-6**		211.0Mpa	Pass
	BBR, m- value	0.3, min.	**-6**		0.334	Pass

Table (14) Summary of Superpave Binder Test Results for Penetration (60-70)

Asphalt	Parameters	Specification M320 (AASHTO,2007)	Temperature Measured		Measured Parameters	Pass/ Fail
Original	Flash Point Temperature	230 °C, min.	-		310 °C	Pass
	Viscosity at 135 °C	3 pa.s, max.	-		0.400 pa.s	Pass
	DSR, G*/sinδ at 10 rad/s	1.00 Kpa, min.	**58**		2.1516 Kpa	Pass
			G*=2.1506	δ=88.3		
			64		1.0603 Kpa	Pass
			G*=1.0601	δ=89.0		
			70		0.5286 Kpa	Fail
			G*=0.5285	δ=89.5		
			76		0.2566 Kpa	Fail
			G*=0.2565	δ=89.9		
RTFO Aged	Mass Loss	1%, max.	-		0.540	Pass
	DSR, G*/sinδ at 10 rad/s	2.2 Kpa, min.	**58**		5.3793 Kpa	Pass
			G*=5.3741	δ=87.5		
			64		2.2066 Kpa	Pass
			G*=2.2056	δ=88.3		
			70		1.3479 Kpa	Fail
			G*=1.3474	δ=88.5		
			76		0.6535 Kpa	Fail
			G*=0.6534	δ=89.2		
PAV Aged	DSR, G*sinδ at 10 rad/s	5000 Kpa, max.	**28**		3100 Kpa	Pass
			G*=2560.9	δ=55.7		
	BBR, Creep Stiffness	300 Mpa, max.	**-6**		103 Mpa	Pass
	BBR, m- value	0.3, min.	**-6**		0.373	Pass

COMPARISON OF MEASURED AND ESTIMATED PROPERTIES

One of the objectives of this study is to compare the estimated performance related properties with the measured Superpave properties in different performance stages, under the same temperature and loading time conditions. The summary of the results are shown in **Table (15)**. It is important to note that the G* values were measured at 10 rad/sec frequency, as required by the Superpave system. This corresponds to a loading time of approximately 0.10 second, which is much higher than the 0.012 second that was chosen for the estimated stiffness values. Therefore the comparison should not be about equivalency but about the obtained final grade for each asphalt cement. The results indicated that a low G* value obtained from Superpave tests corresponds to low stiffness value S(0.012) obtained from the proposed method. It appears that both methods (proposed and Superpave system) give the same performance grade. PG70-16 for asphalt cement with penetration grade (40-50) and PG64-16 for asphalt cement with penetration grade (60-70).

Table (15) Modules of Different Performance Stages

Pen	Original		RTFO		PAV			
	G* (KPa)	S(0.012) (KPa)	G* (KPa)	S(0.012) KPa	G* (KPa)	S(0.012) (KPa)	S (MPa)	S(0.012) (MPa)
40-50	T=70°C	T=70°C	T=70°C	T=70°C	T=31°C	T=31°C	T=-6°C	T=-6°C
	1.0617	20	2.2646	50	3548.3	40840	211	295
60-70	T=64°C	T=64°C	T=64°C	T=64°C	T=28°C	T=28°C	T=-6°C	T=-6°C
	1.0601	10	2.2056	25	2560.9	42000	103	209

CONCLUSIONS

- A temperature zoning map was developed for Iraq based on Superpave criteria. The required PG for asphalt binders are:
- PG70-16 for Mosul and Kirkuk
- PG64-16 for Rutba
- PG70-10 for Baghdad
- PG76-4 for Basrah
- Both of proposed and Superpave method give the same final performance grade. The Daurah asphalt with penetration grade 40-50 is equivalent to PG70-16 while that with penetration grade 60-70 is equivalent to PG64-16.
- Asphalt modifier is needed in the south parts of Iraq to modify asphalt stiffness.

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