RHEOLOGICAL PROPERTIES OF IRAQI ASPHALT BINDERS MEASURED USING SUPERPAVE SYSTEM AND SHELL SOFTWARE

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ABSTRACT

The performance grading system (superpave) has provided means to incorporate binder characteristics with pavement failure types. It's a comprehensive system that relates climate, traffic conditions and aging with critical pavement distress. The objective of this paper is to develop an improved asphalt binder grading system for Iraq based on the principal of superpave. The country was divided into different zones according to the highest and lowest temperature ranges and traffic loading. The Performance graded binder proposed for each zone was compared with some States of USA that have same hot weather of Iraq by using Long Term Pavement Performance (LTPP v3.1) software. Iraqi asphalt samples were tested using the Superpave technology in Wisconsin University and the results were compared with those estimated using Shell pavement design software packages (BANDS 2) at different loading time and frequency. In general, the performance grade of binders produced from the three refineries in Iraq (Daurah, Basrah and Baiji) is PG 64-16. The m- value (slope of log creep stiffness versus log frequency curve at specified temperature) determined by DSR (Dynamic Shear Rheometer) and Shell software was compared.

Keywords: Superpave; Performance Grading; Phase Angle; BANDS; Shell software.

الخلاصة

إن نظام درجة الأداء (التبليط الفائق) يدمج بين صفات الإسفلت والأنواع الرئيسية لفشل الخرسانة الاسفلتية، لذلك يعتبر نظام شامل لربط الظروف المناخية والأحمال وعمر التبليط مع انواع الفشل الحرجة. إن الهدف الرئيسي من هذا البحث هو إيجاد وتحسين نظام الأداء للإسفلت العراقي مبنياً على مباديء التبليط الفائق.تم تقسيم العراق الى عدة مناطق حسب اقصى واقل درجة حرارية وأحمال المرور. لقد تم مقارنة نظام الأداء المقترح مع بعض الولايات الأمريكية ذات امناخ الحار المشابه لحرارة مناخ العراق. لقد تم فحص الاسفلت العراقي في ولايات وسكونسن الامريكية اعتمادا على تكنلوجيا التلبط الفائق ومقارنة النتائج مع برنامج شركة شيل. وبصورة عامة نظام الأداء للأسفلت المنتج في مصافي الدورة والبصرة وبيجي هو 16- 64. ولقد تم مقارنة قيمت م (الميل بين لوغاريتم متانة الاسفلت ولوغاريتم التردد لدرجحة حرارة ثابتة) الناتجة من فحص الداينمك شير ريوميتر مع قيمة م الناتجة من برنامج شيل.

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INTRODUCTION

Conventional measurements of asphalt physical properties cannot be considered reliable to characterize asphalt properties that are critical for pavement performance because of the engineering complications related to the method by which there are interpreted (Asphalt Handbook, 2007)

Performance grading could be defined as "a system in which fundamental mechanical properties that are related to pavement performance are used to select binder to minimize critical failure, rutting, fatigue cracking and low temperature crack, at critical conditions of pavement temperatures and traffic characteristics".(Roberts et al 1996)

The Superpave binder specifications, also called Performance Grading (PG) System has effectively achieved this by using advanced rheometers in which temperature and loading rate are easily controlled. This achievement is arguable one of the most important advancements in asphalt binder quality control technologies during the last 60 years.

The Superpave performance grading system has provided means to contribute binder resistance with pavement failure type. It's comprehensive system related climate, traffic conditions and aging with critical pavement distress.

The specifications of the local asphalt binder are based on the conventional methods "empirical single point–measurements" viscosity measures and susceptibility parameters, climate and failure modes are not directly recognize. In this study samples were collected from the three refineries and tested at the university of Wisconsin-Madison testing lab to determine the physical properties according to the Penetration grading system and the Superpave system. The results were used to study the difference between the two systems and to trying various methods to estimate the performance grading from simple measurements. Based on the results, a map of PG binders was established for Iraq and the binders tested form the Iraqi refineries were fitted for the PG zones. Because it was clear that some of the climatic zones in Iraq will need better grades than what is produced, the study was extended to include modification for the available binders.

PERCENTAGE OF ASPHALTEN

The percentage of asphaltenes has been measured for different types of local asphalt binder according to ASTM (D3279, 2007); Figure (1) shows experimental work to find the percentage of asphaltenes. The results for different asphalt binder are tabulated in Table (1).

Fig. 1 Tools used to find percentage of asphaltenes.

Table 1 Percentage of asphaltenes for local asphalt binders

Type of Asphalt	Daurah PG 64-16	Daurah PG 58-22	Basrah PG 64-16	Baiji PG 64-16
% Asphaltenes	14	15	14	17

SUPERPAVE RHEOLOGICAL PROPERTIES FOR THE LOCAL ASPHALT BINDERS

In the superpave system the physical properties remain constant for all performance grades (PG), but the temperature at which these properties must be achieved varies from grade to another depending on the climate in which the asphalt binder is expected to perform. The stiffness of asphalt can vary by as much as eight orders in magnitude, and their phase angle (relative distribution of response between elastic and viscous behavior) by as much as 85^{o} between peak summer and peak winter conditions. These binders can also vary by similar amounts in response to standing traffic and high-speed traffic (Anderson et al.1994). At any combination of time and temperature, viscoelastic behavior, within the linear range, must be characterized by at least two properties: the total resistance to deformation and the relative distribution of that resistance between an elastic part and a viscous part (Bahia and Anderson, 1995). Although there are many methods of characterizing viscoelastic properties, dynamic (oscillatory) testing is one of the best techniques to represent the behavior of this class of materials. In the shear mode, the dynamic modulus denoted as G* and phase angle (δ) are measured. G* represents the total resistance to deformation under load, while δ represents the relative distribution of this total response between an in-phase component and an out-of-phase component. The in-phase component is an elastic component and is related to energy stored in a sample for every loading cycle, while the out-of-phase component represents the viscous component and is related to energy lost per cycle in permanent flow. The relative distribution of these components is a function of the composition of the material, loading time, and temperature.

RESULTS AND ANALYSIS

In this study the binders collected from refiners in Iraq were tested in the lab. Also, the BANDS2 program, which is based on the vander Poel nomograph (Van der Poel 1954) was used to compare directly measured values with the estimated values. Figure (2) shows a snap shot of a typical screen that displayed of the original binder that estimated using BANDS2. Tables (2) and (3) show results of rheological properties measured for the binders from the Iraqi Refiners. The testing included the rotational viscometer (RV), dynamic shear rheometer (DSR) and bending beam rheometer (BBR) for binders after different aging conditions, following the Superpave PG grading requirements. The tables also include comparison of these measurements with estimated stiffness by van der poel nomograph using (BANDS2) software. The estimated results depends on time of loading (1.59 Hz), which is assumed to correlate G*/sinδ at 10 rad/sec, bitumen temperature, softening point and penetration value at different aging film. To determine creep stiffness at minimum temperature the same procedure of superpave is used by raising test temperature 10ºC to simulate two hour loading time) (Bahia, 2009). Table (4) presents summary of the performance grade of different binders produced in Iraq.

In addition to the testing required for the PG grading, frequency sweep testing was conducted at constant strain (1%) and different temperatures (34 ºC, 31 ºC, 28 ºC, 25 ºC, and 19 ºC) for pressure aging film to measure G* at different frequency, m-value (slope between log complex modulus versus log frequency curve at specified temperature) that calculated from these tests were compared with m-value estimated by shell software at different frequency and temperature for pressure aging film also, Figure (3) and (4) depicted m-value for different types of asphalt binder measured and estimated at different temperature.

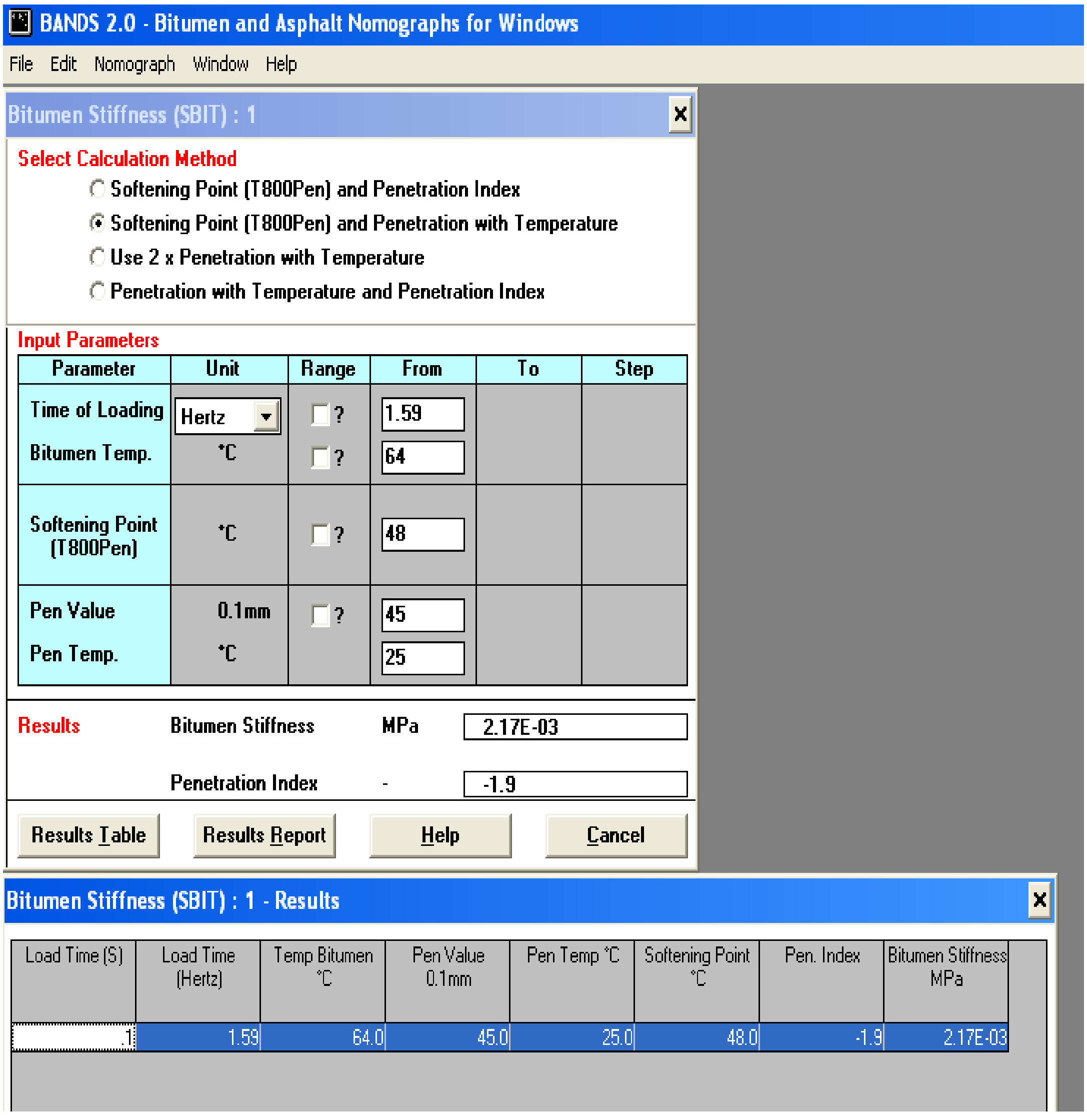

Fig. 2 Snap shot of the displayed screen in BANDS2.

Table 2 Measured (Estimated- BANDS 2) for Daurah Binder

Type of Asphalt	*Daurah 40-50 Pen. Grade*		*Daurah 85-100 pen. Grade*	
Aging	*Original*		*Original*	
Rotational Viscosity Pa.sec	@135 °C	0.516	@135 °C	0.33
G*/sin δ, kPa	@64 °C	2.37 (2.17)*	@58 °C	1.875 (2.61)
	@70 °C	0.958 (1.06)	@64 °C	0.886 (1.22)
True Grade	**69.83** °C	1	**63.32** °C	1
Penetration	@25°C	45	@25°C	88
Softening Point	48 °C		43°C	
Aging	*RTFO*		*RTFO*	
G*/sin δ, kPa	@64 °C	4.05 (4.04)	@58 °C	4.31 (4.34)
	@70 °C	1.887 (1.72)	@64 °C	1.91 (1.81)
True Grade	**69.13** °C	2.2	**63.27** °C	2.2
Loss (%)	0.73	< 1	0.77	< 1
Penetration	@25°C	29	@25 °C	47
Softening Point	52 °C		47 °C	
Aging	*PAV*		*PAV*	
δ	@25 °C	53°(63°)	@22 °C	53°(66.5°)
	@28 °C	59° (67°)	@25°C	59° (68.6°)
m-value	@25 °C	0.525(0.638)	@22 °C	0.53(0.688)
	@28 °C	0.578(0.692)	@25°C	0.586(0.73)
G*.sin δ, kPa	@25 °C	7320(22453)	@22 °C	7770(20633)
	@28 °C	4700 (12334)	@25 °C	4353(11358)
Creep Stiffness, MPa	@-16 °C	182 (200)	@-22°C	222(411)
	@-22 °C	426 (490)	@-28°C	369(839)
True Grade	**-18.9** °C	300	**-25** °C	300
Slop m-value	@-16 °C	0.399 (0.477)	@-22 °C	0.367 (0.349)
	@-22 °C	0.289 (0.269)	@-28 °C	0.26 (0.176)
True Grade	**-21.4** °C	0.3	**-25.8** °C	0.3
Penetration	@25°C	20	@25°C	30
Softening Point	57°C		52°C	

*** Estimated using BANDS 2 Software.**

Table 3 Measured (Estimated- BANDS2) for Basrah and Baiji Binder

Type of Asphalt	*Basrah 40-50 Pen. Grade*		*Baiji 40-50 pen. Grade*	
Aging	*Original*		*Original*	
Rotational Viscosity Pa.sec	@135 °C	0.444	@135 °C	0.444
G*/sin δ, kPa	@64 °C	1.26 (1.18)	@64 °C	1.32(1.79)
	@70 °C	0.605 (0.58)	@70°C	0.638(0.876)
True Grade	**66.36** °C	1	**66.8** °C	1
Penetration	@25°C	48	@25°C	46
Softening Point	45 °C		47 °C	
Aging	*RTFO*		*RTFO*	
G*/sin δ, kPa	@64 °C	2.93 (2.81)	@64 °C	2.41(3.27)
	@70 °C	1.24 (1.25)	@70 °C	1.13(1.43)
True Grade	**66.59** °C	2.2	**65** °C	2.2
Loss (%)	0.34	< 1	0.4	< 1
Penetration	@25°C	32.5	@25°C	29
Softening Point	50 °C		51 °C	
Aging	*PAV*		*PAV*	
δ	@25 °C	58.5°(66°)	@25 °C	54°(65°)
	@28 °C	63° (68.4°)	@28 °C	59° (66.7°)
m-value	@25 °C	0.577(0.685)	@25 °C	0.537(0.667)
	@28 °C	0.635(0.725)	@28 °C	0.578(0.692)
G*.sin δ, kPa	@25 °C	7192 (18728)	@25 °C	6830(20573)
	@28 °C	4340 (11010)	@28 °C	4153(11296)
Creep Stiffness, MPa	@-16 °C	159.5 (205)	@-16 °C	161(203)
	@-22 °C	391.5 (581)	@-22 °C	412(528)
True Grade	**-19.65** °C	300	**-19.3** °C	300
Slop m-value	@-16 °C	0.4 (.51)	@-16 °C	0.402(0.485)
	@-22 °C	0.26 (0.33)	@-22 °C	0.288(0.296)
True Grade	**-20.3** °C	0.3	**-21.4** °C	0.3
Penetration	@25 °C	22	@25 °C	21
Softening Point	55 °C		56 °C	

Table 4 Summary value for PG for different binder

Type of Asphalt	Penetration	Performance Grade
Daurah	40-50	PG 64-16
Daurah	85-100	PG 58-22
Basrah	40-50	PG 64-16
Baiji	40-50	PG 64-16

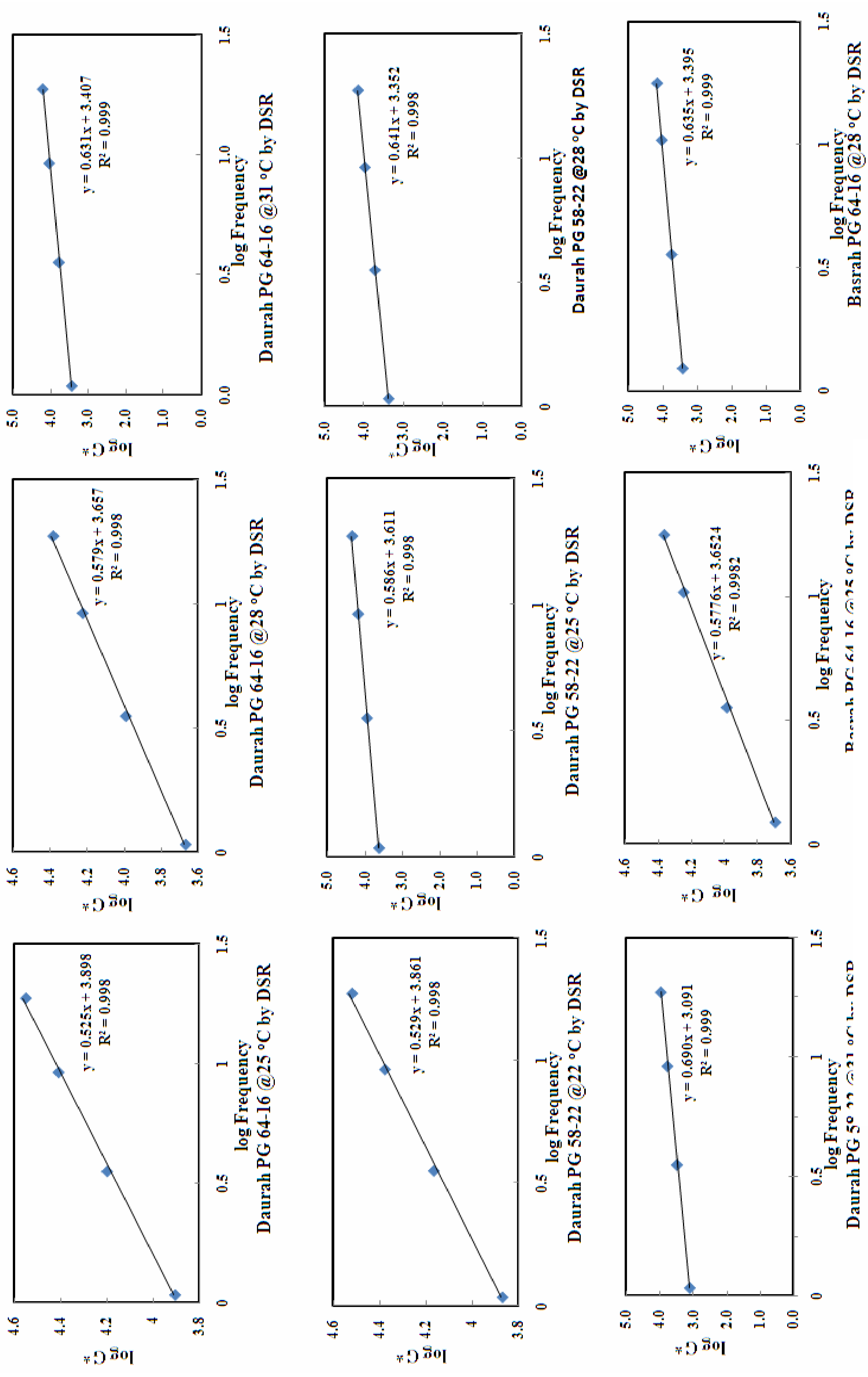

Fig. 3 Log G* versus log frequency measured by DSR

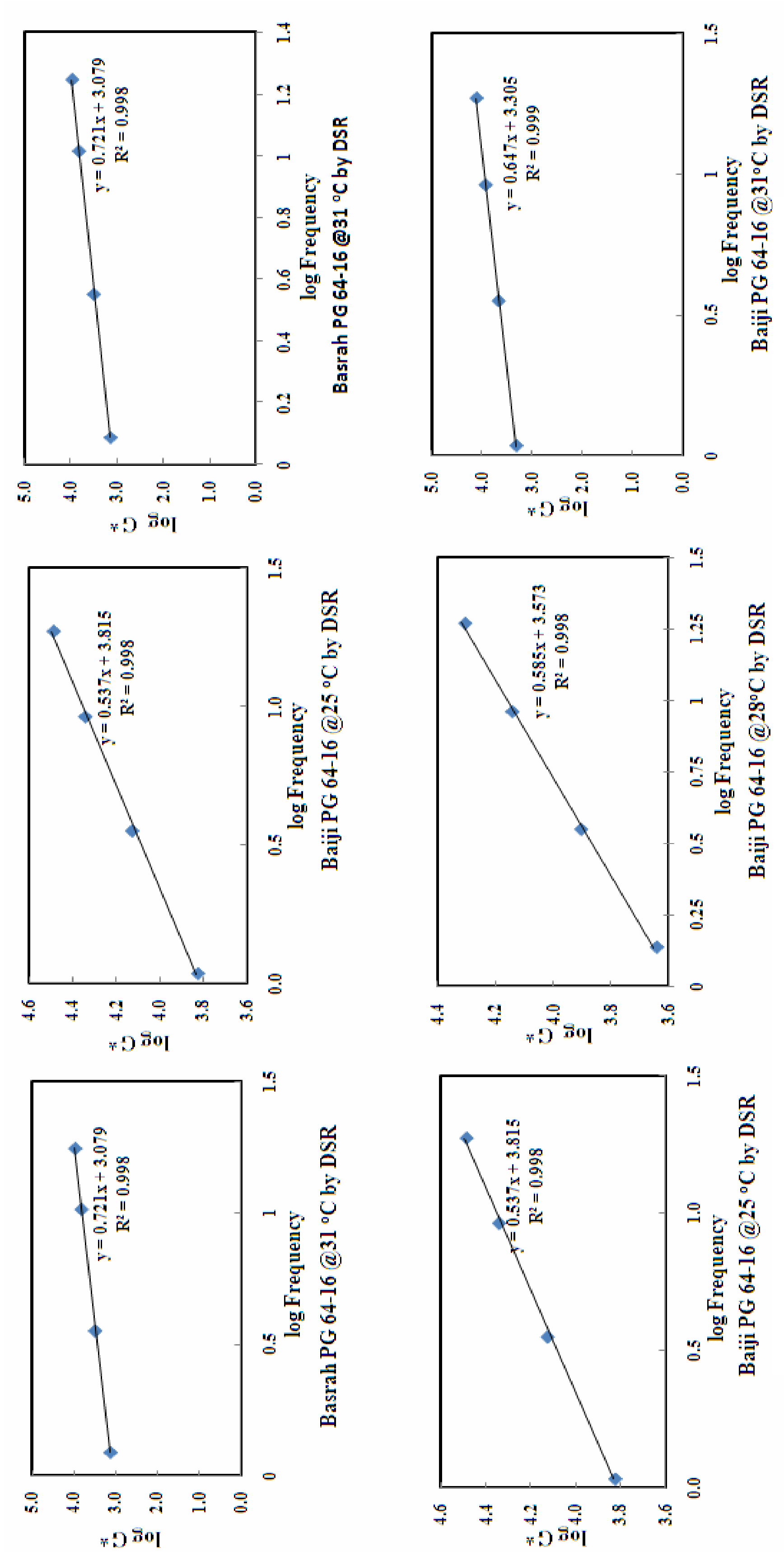

Fig. 3 Log G^* versus log frequency measured by DSR (continued)

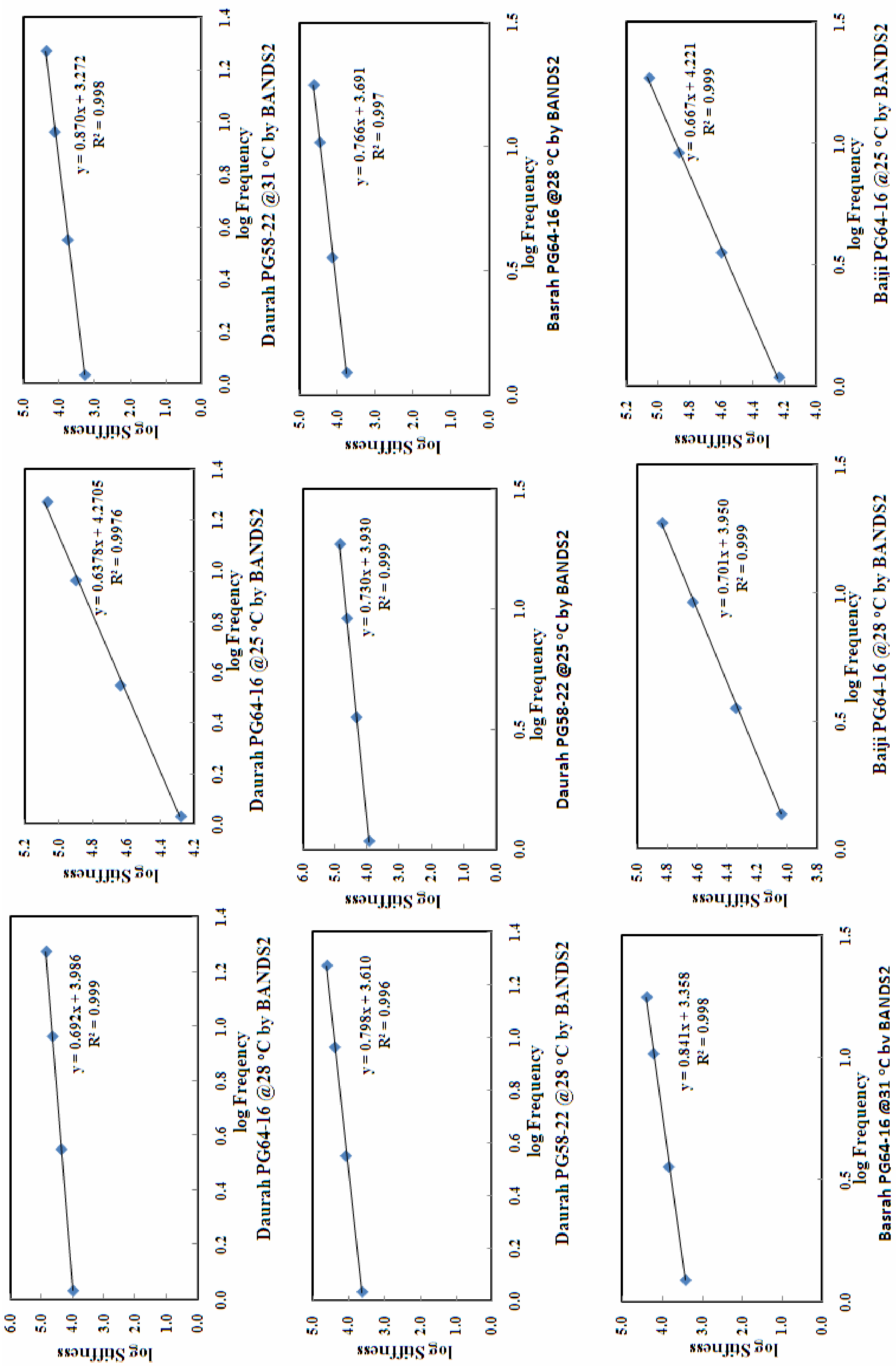

Fig. 4 Log stiffness versus log frequency estimated by BANDS2

When measure G^* /sinδ for original and rolling thin film by dynamic shear rheometer the phase angle dose not effects on results because sinδ almost one, but at intermediate temperature the effect of phase angle increase, since phase angle (δ) cannot calculated by using BANDS2, therefore, there is no indication to consider the elasticity and viscosity values of the binder. As presented in Figure (5), a good correlation for regression relations is obtained when compared m-value measured by DSR and estimated by BANDS2. Accordingly, it is proposed to use the relation in Figure (6) between tanδ and m-DSR to estimate the phase angle (δ) by substitute m-shell instead m-DSR.

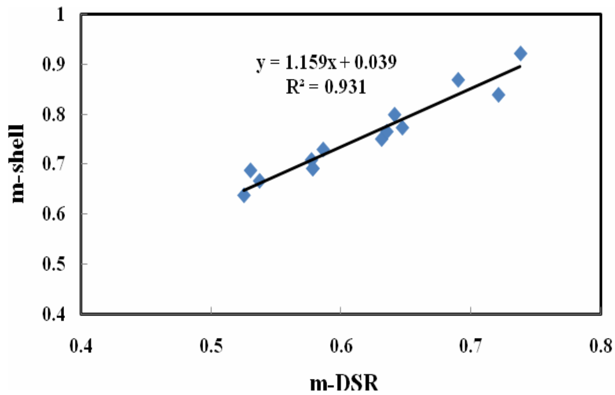

Fig. 5 Relation between m-DSR and m-Shell

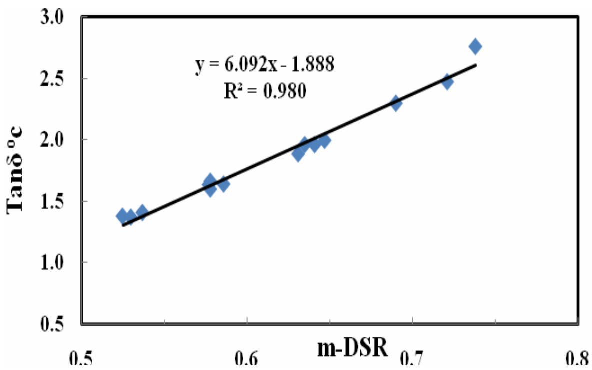

Fig. 6 Relation between m-value and tanδ obtain by DSR

Figures (7) and (8) illustration the relation between complex modulus measures by DSR using frequency sweeps test for rolling thin film at control strain (10%) and stiffness estimated by (BANS2) software for different frequency at softening point and penetration value of rolling thin film .

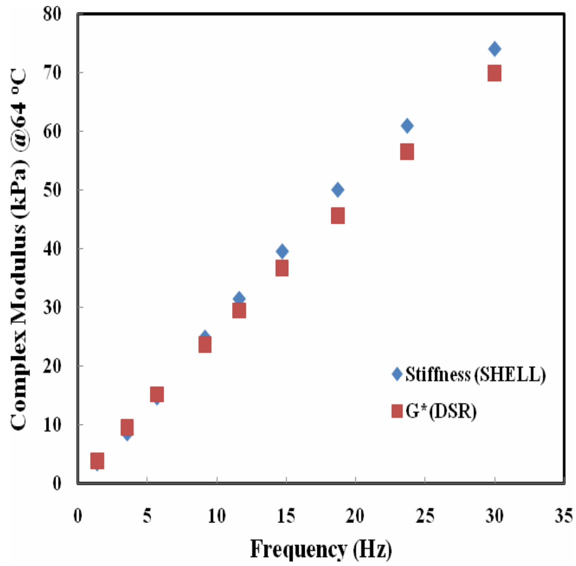

Fig. 7 Complex modulus versus frequency for Daurah PG 64-16

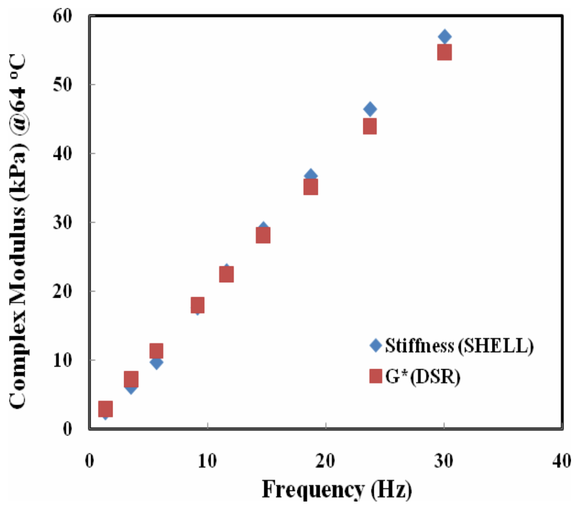

Fig. 8 Complex modulus versus frequency for Basrah PG 64-16

TEMPERATURE ZONING FOR IRAQ

Weather data are collected from five weather stations distributed across Iraq. Collected data from Iraqi Metrological Organization (IMO) is covered a minimum of 17 years of continuous temperature recording. The data are analyzed to obtain the annual minimum recorded air temperature. The annual average consecutive seven-day maximum air temperature, in addition to standard deviation of both high and low temperatures. Calculated average high-low air temperatures for 50% and 98% reliability are shown in Table (5).

Table 5 Average air temperature for Iraq

NO	Station	Latitude	50 % - Reliability				98 % - Reliability	
			High Air Temperature		Low Air Temperature			
			Mean	Standard Deviation	Mean	Standard Deviation	Avg. High Air Temp	Avg. Low Air Temp
1	BAGHDAD	33.23	47.5	1.18	-2.6	1.6	49.9	-5.9
2	BASRAH	30.57	48.3	1.15	1.8	1.76	50.6	-1.77
3	RUTBA	33.05	41.4	2.03	-3.4	2.03	45.46	-7.47
4	KARKUK	35.47	45.4	1.9	-1.4	4.53	49.2	-10
5	MOSUL	36.32	44.8	2.07	-3.4	1.49	48.9	-6.4

LTPPV3.1 Superpave software is used to investigate the performance grade for Iraq. This software has a database of weather information for about 7500 reporting weather stations in the U.S and Canada, Tables (6), (7), (8) and (9) show the data obtained by selected performance grade searching, 50% reliability (critical), to find weather information for these countries. Figure (9) depicted Iraq map which divided according to weather station after analyzing the obtained data as presented in the above tables and comparing them with the Iraqi database for weather information then converted to the pavement performance grade according to the superpave grade.

Selected performance grades have to be shifted up at least one grade for high numbers of heavy traffic loads (ESAL higher than 30 million) or slow, standing loads, Figure (10) shows Iraq map proposed and divided according to climate and traffic loading. Since refineries of Iraq product generally asphalt grade PG 64-16 as measured in Table (4), therefore to reach required grade, polymers should be added to modify binder for shifting grade.

Table 6 PG 70-10, 50% reliability, weather data information

NO	PG	State	No. of countries	Country which have Highest Average High Temperature				
				Station	Avg. High	Avg. Low	Latitude	Country
1	70-10	AZ	69	AZ6471	44.7	-3	36.1	COCONINO
2	70-10	CA	36	CA6699	44.8	0	34.28	SAN BERNAR.
3	70-10	FL	65	FL1986	36.3	-8.9	30.78	OKALOOSA
4	70-10	GA	13	GA4674	36.9	-7.3	31.65	WAYNE
5	70-10	NM	23	NM1153	39.5	-11.8	32.52	EDDY
6	70-10	LA	4	LA5527	36.9	-10.5	31.98	DESOTO
7	70-10	MS	2	MS5789	36.5	-9.8	30.98	GEORGE
8	70-10	NV	13	NV7925	44.8	-10.4	36.2	CLARK
9	70-10	OK	7	OK5509	40.5	-16.1	34.83	COMANCHE
10	70-10	PR	23	PR8881	34.7	11.6	18.35	AGUADILLA
11	70-10	TX	203	TX1524	42.9	-6.9	29.13	CUSTOLON
12	70-10	UT	4	UT7516	41.8	-10.7	37.12	WASHINGTON

Table 7 PG 76-10, 50% reliability, weather data information

NO	PG	State	No. of countries	Country /District that have Highest Average High Temperature.				
				Station	Avg. High	Avg. Low	Latitude	Country
1	76-10	AZ	18	AZ1050	47.1	-0.9	35.17	MOHAVE
2	76-10	CA	14	CA2319	49.4	-3.4	36.47	LNYO
3	76-10	NV	2	NV4480	47	-6.6	35.17	CLARK
4	76-10	TX	1	TX0950	43.2	-8.4	28.12	BREWSTER

Table 8 PG 70-16, 50% reliability, weather data information

NO	PG	State	No. of countries	Country /District that have Highest Average High Temperature.				
				Station	Avg. High	Avg. Low	Latitude	Country
1	70-16	NM	1	NM0992	39.1	-19.5	33.47	CHAVES
2	70-16	OK	1	OK1243	40.4	-19.9	36.83	HAPRER
3	70-16	UT	1	UT5733	39.9	-16.3	38.58	GRAND

Table 9 PG 64-22, 50% reliability, weather data information

NO	PG	State	No. of countries	Country /District that have Highest Average High Temperature.				
				Station	Avg. High	Avg. Low	Latitude	Country
1	64-22	CO	12	CO4834	38.6	-24.3	38.07	BENT
2	64-22	ID	1	ID9683	36.8	-22.3	44.23	WASHINGTON
3	64-22	KS	22	KS3897	39	-25.2	39.23	MITCHEL
4	64-22	MO	7	MO1759	37.1	-25.8	38.33	BENTON
5	64-22	NE	14	NE0640	38.8	-26.5	40.13	FURANS
6	64-22	NM	2	NM1647	34.9	-25.9	36.03	SANJUAN
7	64-22	NV	2	NV0691	37.2	-24.7	37.2	LANDER
8	64-22	OR	2	OR8797	38.2	-23.9	38.2	MALHEUR
9	64-22	UT	12	UT9152	37.6	-25.3	37.6	BEAVER

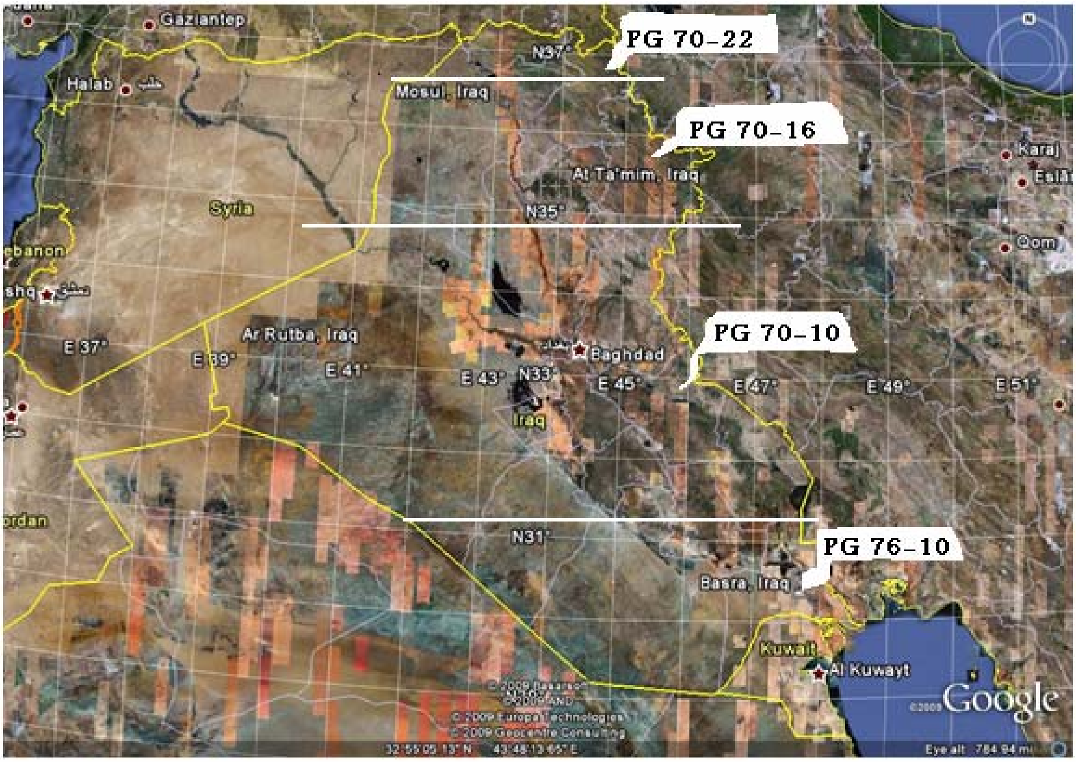

Fig. 9 Iraq map divided according to weather stations

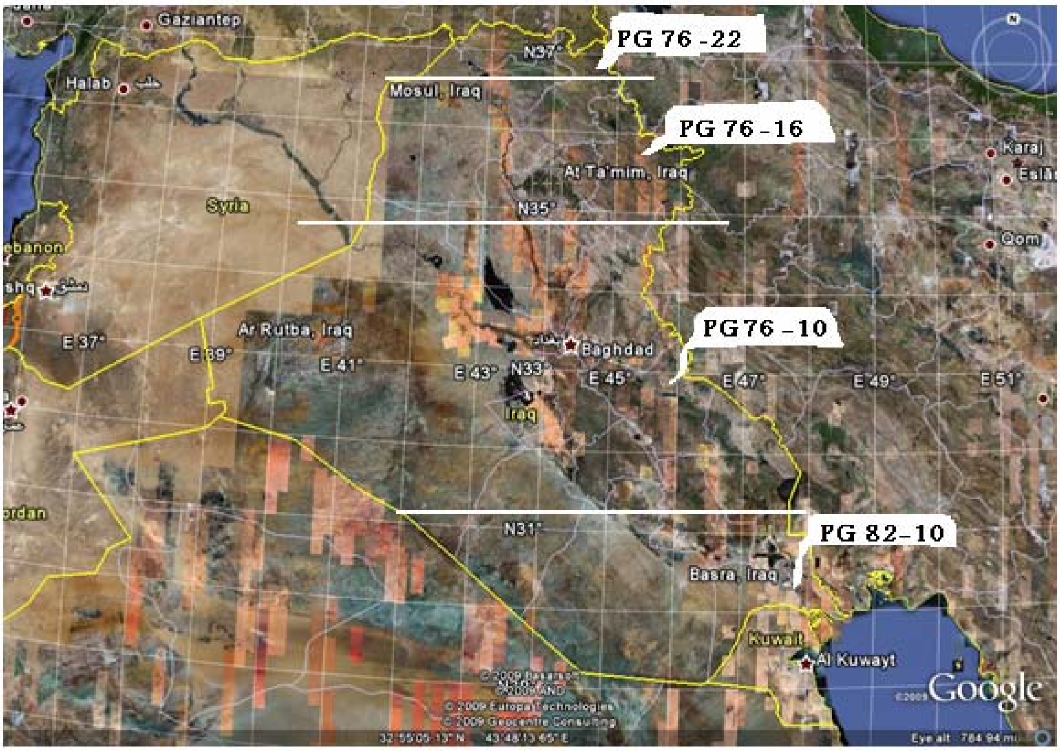

Fig. 10 Iraq map divided according to traffic loads

CONCLUSIONS

Based on the principal of superpave technology, the performance grade PG 64-16 represent asphalt binders produced in the following Iraq refineries; (Daurah, Basrah, Baiji)- (40-50) penetration grade while, PG 58-22 for Daurah (85-100) penetration grade.

The country is divided into different zones according to the highest and lowest temperature which that collected from Iraqi Metrological Organization (IMO) and converted to performance grade using SHRP temperature models as follows; PG 76-22 and PG 76-16 for the north, PG70-10 for the middle and PG 76-10 for the south.

The proposed performance grade divided according to climate and traffic condition, after compared with some states in the USA that have the same hot weather by using Long Term Pavement Performance (LTPPBind V3.1) software, the Iraqi map can be covered by the following PG's of asphalt binders : PG 76-22 for the north of N 36.5^{o} latitude (extreme north), PG 76-16 for the area between N35^{o} and N 36.5^{o} (north), PG 70-10 for the reign between N31^{o} and N 35^{o} (middle), and

PG 82-10 for the reign beyond N31^{o} (south).

The m- value (slope of log creep stiffness versus log frequency curve at specified temperature) determined by DSR (Dynamic Shear Rheometer) and (BANDS2) Shell software is compared .The estimated phase angle by the mentioned relation reflects good indication for binder elasticity at intermediate temperature.

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REFRENCES

Anderson, D., D. Christensen, H. Bahia, R. Dongre, Sharma M., and J. Button,(1994) “Binder characterization and evaluation”, Volume 3:“Physical characterization,” Report No. SHRP-A- 369, the Strategic Highway Research Program, national Research Council, Washington, D.C.

Asphalt Handbook, (2007), Asphalt Institute, MS-4, 7thEdition, Manual Series, Lexington, Kentucky.

ASTM, (2009), “Road and Paving Materals,” Annual Book of ASTM Standards, Volume 04.03, American Society for Testing and Materials,” West Conshohocken, USA.

Bahia H., Vivanco, “The transition to a PG grading system for asphalt binders in developing countries,” Conference Proceeding First Middle East International Conference on Advances in Civil, Mechanical and Materials Engineering, May 10-13, 2005, Amman-Jordan.

Bahia, H.U., (2009), “Materials for Constructed Facilities,” CEE/EMA 395, Lectures at University of Wisconsin-Madison during (March 3-August 12).

Bahia, H.U., and D.A. Anderson, (1995), “The New Proposed Rheological Properties of Asphalt Binders: Why are They Required and How Do They Compare to The Conventional Properties,” Physical Properties of Asphalt Binders, ASTM, STP 1241.

Roberts, F., Kandhal P., Brown et al. “Hot mix asphalt materials, mixture design, and construction”, NAPA education foundation, Second Edition, Maryland, USA, 1996.

Van de poel, (1954), "A General System Describing the Viscoelastic Properties of Bitumens and its Relation to Routine Test Data," Journal of Applied Chemistry, Vol. 4, p.221.