Evaluation of Local Asphalt Production and Performance Grade (PG) for Kurdistan Region-Iraq

By
Agreen Abdoulla Azeez

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A Thesis
Submitted to the Council of the Hawler Technical Engineering College - Civil Engineering Department at Erbil Polytechnic University in Partial Fulfillment of the Requirements for the Degree of Master of highway engineering

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Authors' introduction;

During a period of six years, from 2006 until 2012, I have been working as the director of Road Maintenance in Erbil governorate. The primary concern of these institutions was the restoration and maintenance of the external road network throughout the Erbil governorate. Huge efforts were made in corporation between me, the engineers and the technical staff of my directorate to protect and maintain the external roads. This was done through renovation of the existing roads, placing road signs for safety and recovering the asphalt layers. The restoration/renovation of the asphalt layers was always a big challenge in which we faced many difficulties and failures due to several reasons. The most vital reason was the quality of the bitumen that was used during the restoration. On numerous occasions we faced the problem of damaged asphalt layers that occurred after a short period when the asphalt was laid, resulting in an embarrassing situation for the directorate of Road Maintenance.

The asphalt layer distresses was the main reason that motivated me to make various research into understanding why this phenomenon occurs on continues basis and finding feasible solutions to solve this problem. Due to this interest, I found myself in the master course at the civil department of the Erbil University of Polytechnic in the Kurdistan region of Iraq. After the completion of the formal course I dedicated myself to seek the best method for strengthening the asphalt pavement, which became my mission with the help of my supervisor Dr. Fars Najer and the support of Erbil Construction Laboratory. With the help of many colleagues I was able to successfully finish this dissertation by providing a solution for the asphalt layers in which it comprised of a group of polymer modification for the bitumen that is produced in the Kurdistan region of Iraq.

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Evaluation of Performance Grade (PG) of Local Asphalt Binders for Kurdistan Region-Iraq

Abstract

Until now, the Iraqi specifications for asphalt binders depend on two methods for asphalt grading system, either based on penetration or viscosity. However, these two specifications describe the physical properties at standard test temperature by employing empirical means of testing which cannot simulate the performance of asphalt at field during its life service. This problem was existing in other parts of the world. To overcome this shortage, the Super-pave method was invented in USA; the method contains evaluation of asphalt binders through performance grade.

This research studies evaluation of local asphalt binders according to the performance grade (PG) system, based on Super-pave (Superior Performing Asphalt Pavements) method. The method is presently applicable in Kurdistan Region-Iraq. And the required test equipment is available in Hawler construction laboratory / Ministry of Construction and Housing.

Kurdistan Region-Iraq is divided into different zones depending on weather records (maximum and minimum air temperatures), which were achieved from General Directorate of Meteorology and Seismology / Ministry of Transportation and Communications, for a period of 14 years (2000-2014). According to these data, and after calculating pavement maximum and minimum temperatures based on Super-pave criteria, Kurdistan region was distributed into four zones:

- First PG zone; is PG (64-16) represents the area adjacent to the border with Turkey and Iran (i.e., Qaladze-Choman and Amadiyah).

- Second PG zone; is PG (70-10) includes Duhok center- Soran - Sulaymaniyah center- Halabja and Hawler center.
- Third PG zone; is PG (76-10) includes Kirkuk governorate and Germiyan administration area.
- Fourth PG zone; is PG (64-22) covers; Pynjween / Sulaymaniyah governorate.

Samples of asphalt with penetration grades of (40-50) and (60-70) were taken from three different refineries; Lanaz refinery-Erbil, Phoenix bitumen plant-Sulaymaniyah and KAT plant for asphalt-Kirkuk. Over 400 tests were made by Super-pave method and showed that Lanaz and Kat grade (40-50) and (60-70) were equivalent to PG (70-28), Phoenix grade (40-50) was equivalent to PG (70-22) and for grade (60-70) was equivalent to PG (64-22).

In the experimental work both Elastomer and Plastomer were used. The results showed that both of them are helpful for local asphalt modification. The results showed that 2 percent of Kraton / Elastomer gives PG (82-28), and 2 percent of Iterprene / Elastomer gives PG (82-22) for Lanaz asphalt, those are applicable for all zones of Kurdistan Region-Iraq. 2 percent of Plastomer gives PG (82-22) for both Lanaz and Kat asphalts, this also is applicable for all zones of Kurdistan Region-Iraq.

KEY WORDS: Performance grade, Super-pave, Asphalt modifier.

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ABBREVIATIONS

AASHTO	: American Association of State Highway and Transportation officials.
AR	: Asphalt Residue.
AC	: Asphalt Cement.
ASTM	: American Society of Testing and Materials
BBR	: Bending Beam Rheometer.
DTT	: Direct Tension Tensile.
DSR	: Dynamic shear Rheometer
DOT	: Department of Transportation
ESALS	: Equivalent Single Axel Load
FDS	: Facilities Development Manual
HMA	: Hot Mixed Asphalt.
HDPE	: High Density Polyethilene.
Mpa	: Mega Pascal.
KRI	: Kurdistan Region- Iraq
KRG	: Kurdistan Regional Government
KPa	: Kilo Pascal.
PAV	: Pressure Aging Vessel
Pa.s	: Pascal
PB	: Poly Butadiene
PG	: Performance Grade.
PT	: Penetration Test
PMA	: Polymer Modified Asphalt.
PMB	: Polymer Modified Bitumen.

Abbreviations

PE : Polyethilene.

PO : Poly Olefins

SHRP : Strategic Highway Research Program

Super-pave: Superior Performing Asphalt Pavements

SSFRB : Standard Specifications for Roads & Bridges

SCFRB : State Corporation for Roads & Bridges.

SB : Styrene-Butadiene.

SBS : Styrene-Butadiene-Styrene.

SBR : Styrene-Butadiene-Rubber.

SBS-R : Radial Styrene-Butadiene-Butadiene.

LDPE : Low Density Polyethilene.

EVA : Ethylene Vinyl Acetate.

RTFOT : Rolling Thin Film Oven Test.

RV : Rotational Viscometer.

OB : Original Bitumen

OMB : Original Modified Bitumen

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CHAPTER ONE
INTRODUCTION

1.1 Background

Asphalt pavement is considered as one of essential issues of Highway flexible pavement technology. The evaluation of asphalt binders properties and specifications witnesses dramatic change in last 20 years. Instead of simple empirical tests visco-elastic and damage characterization methods have been adopted (Ven et al., 2004). According to standard specifications of roads and bridges-Iraq (SORB, R/9), the local specifications for asphalt binder states two methods for asphalt cements grading, Viscosity and Penetration of row asphalt. The two methods describe physical properties of asphalt cements at standard test temperatures employing empirical means of testing which cannot be related to field performance during service life (Alani et al., 2010). Due to this fact, it is important to choose proper materials in asphalt pavement layers that perform its duty according to field requirements. In this regard, new techniques are invented for a better control as; Super-pave method, performance grading technique and asphalt polymer modification.

In Kurdistan Region-Iraq, as other parts of the world, asphalt binder is widely used in road sector. The asphalt binders which is obtained from crude oil refinery are available in wide scope throughout regions area because of petrol existence, this substance is considered as petroleum asphalt which is made of asphaltenes, resins and oils" (Kerbs and Walker 1971).

The constructed roads in Kurdistan Region-Iraq are mostly of asphalt paved roads. Asphalt materials obtained from distillation of petroleum are in the form of different types as asphalt cement, slow-curing liquid asphalt, medium-curing liquid asphalt, rapid-curing liquid asphalt, and asphalt emulsion (Garber and Hoel, 2009).

Pavement defeats that are related to asphalt binders have been tested based on conventional tests as; penetration and viscosity grading. However, these tests do not fulfill the aimed requirements. The defeats were continued in wide scope. These defeats lead to huge economic losses which enhance technical institutions to discover new methods to overcome them.

Kurdistan Region- Iraq possess a high temperature climate condition especially during summer season reaches above 48°C and in winter lowers to -27°C temperature (i.e., Pynjween District). This lead to a group of asphalt pavement defeats related to high and low temperature condition in the same time.

1.2 Problem Statement

According to engineering experiences and practices, penetration grading and viscosity grading of asphalt binders are somewhat limited in their ability to fully characterize asphalt for use in hot mixed asphalt pavement (Papagiannakis and Masad, 2007). Researchers have tried to improve methods and performance of asphalt binders and asphalt pavement mixture so that the system can sustain under different and critical weather and traffic load conditions. In this regard, Strategic Highway Research Program (SHRP) invented Super-pave between the periods of 1987-1993 which efforts new binder tests, aggregate tests and specifications to substitute conventional mix design methods as Marshal and Hveen (SHRP-A-410, 1994), among these specifications, performance grading is fundamental for asphalt evaluation.

Performance grading is based on the concept that asphalt binders properties should be related to the conditions under which asphalt is used including air and pavement temperatures, vehicle speed and traffic loads. In other words, it could be defined as new asphalt binder specifications for selecting the appropriate asphalt binders for pavement performance in terms of rutting, fatigue cracking, and low temperature cracking.

In Super-pave, proper asphalt binders need to be selected carefully "The Super-pave binder grade selection process utilizes procedure that directly relates laboratory analysis with laboratory performance" (Super-pave 2012). The process of determining performance grade for asphalt binders will start through execution of tests; Dynamic Shear Rheometer DSR for neat asphalt, Dynamic Shear Rheometer DSR for asphalt after RTFOT and after PAV test, and Bending beam Rheometer BBR test after PAV test. In this technology, investigation were made to determine; during which stage of pavements life, with which air temperature and according to what traffic condition the main distresses will occur.

1.3. The Aim and Objectives

Local professional institutions in pavement works faced great challenge in implementing road projects. There are many asphalt pavement defeats (i.e., rutting, shoving and thermal cracking). To control this problem, improvement of physical and rheological properties of local asphalt binders should be achieved to sustain high and low temperature and become more resistant under heavy axle and repetitive loads.

Based on Super-pave method, performance grade could be used to control those properties. The method makes use of both air and pavement surface layer. Furthermore, the asphalt binders could also be modified through the different types of additives. This is to gain better asphalt binders that sustain under the different traffic and environmental conditions.

This research used polymer modification to achieve the required performance grade of asphalt binders.

The aim of this research is to establish a procedure for finding temperature performance grade zones in Kurdistan Region-Iraq and establishing performance grade table for local asphalt. In the same time it investigates the effect of different polymer on asphalt binder properties. Accordingly, this research aims to:

1- Conduct the conventional tests for local asphalt produced in Kurdistan Region-Iraq to check their quality as first guidance.
2- Finding Performance grade for different areas through Kurdistan Region-Iraq by using (Super-pave / performance grade) method, depending on the data of maximum and minimum air temperature from all available stations in all cities, towns, districts and even remote areas. Then converting them into pavement temperature, and establishing the performance grade zones of Kurdistan Region-Iraq.
3- Finding performance grade (PG) of locally produced asphalt binders using Super-pave technique.
4- Using local asphalt binders and modifying them with polymer Elastomer type (Kraton-SBS and Iterprene SBS G-L) and polymer Plastomer type (Iterplast 1806 brand) to determine the optimum percentage by weight of asphalt that most appropriate to endure conditions as; pavement temperatures, traffic load, applicable for pavement road projects in Kurdistan Region-Iraq in order to achieve stable and durable mix.

In this research, three sources of local asphalt were selected which are considered as main sources of asphalt production in Kurdistan Region-Iraq;

1- Lanaz oil refinery-Erbil.

2- Phoenix bitumen plant-Sulaymaniyah.

3- KAT plant for asphalt-Kirkuk

Samples of these refineries are both of penetration grade (40-50) and (60-70). Characterization and evaluation of these three sources of asphalt assessed through physical properties as; Penetration, Softening Point test, Viscosity and Rolling Thin Film Oven test, and rheological properties as: Dynamic Shear Rheometer DSR test, Pressure Aging Vessel PAV test and Bending Beam Rhyometer BBR test.

1.4 Structure of the Thesis

This research contains five chapters; Chapter One presents an introduction and scope of the study. Chapter Two contains principles, review about evaluation of asphalt binders, and a brief of some researcher and reports relevant to asphalt binders performance grading. Chapter Three is experimental program both performance grade zoning for Kurdistan Region-Iraq, and sampling and testing are explained. Chapter Four is concerned with the results and their discussions, and finally, Chapter Five presents the research conclusions and recommendations. Figure (1-1) shows flow chart of research design.

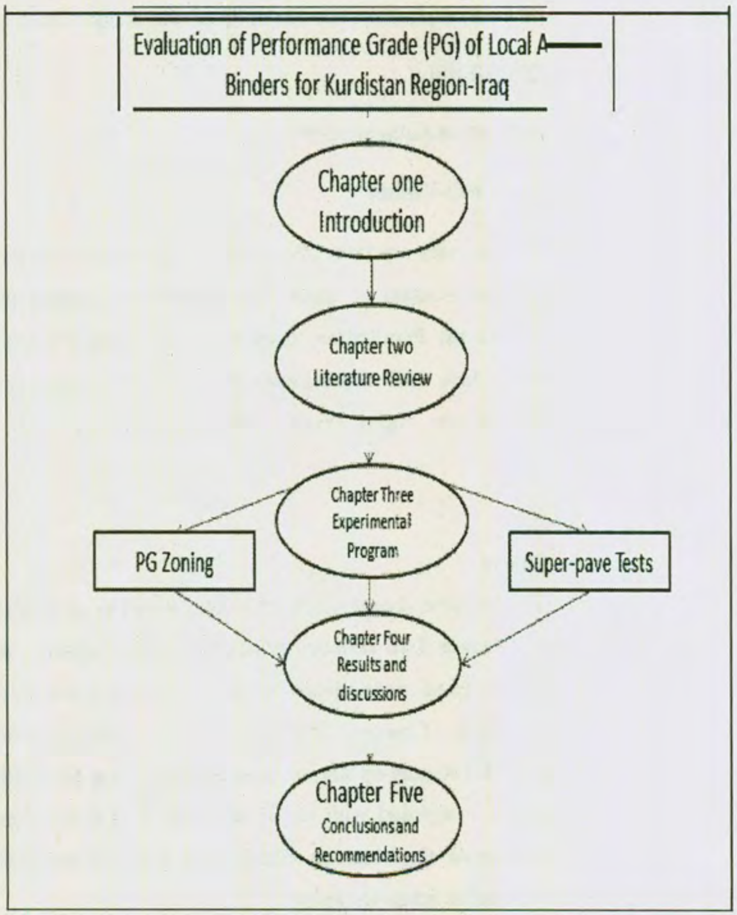


Figure (1-1) Flow Chart of Research Design

CHAPTER TWO

BACKGROUND AND LITERATURE REVIEW

2.1 Background

Studying stable asphalt pavement without mentioning asphalt properties is a worthless matter as asphalt contents and its characteristics beside aggregate gradation play a vital role in gaining stability and durability of pavement layers (Yodar and Witczak, 1975). Before, the studying of asphalt was through tests as Penetration and Viscosity grading. While according to new technique, evaluation should be according to its performance grade based on Super-pave method.

It is important to address those types of deformation related to warm and cold climate conditions in the same time to implement asphalt pavement that durable and resists weathering (Wallace and Martin, 1997).

Asphalt is a dark brown to black cementitious material. It is composed principally of high molecular weight hydrocarbons with properties of consistency, aging, temperature sustainability, rate of curing and resistance to water action. The term (Asphalt) or (bitumen) is used in highway engineering and both have the same meaning. In some countries as USA and UK, the term asphalt is used (Chakroborty and Das, 2010). These terms are taken originally from old human civilizations, the asphalt is from the Accadian term and bitumen originated from Sanskrit (Abraham H, 1938).

Due to the important role of asphalt binders, researchers have invented different techniques to improve the durability and elasticity of asphalt binders. The following sections present the most common defeats of asphalt pavement and different techniques that have been made.

2.2 Pavement Distresses

Different places in the world owe different types of pavement distresses. Countries located in north of Europe have pavement distresses related to cold weather while in Gulf countries the pavement distresses are related to very hot weather. However, in general road distress related to performance of asphalt binders relevant to this research are the following:

2.2.1 Permanent Deformation

There are many types of permanent deformation for asphalt pavement, the most relevant to asphalt pavements are:

1-Rutting

It is permanent deformation which occurs at high pavement temperature in various pavement layers. It also could be defined as accumulated plastic permanent deformation along wheel path of vehicles caused by repeated traffic loading (Chakroborty and Das, 2010).

The important factor effecting rutting is high asphalt content and its properties in the asphalt mixture. However, instead of that many other factors will influence rutting such as aggregate gradation, mixture properties, condition of base, sub-base, traffic loading and pavement temperature in summer season. Figure (2-1) shows rutting phenomena in one of Kurdistan Region-Iraq roads.

Figure (2-1) Rutting Phenomena (Qetewy-Dustepa Road Erbil Governorate/2011)

2- Shoving

This type of distress is usually caused by traffic action (starting and stopping of vehicles), mostly in check point stations or traffic light intersection locations. Shoving is a permanent, longitudinal displacement of a localized area of the pavement surface caused by repeated traffic loading in warm weather. The main reason is due to unstable liquid asphalt mix pavement. Shoving is shown in figure (2-2) below.

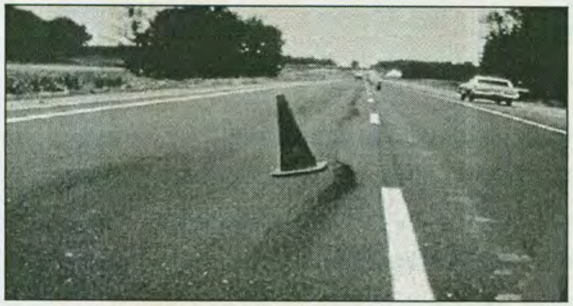


Figure (2-2) Shoving (Fwa, 2006)

3-Courrugated

This type of failure is very close to shoving type. It is a type of plastic movement occurs across pavement surface, the possible causes are due to high content of asphalt, low air voids, high content of fine aggregate, excessive moisture or contamination in granular base (Asphalt institute, 1989). Figure (2-3) shows this type of pavement failure.

Figure (2-3) Courrugated Distress (www.pavementinteractive.org).

2.2.2 Cracking:

1- Thermal Cracking;

It is thermal shrinkage and fatigue cracking at low temperatures. Some sources denoted it by (TC), which occurs at low pavement temperature (Super-pave Fundamentals, 2010). This type of asphalt pavement defeats mostly occurs in cold weather countries (Marasteanu, et al., 2004). Figure (2-4) below shows this type of asphalt cracking.

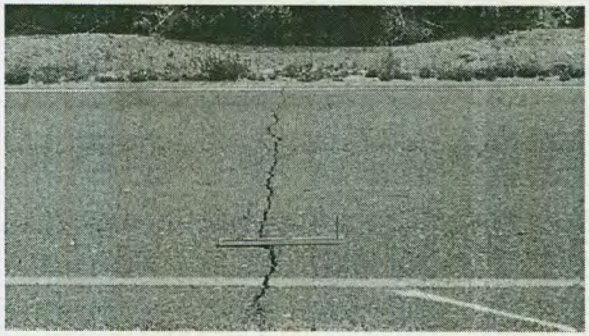


Figure (2-4) Thermal Cracking of Asphalt Paved Road (Fwa, 2006)

2- Fatigue Cracking:

This type of crack is load-associated with intermediate pavement temperatures. It is directly related to axle load (Super-pave Fundamentals, 2010). The main view of this crack is alligator shape. Figure (2-5) shows fatigue cracking. This distress is classified into two types; first in thin pavement layer and second in thick pavement layer.

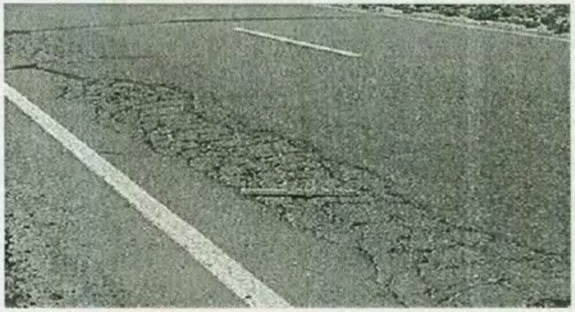


Figure (2-5) Fatigue Cracking (Fwa, 2006)

2.3 Principles of Asphalt Paving Mixture

2.3.1 Asphalt binders

Asphalt binders are considered as essential materials in pavement mixture. The majority of countries use asphalt in their roads. 96% of USA roads are of asphalt (Grant, 2001). From beginning of asphalt pavement and till now, Hveem and Marshal Methods of asphalt mixture design implemented for most of road pavements. In these methods, evaluations of asphalt binders are made according to penetration grading system and viscosity grading system.

Currently in Iraq, mixture design is according to standard specifications of roads and bridges (SORB, R/9). In these specifications, evaluation for asphalt binders is done based on Viscosity or Penetration of original asphalt (Alani et al., 2010). These two methods describe the physical properties of asphalt binders at standard test temperatures 25°C and 60°C for both Penetration and Viscosity respectively (Zaniewski and Pumphery, 2004). It is obvious that only one temperature could not simulate the real temperatures that imposed on asphalt pavement in field. The asphalt pavement is subjected to a wide range of temperatures. In winter, it is subjected to low and intermediate temperature while in summer, it is subjected to very high temperature.

In 1993, Strategic highway research program / USA invented Super-pave method which is advanced technology to design asphalt mixture based on pavement temperature, traffic load and traffic speed. Super-pave uses performance grading to evaluate asphalt rheological properties based on different tests (which will present under Super-pave section later on).

The Penetration and Viscosity grading system differ from performance grading PG system; Viscosity grading system is based on binder viscosity at 60 degree Celsius. The PG system measures the fundamental properties (stresses and strains) of the binders at the various stages of binder conditions (service temperatures and binders aging) throughout the expected life of the pavement.

The difference with Penetration grade is that; PG system evaluates asphalt binders for high and low temperature while in Penetration test there is only one temperature in testing "When the Penetration grading system was initially developed, it consisted of testing asphalt cements at one temperature (i.e. 25^0C or 77^0F). However, the performance of HMA cannot be adequately captured with one test at one temperature. There needed to be a way of evaluating asphalts at both high and low temperatures" (Fwa, 2006).

2.4. Super-pave

2.4.1 Definition and History

After long history of asphalt mixture design in road engineering which started from beginning of twentieth century, the continuous fall and defeats of asphalt pavement lead to creation new methods for asphalt mixture. The USA Congress established SHRP (Strategic Highway Research Program) in 1987 and dedicated a $150 million research program for five years to improve the performance and durability of United States roads. One of the principal results from the SHRP was the Super-pave mixture design method (Super-pave Fundamentals, 2010). Super-pave is an acronym for Superior Performing Asphalt Pavements, it provides specifications for both asphalt binders and asphalt-aggregate mixtures and allow selection of materials and design of mixtures on the basis of pavement performance requirements for predicted traffic and environmental conditions. Super-pave specifications provide asphalt mixture for a specified level of performance in terms of rutting fatigue cracking and thermal cracking (SHRP-A-410, 1994).

2.4.2 Performance Grade

Performance grade (PG) is Super-pave specifications for asphalt binder evaluation which is applicable for both neat asphalt and polymer modified asphalt. The specifications are showed in table (2-1), these specifications were first adopted by Asphalt Institute then become AASHTO standards (Nikolaides, 2015).

The specifications are based on stiffness of aged asphalt binders for a specific combination of traffic loading and environmental conditions. Asphalt binders specified primarily with respect to pavement temperatures which allows one binder to be selected for a specified design combination of high and low temperature with a loading related to high temperature performance of vehicle speed 100km/hr. and traffic volume of less than (10,000,000) equivalent single axle loads(ESAL) (SHRP-A-410, 1994). Super-pave system is invented to control the main defeats of asphalt mixture during pavements life through a group of rheological tests, the main criteria for this control is binders (asphalt) grading (Huang, 2003).

It is important to clarify that the PG increment is by every +6°C for high temperatures and -6°C for low temperatures, for this, there are two opinions; the first relates it to statistical point of view that an error of about 6°C in the performance prediction for two binders could mean a reduction in confidence from 98 to 50 percent, the second relates it to time conditioning which is based on study on 16 different binders losses ranging from a low of 1.5°C to a high of 6°C after a 24-hour conditioning period the biggest difference for the one-hour conditioning time is 6 C°" (Hesp, 2004).

Other important issue that should be cleared is value of Bending Beam Rheometer BBR test, the value of BBR test for creep stiffness is to indicate minimum temperature of performance grade, the test time is 60 seconds this duration goes back to the time where BBR test originally developed this lead to 10°C increment. For the purpose of explaining this matter, two ideas give justifications; one idea related it to time of loading which for most asphalt binders, if the test temperatures were increased by 18°F (10°C) the BBR stiffness at 60 seconds loading time could be equated to the asphalt binders stiffness at 2 hours in the field at the low temperature specifications (Hesp, 2004).

The other idea related it to change in ductile to brittle behavior of asphalt. The use of a binders to temperatures at which the fracture energy reaches 100 J/m^2 at 0.01 or 0.001 mm/s rates of loading the ductile to brittle transition temperatures determined are shifted by -10 °C in order to account to some extent for loading rate effect (Hesp, 2004). Therefore if test temperature is -12 °C the PG will be (-22).

Table (2-1) Performance Graded Asphalt Binders Specifications ASTM D6373

Performance Grade	PG 46	PG 52	PG 58	PG 64	PG 70	PG 76	PG 82
	-34 -40 -46	-10 -16 -22 -28 -34 -40 -46	-16 -22 -28 -34 -40	-10 -16 -22 -28 -34 -40	-10 -16 -22 -28 -34 -40	-10 -16 -22 -28 -34	-10 -16 -22 -28 -34
Average 7-day maximum Pavement Design Temperature °C	<46	<52	<58	<64	<70	<76	<82
Minimum Pavement Design Temperature °C	>-34 >-40 >-46	>-10 >-16 >-22 >-28 >-34 >-40 >-46	>-10 >-16 >-22 >-28 >-34 >-40	>-10 >-16 >-22 >-28 >-34 >-40	>-10 >-16 >-22 >-28 >-34 >-40	>-10 >-16 >-22 >-28 >-34	>-10 >-16 >-22 >-28 >-34
Original binders							
Flash point temperature, D92, min °C	230						
Viscosity, D4402 max. 3Pa.s, Test Tamp., °C	135						
Dynamic Shear, P 246 G*/ Sin δ, min 1.0 kpa 25mm plate, 1 mm Gap Test Temp. at 10 rad/s, °C	46	52	58	64	70	76	82
Rolling thin film oven (test method D 2872)							
Mass loss, max. percent	1.00						
Dynamic Shear, P 246 G*/ Sin δ, min. 2.2 KPa 25mm plate, 1mm Gap Test Temp. at 10 rad/s, °C	46	52	58	64	70	76	82
Pressure Aging Vessel Residue (AASHTO PP1)							
PAV Aging Temperature. °C	90	90	100	100	100(110)	100(110)	100(110)
Dynamic Shear, P 246 G*/ Sin δ, max 5000 kpa 8mm plate, 2 mm Gap Test Temp. at 10 rad/s, °C	10 7 4	25 22 19 16 13 10 7	25 22 19 16 13	31 28 25 22 19	34 31 28 25 22 19	37 34 31 28 25	40 37 34 31 28
Creep Stiffness, P245. S, max. 300 MPa m-value; min 0.300 Test Temp at 60 s, °C	-24 -30 -36	0 -6 -12 -18 -24 -30 -36	-6 -12 -18 -24 -30	0 -6 -12 -18 -24 -30	0 -6 -12 -18 -24 -30	-6 -12 -18 -24 -30	0 -6 -12 -18 -24
Direct Tension, P252. Failure strain, min 1.0% Test Temp. at 1.0 mm/min., °C	-24 -30 -36	0 -6 -12 -18 -24 -30 -36	-6 -12 -18 -24 -30	-6 -12 -18 -24 -30	0 -6 -12 -18 -24 -30	-6 -12 -18 -24 -30	0 -6 -12 -18 -24

2.4.3 Conventional tests

It is important to conduct conventional tests pre Super-pave tests. There are conventional tests which are important as Penetration Test, Flash Point, and Softening Point. This is to ensure that asphalt has correct physical properties (Rogers, 2003).

1- Penetration Test

The test is done according to AASHTO T49-07(2011) and ASTM D5-06, the Penetration test is the oldest asphalt test, this test method covers determination of the penetration of semi-solid and solid bituminous materials. The basic principle of the test is finding consistency of a bituminous material which expressed as the distance in tens of a millimeter that a standard needle vertically penetrates a sample of the material under the following conditions: Load = 100 grams, Temperature = 25° C and Time= 5 seconds. Figure (2-6) shows penetration test equipment.

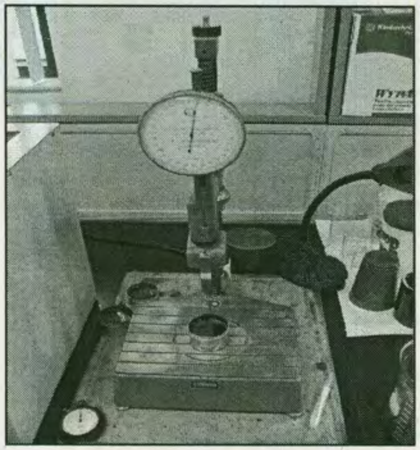


Figure (2-6) Penetration Test Equipment

2-Softening point Test

This test is done according to AASHTO (T53-09) and ASTM D36-06; it is defined as the temperature at which a bitumen sample can no longer support the weight of a 3.5 g steel ball. This test method covers the determination of the softening point of bitumen in the range from 30°C to 157°C using the ring-and-ball apparatus immersed in distilled water. Figure (2-7) shows the equipment used to apply the test.

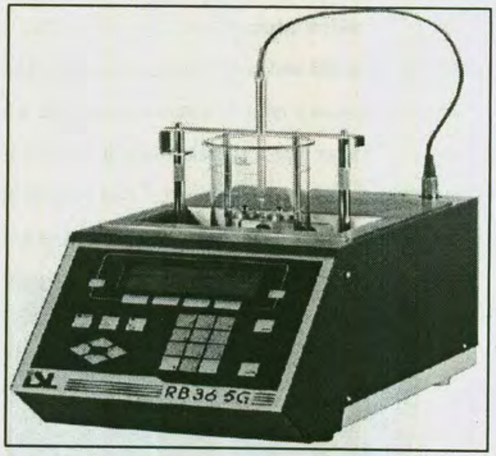


Figure (2-7) Softening Point of Bitumen Test Equipment

2.4.4 Super-pave Tests

The Super-pave tests contain the following:

1- Rotational Viscometer (RV) Test

This test evaluates high temperature workability and is conducted according to AASHTO (T 316-06), 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 binders at a constant temperature. This torque is then converted to viscosity and displayed automatically by the RV. In order to have adequate mixing and pumping capabilities, Super-pave specifications under (AASHTO M320) requires the binders to have a rotational viscosity less than 3.0 Pa.s at 135 °C. The equipment is showed in figure (2-8) below.

A-Rotational Viscometer Equipment. **B- Viscometer Device.**

Figure (2-8) Rotational Viscometer Test Equipment Set

2- Dynamic Shear Rheometer (DSR):

The Dynamic Shear Rheometer (DSR) is a measure of materials stiffness (AASHTO T315) performed at multiple temperature (environmental chamber). It is used in the Super-pave system for testing medium to high temperature viscosities (the test is conducted between 46°C and 82°C); it is used to find maximum temperature and intermediate temperature which asphalt binders could bear under the service. It is important to note that this test will be conduct in three stages (neat asphalt, after rolling thin film oven test RTFOT and after pressure adding vessel test PAV). The DSR test uses two circulate thin plates to conduct, the lower plate is fixed while the upper plate oscillates back and forth across the sample at 1.59 Hz (10 radians/sec) to create a shearing action(Roberts et al., 1996). Figure (2-9) shows DSR equipment.

Figure (2-9) DSR Test Equipment

The Dynamic Shear Rheometer (DSR) is used to characterize the viscous and elastic behavior of asphalt binders. Operational details of the DSR can be found in (AASHTO, TP5). Figure (2-10) shows the oscillating process.

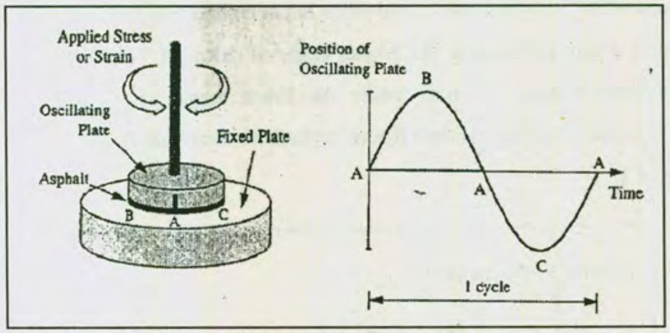


Figure (2-10) Oscillating Process in DSR Test (Roberts et al., 1996)

As asphalt is viscoelastic material, it has different properties in the same time, in the medium to high temperature range it behaves partly like elastic solid and a viscous liquid (Super-pave fundamental, 2010). Figure (2-11) below shows the illustration of this property.

Ʈ; Shear stress, γ; Shear strain and Δt; Time log

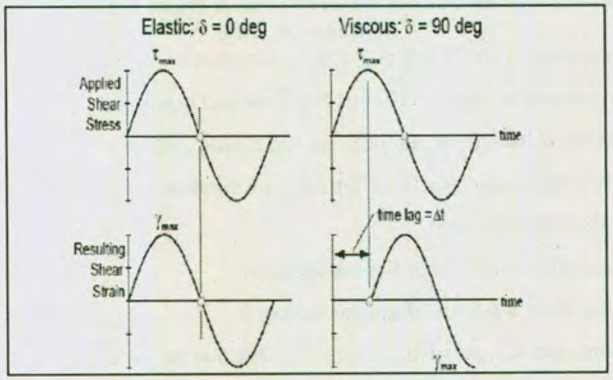


Figure (2-11) Elastic and Viscous Property of Asphalt (Super-pave fundamental, 2010)

Figure (2-12) shows the relationship between viscous & elastic behavior of two samples of asphalt binders, the higher angle of delta (δ) the more tendencies of asphalt binders toward viscosity while the lower angle of delta (δ) the more tendency toward elasticity, in this figure asphalt binders sample 2 is more elastic than asphalt 1.

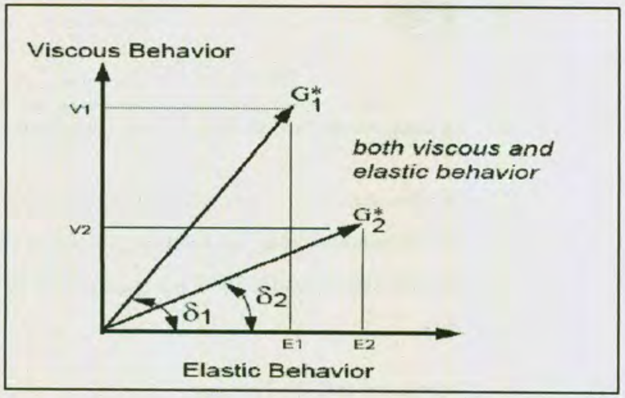


Figure (2-12) The Relationship between Viscous & Elastic Behavior (Super-pave fundamental, 2010)

The parameters of figures (2-10 to 2-12) are as follow:

δ-delta; is face angle between viscous behavior and elastic behavior, it establishes the relationship between viscous stiffness and elastic stiffness.

G*; Complex shear modulus, it is the ratio of maximum shear stress (Ʈ max) to maximum shear strain (γ max).

G^*_1; complex shear modulus of asphalt sample 1

G^*_2; complex shear modulus of asphalt sample 2

The equations used for calculating torque in DSR test are as follow:

Ʈ max = 2T/πr3... (2-1)

γ max = $\boldsymbol{\delta}$ r/h.. (2-2)

Where;

T = maximum applied torque, r = radius of specimen/plate (either 12.5 or 4 mm), $\boldsymbol{\delta}$ = deflection (rotation) angle and h = specimen height (either 1 or 2 mm).

3- Rolling Thin Film Oven Test (RTFOT)

The Rolling Thin Film Oven Test ASTM (D2872) was developed to simulate short term 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.

In this new approach, the sample being placed in rotating shelves instead of pans; the samples are poured into specially designed bottles, and these bottles are placed into a vertically rotating rack in an oven maintained at 163°C within 85 minutes. The residue from the rolling thin film oven test is subsequently tested to determine the effects of aging. Figures (2-13) shows the equipment.

A- RTFO Device (http://www.humboldtmfg.com)

B- RTFO Jars (www.pavementinteractive.org)

Figure (2-13) Rolling Thin Film Oven Test (RTFOT)

4- Mass Loss Test

This test is for determination of loosed amount of bitumen by a certain heating, it shows the amount of water mixed into the bitumen and determines the mass of water evaporating by heating from bitumen ASTM (D2872). This test is a part of RTFOT.

5- Pressure Aging Vessel (PAV) test

The Pressure Aging Vessel is a method of aging asphalt to simulate the effects of long term aging in the field. The procedure of testing is according to (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 Super-pave to simulate approximately 5 to 10 years HMA pavement service. The PAV is an oven-pressure vessel combination that takes RTFO aged samples and expose them to high air pressure (2070 Kpa) and temperatures of (90°C, 100°C or 110°C) depending upon expected climatic conditions for 20 hours. Figure (2-14) bellow shows the test devices.

Figure (2-14) Pressure Aging Vessel (PAV) Equipment (Super-pave Fundamentals, 2010)

6- Bending Beam Rheometer (BBR) test

The Bending Beam Rheometer (test procedure according to ASTM D6648 and AASHTO T313) used for measuring stiffness of asphalt based on measured deflection and standard beam properties. It is used in the Super-pave system to test asphalt binders at low temperatures where the chief failure mechanism is thermal cracking. The BBR basically subjects a simple asphalt beam weighted (100-g) and load over 240 seconds. Then, using engineering beam theory to measure the stiffness, the BBR calculates beam stiffness (S (t)) and the rate of change of that stiffness (m-value) as the load was applied are calculated based on the following equation:

$S(t) = PL^3 / (4 bh^3 \delta(t))$ .... (2-3)

Where:

S (t) = Creep stiffness MPa, at time t = 60 seconds

P = applied constant load (980 ± 20 mN) in Newton, obtained using a 100 g load.

L = distance between beam supports

=102 mm, (beam length = 127 mm).

b = beam width

= 6.35 mm

h = beam thickness

=12.7 mm

δ (t) = deflection at time, t

= 60 seconds

Two parameters are evaluated with the BBR test; creep stiffness and creep rate or (m-value) unit is in (MPa), evaluation will be based on creep stiffness value and m- value that should satisfy both criteria.

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 binders relaxes under load. Super-pave specifications AASHTO (M320) requires that the creep stiffness (which is a measure of how the asphalt resists constant loading) at the specified grade temperature must be less than or equal to 300 MPa at 60 seconds and creep rate m-value (which is a measure of how the asphalt stiffness changes as loads are applied) greater than or equal to 0.300 at 60 seconds. Figure (2-15) describes the relationship between creep stiffness and time of loading the slope is m-value.

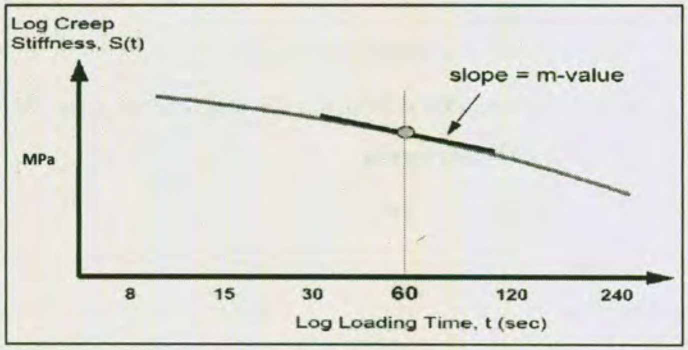
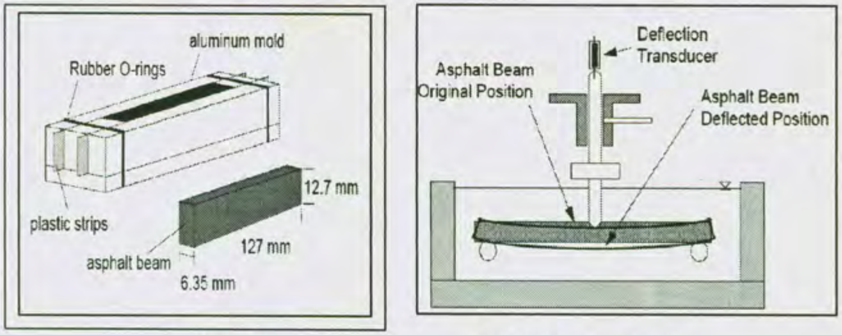


Figure (2-15) Rate of Change of Stiffness with Time (Super-pave Fundamentals, 2010)

Figure (2-16) below, describes the detail of beam casting and all related dimensions.



A- Beam dimensions **B- BBR test explanation**

Figure (2-16) BBR Test Equipment (Super-pave Fundamentals, 2010)

7-Elastic Recovery

This test is used for asphalt evaluation. The process includes check elastic recovery for neat asphalt binders then after RTFO. The same tests will be conducted after adding polymer to asphalt. The test is made by ductility instrument for 10 cm declared at (ASTM D6084, 1997). The neat asphalt does not recover efficiently while modified asphalt is better (Zhu, 2015). Testing procedure is as following.

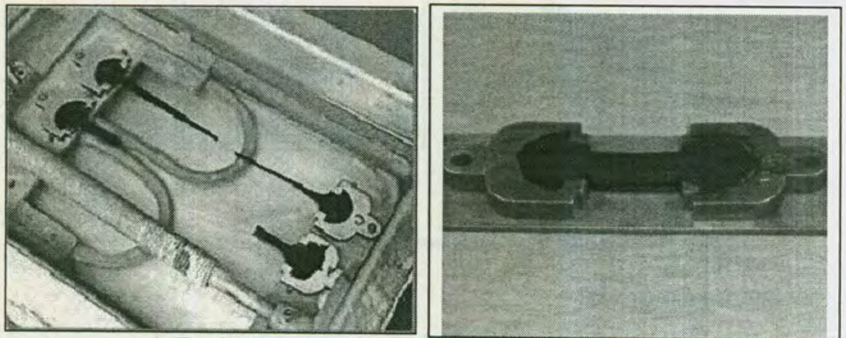
Measuring the percentage at which the asphalt binders residue will recover its original length after it has been elongated to a specific distance at a specified rate of speed and then cut in half, then distance to which the specimen contracts during a specified time is measured and the elastic recovery is calculated. Figure (2-17) shows test equipment. The elastic recovery could be found by this equation (ASTM, 1997):

Recovery %={ (E-X)/ E}* 100.. (2-4)

Where;

E=original elongation of specimen

X=elongation of specimen with several ends (cm).



A- Test Device B-Test Mold

Figure (2-17), Elastic Recovery Test Equipment (http://www.priasphalt.com)

2.4.5 Comparison between Penetration Test and Performance Grade Test

A significant comparison between Penetration test method and performance grade test by Super-pave is described on the table (2-2) (Roberts et al., 1996). The table shows that penetration limitations depend on both asphalt cement and asphalt residue grading systems, where;

AC; Asphalt cement

AR; Asphalt residue

Table (2-2) Prior Limitations vs. Super-pave Testing and Specifications Features (Roberts et al., 1996).

Limitations of Penetration, AC and AR Grading Systems	Super-pave Binders Testing and Specifications 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 binders will be used.	Test criteria remain constant, however, the temperature at which the criteria must be met changes in consideration of the binders 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 binders aging (thin film oven test) although long-term aging is a significant factor in fatigue cracking and low temperature cracking.	Three critical binders ages are simulated and tested: 1. Original asphalt binders prior to mixing with aggregate. 2. Aged asphalt binders after HMA production and construction. 3. Long-term aged binders.
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.

2.4.6 Super-pave Testing Procedures

Nowadays, most of the developed countries implement Super-pave technology (Super-pave Fundamentals, 2010). The Super-pave tests are shown in Table (2-3) and Figure (2-18). Testing should be implemented by steps, each step should be followed by the next. The DSR test considered as main test in performance grade tests (Bakløkk, et al., 2002).

Table (2-3) Super-pave Testing Procedure

Test name	Asphalt binders condition	Purpose of the test	specifications	Test Stage	ASTM Designation
Rolling thin film oven test	Original asphalt (Neat)	Short Term Aging	-	Second Stage	ASTM D2872
Pressure Aging vessel	RTFO Aged Asphalt	Long term Aging	-	Third Stage	ASTM D6521
Rotational Viscometer (RV)	Original asphalt (Neat)	Workability temperature	Max. 3Pa.s	First Stage	ASTM D4402
Dynamic Shearing Rheometer (DSR)	Original Asphalt	High temperature (Rutting)	$G^*/\sin\delta > 1.0$ Kpa	First Stage	ASTM D7175
	RTFO Aged asphalt	High temperature (Rutting)	$G^*/\sin\delta > 2.2$ Kpa	Second Stage	
	RTFOT and PAV Aged Asphalt	Intermediate temperature (Fatigue Cracking)	$G^*\sin\delta <$ 5000 Kpa	Third Stage	
Bending beam Reheometer (BBR)	RTFOT and PAV Aged Asphalt	Low Temperature (thermal cracking)	Stiffness (S) ≤ 300 MPa	Third Stage	ASTM D6648
			m-value ≥ 0.300		
Direct Tension Test (DDT)	RTFOT and PAV Aged Asphalt	Low Temperature (thermal cracking)	Failure strain. Min 1.0%	Third Stage	ASTM D6723

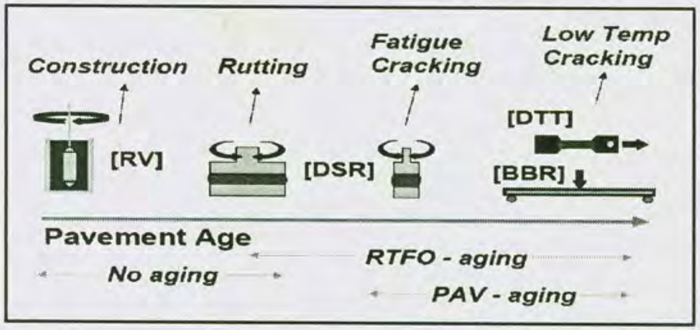


Figure (2-18) Super-pave Test Process (Super-pave Fundamentals, 2010)

Dynamic Shear Rheometer (DSR) test; is for the purpose of determining the rheological properties of Asphalt at high and intermediate temperatures.

Bending Beam Rheometer (BBR) test; is to determine the low-temperature rheological properties of asphalt binders.

Direct Tension Test (DTT); this is also to determine the low-temperature rheological properties of asphalt binders.

Rolling Thin Film Oven Test (RTFOT); simulates binders hardening during mixing with the aggregate stage.

Pressure Ageing Vessel (PAV) test; accelerates long-term binders ageing.

Rotational Viscometer Test; gives indication for workability of asphalt mixture.

All these tests of PG conducted on a wide range of temperatures staring from low to high. The Figure (2-19) below shows testing procedure with its specific temperature.

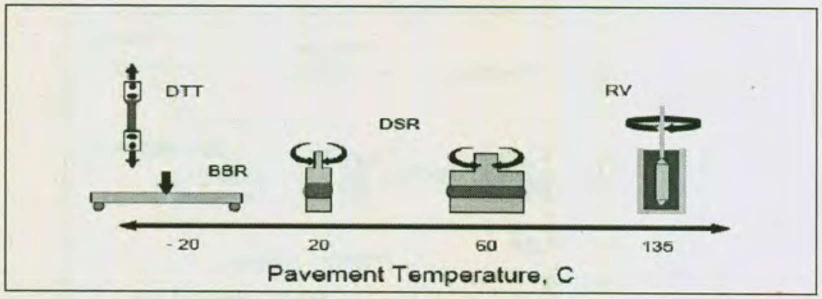


Figure (2-19) Temperature Range for PG Test. (Super-pave Fundamentals, 2010)

2.4.7 Selecting the Asphalt Binders PG

Selection of asphalt binders PG for road application depends on many factors like climatic conditions, traffic volume and traffic speed. There are different methods to deal with this subject like:

One method for selecting performance grade is Wisconsin-Dot binder selection guidance (Facilities Development Manual, 2015). In which a number of tables for traffic volume (ESAL), traffic speed and asphalt binders are used to select the performance grade. Following table shows selection of asphalt binder PG:

Project situation	Traffic volume, ESALS	Base type	Speed	PG specification
Rural Projects	>= 4 million	New & Overlay	-	PG58-28
Urban Projects; Sections turning, Stopping & Parking	>= 4 million	New	-	PG 64-28
Urban Projects	>= 4 million	-	=55mph(88.5kph)	PG64-22
Urban Projects	>= 10 million	-	=55mph(88.5kph)	PG70-28
Urban Projects	>= 10 million	-	>55mph(88.5kph)	PG64-28.

There is another method selects PG for asphalt binders according to Stratigic Highway Research Program SHRP criteria which developed a table for this purpose. It help designers in USA and Canada to select suitable performance graded asphalt binders based on loads, low and high pavement design temperature (Cominsky et al., 1994). Table (2-4) will be used based on the following steps:

1- Selection type of loading (speed of vehicles).
2- Moving horizontally to the high pavement design temperature.
3- Moving down the low pavement design temperature.
4- Identifying the binder grade. (if ESALS >10 million considers increase of one high temperature grade)

Table (2-4) Selection of Asphalt Binders Performance Grades

Recommendation for Selecting Binders Performance Grades								
Loads		High – Pavement Design Temperature °C						
Standing		28 to 34	34to 40	40 to 46	46 to 52	52to 58	58to 64	64to 70
(50kph) Slow Transient		34 to 40	40to 46	46 to 52	52 to 58	58to 64	64to 70	70to 76
(100kph)Fast Transient		34 to 46	46to 52	52 to 58	58 to 64	64to 70	70to 76	76to 82
Low – Pavement Design Temperature C	> - 10	PG 46-10	PG 52-10	PG 58-10	PG 64-10	PG 70-10	PG76-10	PG 82-10
	-10 to -16	PG 46-16	PG 52-16	PG 58-16	PG 64-16	PG 70-16	PG76-16	PG 82-16
	-16 to -22	PG 46-22	PG 52-22	PG 58-22	PG 64-22	PG 70-22	PG 76-22	PG 82-22
	-22 to -28	PG 46-28	PG 52-28	PG 58-28	PG 64-28	PG 70-28	PG 76-28	PG 82-28
	-28 to -34	PG 46-34	PG 52-34	PG 58-34	PG 64-34	PG 70-34	PG 76-34	PG 82-34
	-34to-40	PG 46-40	PG 52-40	PG 58-40	PG 64-40	PG 70-40		
	-40 to -46	PG 46-46	PG 52-46	PG 58-46	PG 64-46			
	Note	Alaska – Canada Northern U.S.		Canada North U.S.	Southern U.S.	Southwest U.S.-Desert Continental U.S.-Slow/ Heavy Traffic		

2.4.8 Polymer Modification

Polymer modification of asphalt binders is essential in field of asphalt pavement. Polymer improves property of asphalt binders, it leads to improvement of stiffness at both low and high temperatures (Chakroborty and Das, 2010). It also improves resistance to permanent deformation, thermal cracking, fatigue cracking, and moisture damage (Fwa, 2006).

Asphalt should be visco-elastic not plastic, when polymer concentration and asphalt compatibility allow a continuous polymer network to be established, modification is provided by a strong elastic network. This network increases the stiffness, viscosity and elastic response of the mixture especially at high temperature. The rheological properties of polymer modified asphalt (PMA) will depend on polymer type, content and compatibility

Sources emphases on using polymer modification to achieving the required performance grade PG especially when the range of PG is wide. As a rule of thumb, performance grades with a numeric difference of greater than 92 require polymer modified asphalts (Fwa, 2006), (i.e., PG 72-22).

Polymer contribution in asphalt industry goes back to nineteenth century, but the most effective contribution was in 1980 after SHRP recognition for using polymer in asphalt modification. A history of polymer usage is shown below:

• 1873; Latex from the balata plant (patent).

• 1902; First rubberized bitumen in France.

• 1930's; British and French recognize benefits for rubberized roads.

• 1945 – 1980s; SBS, SBR, EVA, PE, Neoprene.

• Late 1980s; US Federal Government encourages research into PMA under SHRP.

2.4.9 Types of Polymer

Evaluation of asphalt behaviors used in pavements is assessed based on providing durable surface in terms of impermeable, good binding and elastic enough to resist rutting, fatigue and thermal cracking (Rangwala, 2007). Most of the time, neat asphalt did not satisfy the required performance grade and therefore, it needs polymer modification. It is important to know which types of polymer give better result in terms of performance grade for asphalt binders whether elastomer or plastomer and with what percentages?(Fwa, 2006).

Polymer has petrochemical origin, it is produced from crude oil base (Yen and Chilingarian, 2000). There are many types of asphalt modifiers, some are organic and others are chemically manufactured (Nikolaides, 2015). Common types of polymer are:

A-Thermoplastic Elastomers (elastomeric polymer)

This type is used in pavement work, it behaves as elastic materials (Nikolaides, 2015), and its major types are:

-SBS styrene-butadiene-styrene (SBS).

-SB styrene-butadiene (SB).

-Elvaloy RET (custom designed polymer from DuPont).

-Radial Styrene-Butadiene-Styrene (SBS-R).

-Linear Styrene-Butadiene-Styrene (SBS-L).

-Styrene-butadiene-rubber (SBR).

-Poly/Butadiene (PB)

B- Thermoplastic Plastomers

This type is not common as elastomer. However, sometimes it used in pavement works. Its behavior is as plastic materials (Nikolaides, 2015), the major types are;

-Polyethilene (PE).

-Low Density Polyethilene (LDPE).

-High Density Polyethilene (HDPE)

-Ethylene Vinyl Acetate (EVA).

-Ethylene-Methyl Acetate (EMA).

-Atactic Polypropylene (APP).

-Isotactic Polypropylene (IPP).

-Poly Olefins (PO).

C- Polyphosphoric Acid

This type of polymer often used in combination with polymer in order to stabilize the modified asphalt. Also it improves the storage ability of polymer modified asphalt. This polymer increases stiffness of bitumen in high temperature (Moisture Sensitivity of Asphalt Pavements, 2003).

D- Recycled Crumb Tire Rubber

There are several tire rubber modified asphalt methods as wet, dry, terminal blend and terminal blended (Hybrid) (www.asphaltroads.org). The use of this type of product is encouraged in most of European countries for environmental reasons.

2.4.10 Effects of Polymer on Asphalt Binders

Polymer has many effects which can be counted as advantages for asphalt binders in terms of some rheological properties. In the same time, it has disadvantages in terms of other properties. One of the disadvantages is increasing the stiffness of the bitumen. The higher grade PG (82-22), the stiffer bitumen and have more ability to resist the rutting while lower resistance for thermal cracking. Therefore, to achieve the targeted performance grade, the structural and chemical changes should be observed and evaluated during the process of asphalt polymer-modification. Adding polymer to asphalt will lead to a series of changes in chemical composition of bitumen structure (DOĞAN, 2006); Figure (2-20) below shows the schematic structure of thermoplastic elastomers when added to asphalt.

Amount and type of adding polymer, will depend upon the required performance properties of the pavement. The percentage plays an active role in gaining the required object. This percentage will be found through a process of trials which are executed in laboratory to get best percentage. Also it is important to mention that different types of polymer and different percentages have different effects.

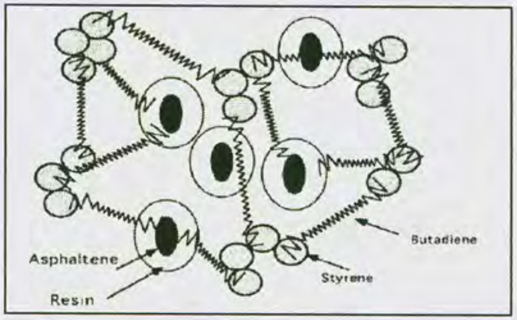


Figure (2-20) SBS Interacts with the Asphaltene Forming a 3D Network (DOĞAN, 2006)

2.5 Performance Grade Zoning Process

Performance grade (PG) zoning for any country should be found in order to help pavement designers to select the right asphalt for projects in specific field. Classification and performance zoning will be based on temperature range of the concerned area. Some sources put a procedure for this selection; for example, in USA designers may select binders based on the geographic location of the pavement, the design pavement temperatures or the design air temperatures which are then converted to design pavement temperatures (Garber and Hoel, 2009).

The zoning process extremely depends on weather data and geographic compositions of the concerned areas. For example, in Saudi Arabia, with area of 2,150,000 km^2, there are only 4 PG zones; PG 76-10, PG 70-10, PG 64-10 and PG 58-10" (Abdulwahhab et al, 1997). While in Pakistan, of 796.095 km^2 area, there are 6 PG zones (Mirza et al., 2011).

2.6 Previous Studies

2.6.1 Local Studies

(Alani et al., 2010) tried to highlight the importance of performance grading system in asphalt pavement application and attempted to implement PG system without the need for Super-pave equipment in Iraq. His study includes the development of a performance based system employing the conventional test methods and available nomographs from literature. He showed that climatic data, traffic data, and asphalt binders properties can be combined to propose major improvement for the specifications of asphalt in Iraq.

The five cities Mousl, Kirkuk, Rutba, Baghdad, and Basrah were examined to establish the required PG of asphalt binders for each city. The currently local used asphalt cement was examined with penetration grades of (40-50) and (60-70) which are tested by both conventional test method and Super-pave test method to determine the equivalent performance grade for each type of the penetration graded asphalt. Capabilities for those two types of asphalt cement were evaluated to satisfy the required performance of pavement for each city. The result indicates that both new proposed and super-pave method give the same final performance grade. The asphalt with penetration of 40-50 is equivalent to PG70-16 while with penetration 60-70 is equivalent to PG 64-16.

(Aljumaly, 2010) believed that the Iraqi general specifications for roads and bridge (SORB) till the time of the study, did not adopt the performance grade PG system of Super-pave method in evaluation of asphalt cement. The asphalt concrete mixtures should be prepared in order to ensure that paving materials conform to Super-pave mix design requirements.

For the purpose of conducting Super-pave, temperature data were collected for a period of 20 years and covered 7 areas in Iraq (Kirkuk, Mosul, Rutba, Baghdad, Kut, Najaf and Basrah) which represent areas with different climate conditions. Two asphalt cement penetration grades were considered (40-50) and (60-70) which are obtained from the Daurah refinery south-west of Baghdad.
Finally, three types of relationships between (Penetration test and Rotational Viscosity test), (Penetration test and Dynamic Shear Rheometer test) and (Penetration test and Bending Beam Rheometer test) were developed for estimation of Super-pave tests depending on penetration value.
The seven areas of Iraq were changed into four zones as shown in table (2-5).

Table (2-5) Iraq Performance Grade

Region	PG
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) could be used for required PG (70-16), PG (70-10) and PG (76-4), while asphalt with penetration grade (60-70) is equivalent to PG (64-10).

2.6.2 Neighbor Studies

(Asi et al., 2006) generated a performance grading map for Hashemite Kingdom of Jordan. The map divided the country into different zones according to highest and lowest temperature ranges that the asphalt pavement might be subject to. The grade zones are PG (64-10), PG (64-16) and PG (70-10). The local produced asphalt in Jordan with penetration grade 60-70 was tested and was equivalent to performance grade PG (64-16).

It discovered that the locally produced asphalt can be used without the need for modification in all parts of Jordan except some areas like Aqaba, Ruwaishied, and Ghorsafi. In these areas, the local asphalt should be modified to shift its grade to PG 70-10. The local materials, loading and environment conditions examined, and a comprehensive study of the performance of two mixes designed using Super-pave and Marshall Mix techniques. Samples of both mixes were prepared at the design asphalt contents and aggregate gradations and were subjected to a comprehensive mechanical evaluation testing as Marshall Stability, Loss of Marshall Stability, Indirect Tensile Strength, Loss of Indirect Tensile Strength, Resilient modulus, Fatigue life, Rutting and Creep. In all the performed tests, Super-pave mixes proved their superiority over Marshall Mixes.

(Saglik et al., 2012) utilized from polymer modification to evaluate the local asphalt binders in Turkey. In this regards four different penetration grade bitumen samples from the all four crude oil refineries of Turkey were selected, one is of distinctly higher asphaltene content. All asphalt samples were modified with SBS, Elvaloy, SBR and Lucobit modifiers. Both unmodified and polymer modified bitumen were subjected to conventional and Super-pave binders performance tests, namely penetration, softening point, force ductility, rotational viscometer (RV), rolling thin film oven (RTFO), dynamic shear rheometer (DSR) and bending beam rheometer (BBR) . The results showed that the base asphalt of the high aphaltene content refinery and its modified bitumen have generally one grade better performance grade than the others, which was verified by polymer dispersion tests.

(Hassanpour, 2014) conducted a survey of applied bitumen based on PG, climatic and traffic conditions to find the adoptability of applied bitumen specifications to the Shiraz Province -Iran. Using environmental conditions and an experimental study on hot asphalt, Marshall, aggregate and base layer samples were carried out. These tests included temperature of pavement, Coarse and Fine Aggregate Angularity, Sand Equivalent, Coarse and Fine Aggregate and Los Angeles test, Resistance, Softness, Breakage, Deformation, Specific Gravity, Moisture of fine aggregate, Density, Aggregate Grading, LL, PL, PI, Empty space of asphalt, Compaction, Thickness of asphalt, Thickness of base layer, Space filled with bitumen, Bitumen/mixed asphalt, Bitumen / asphalt without bitumen, Empty space asphalt, aggregates and aggregate filled of bitumen.

The ESRI ARC GIS 10.2 Software program was used to depict a performance grading map to Iran. According to the highest and lowest available temperature ranges of the asphalt, the country was divided into different zones. The asphalt properties with light, medium and heavy traffic were obtained in full agreement with required standard specifications of asphalt for roads with heavy, medium and light traffic loads wearing course belong to case study (which represent Shiraz province).

Three climatic zones were obtained for Shiraz province based on the PG results. Locally produced asphalt can be used without the need of modification in all parts of case study province. Local aggregate meet both requirement properties and source properties.

(Abdulwahhab and Abaker, 2003) tried to use the effect of polymer modification in evaluation of locally produced asphalt binders in Saudi Arabia. Ten polymers were identified as potential asphalt modifiers based on their physical properties and chemical composition. After preliminary laboratory evaluation for the melting point of these polymers, five polymers were selected for local asphalt modification. In the initial stage, required mixing time was decided based on the relation between shear loss modules and mixing time.

The optimum polymer content was selected based on Super-pave binders performance grade specifications. The suitability of improvement was verified through the evaluation of permanent deformation and fatigue behavior of laboratory prepared asphalt concert mixes. The result indicated that the rheological properties of modified binders improved significantly with sufficient polymer content (3%). The aging properties of the modified binders were found to be dependent on the type of polymer. The fatigue life and resistance to permanent deformation were significantly improved due to enhanced binder's rheological properties. At the end, it was concluded that local asphalt can be modified using thermoplastic polymers.

2.6.3 Other Studies

(khedr et al, 2008) presented developing of asphalt binders performance grade PG requirements according to Super-pave. The PG is suitable for different climatic conditions all over Egypt. Twenty one weather stations covering Egypt were selected, then, after analysis of their air temperature, data was converted to pavement temperatures.

Three models were used to predict pavement temperature from air temperature. Long term performance pavement LTPP model was selected to predict low pavement temperature and consequently low PG grade. As for the high pavement temperature prediction, both LTPP and the performance model were used to select the high PG grade. The later was an improved performance model applied to identify the high temperature PG grade for asphalt binders based on the rutting damage concept.

The converted pavement data were used to propose asphalt binders performance grades (PG) for various regions of Egypt. It found that when the LTPP model is considered, Egypt could be divided into 3 zones. The change in zones is for high PG whereas for low PG remains constant all over Egypt. The proposed grades range from PG52-10 to PG76-10 depending on the location, the applied model, and the degree of project reliability.

(Abdullah, 2008) investigated the application of Super-pave system in West Bank region (Palestine) through performance grade determination. Temperature data were obtained from directorate of meteorology belongs to the Ministry of Transportation. The analysis of data showed that most of Palestinian areas require one type of asphalt binders which is PG (64-10) excluding Jericho, which requires PG (70-10).

Based on a study conducted in Jordan about the properties of local asphalt binders, which is the same type of binders used in West Bank, it appeared that it has the same properties of PG (64-10). Therefore, the local asphalt binders with the same performance grade properties could be used for all area of West Bank-Palestine regions excluding Jericho. Furthermore, several special cases were studied such as low traffic, standing traffic, and heavy traffic volume. The optimum binders for these cases were determined accordingly.

(Merza et al. 2011) documented the initial ground work towards implementation of Super-pave mix design for establishing high and low geographical temperature zones in Pakistan. The temperature zoning was carried out by using temperature data obtained from 64 weather stations.

The SHRP and LTPP prediction models were utilized for predicting pavement temperatures. A significant difference was observed between the predicted pavement temperatures from both the models. The SHRP model gives higher, high temperature PG grade providing additional protection against rutting. Since rutting is the most common distress on flexible pavements in Pakistan. SHRP models at 98% level of reliability are recommended.

The study investigated that PG 70-10 binders was the most common grade that encompasses more than 70% area of Pakistan. However, currently none of the two local refineries produce PG 70-10 binders. This should be a concern for the highway agencies. The polymer modified asphalt binders produced by Attock refinery (A-PMB) corresponds to harder PG 76-16 while A-60/70 (PG 58-22) or K-60/70 (PG 64-22) produced at Attock and National refineries respectively are softer compared to the PG 70-10. Harder grade is more prone to cracking, whereas softer grade is more prone to rutting. Finally, it is discovered that the current construction practices which utilize A-60/70 or K-60/70 may be prone to excessive rutting.

(Prowell, 1999) evaluated performance graded (PG) binders for use in hot mix asphalt in Virginia-USA. Ten conventional viscosity-graded asphalt binders, representing the asphalt typically available in Virginia were selected under the PG system to develop a cross-reference with new system. Based on the past performance of viscosity graded asphalt and the PG binders testing, PG 64-22 binders were selected as the base grade of asphalt for Virginia-USA.

Laboratory studies were performed with the Georgia loaded-wheel tester and asphalt pavement analyzer to evaluate the use of increasing the high-temperature binder's grade for heavy or slow-moving traffic. Based on the success of these studies and field trial sections, two new mix types, SM-2D and SM-2E, both 50-blow Marshall Mixtures with PG 70-22 and PG 76-22 binders, respectively, were developed. A lower laboratory compaction effort will increase the asphalt content for durability, and the stiffer binders will prevent rutting.

A large database of field rut depth data was developed for Virginia Department of Transportation surface mixes with the asphalt pavement analyzer. The data were used to estimate maximum rut depth criteria for quality assurance and evaluation of future asphalt mix designs, binders, and stabilizers.

(Ven et al., 2004) tried to show how the Bitumen Test Data Chart (BTDC), and the Van Der Poel nomograph figure (2-21), which is based on penetration and softening point, could be used to link the empirical test results to performance related properties such as stiffness and strength and how these derived measures could be linked to traffic volume, traffic speed and pavement design temperatures similar to the Super-pave PG system.

The approach is used to discuss the current South Africa Specifications and to propose a possible performance grading system for South Africa using actual climatic and traffic data.

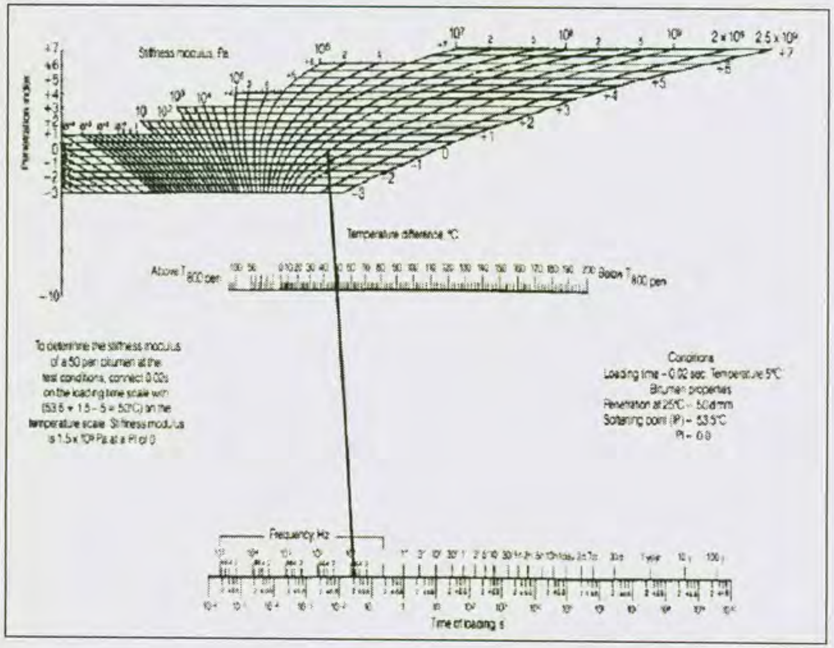


Figure (2-21) Van der Poel Nomograph (Demirci, 2010)

CHAPTER THREE
EXPERIMENTAL PROGRAM

The program of this work consists of two main parts, performance grade zoning for Kurdistan Region-Iraq and Super-pave tests. The procedure of collecting (gathering) the data in this research work are as follow;

3.1 Performance Grade Zoning for Kurdistan Region-Iraq

3.1.1 Introduction

In general, performance grading is reported using two numbers, the first is average seven-day maximum pavement temperature in (°C) and the second is minimum pavement temperature likely to be experienced in (°C). Thus, a PG 82-16 could be used for an area having a climate with the average of seven-day maximum pavement temperature equal to 82°C and the minimum pavement temperature equal to -16°C.

The first step of performance grade determination is finding out pavement temperatures based on air temperature for the specific area (NCHRP, 2011). The zoning procedure is explained in the flow chart in Figure (3-1).

3.1.2 Data Collection

The air temperature data collected from meteorology centers for the last fourteen years, and the mean for maximum and minimum air temperatures were found. In order to control and classify the concerned data of maximum and minimum air temperatures, different regions for every governorate and administration of Kurdistan Region-Iraq were established. The classification is based on closeness of temperature data of each region. Each station represents a city center or district.

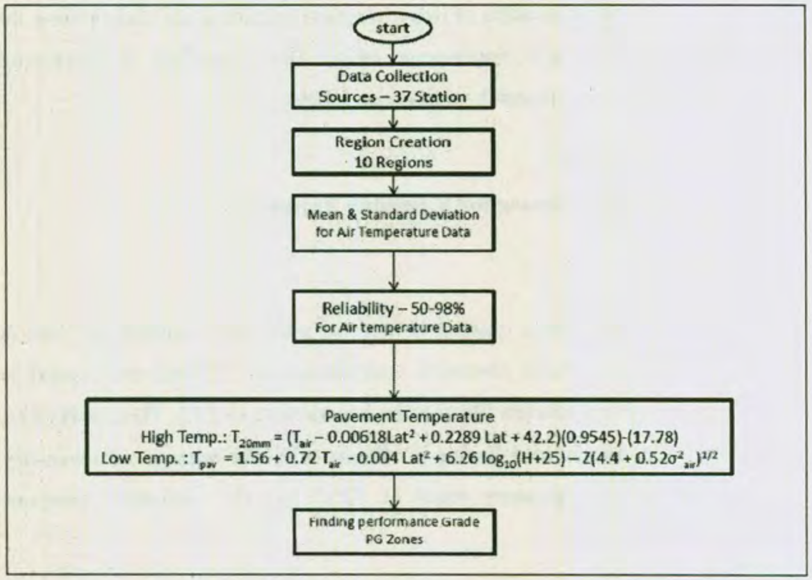


Figure (3-1) Flow Chart of Zoning Procedure

3.2 Super-pave Tests

3.2.1 Overview

The experimental program used in this research is to achieve benefit from modern technology tests and develop the local asphalt performance grade for Kurdistan Region-Iraq. A number of traditional and Super-pave asphalt tests have been performed in Hawler Construction Laboratory.

In Kurdistan Region-Iraq, there are three main oil refineries (Lanaz bitumen & oil refinery, located in Erbil governorate, Phoenix bitumen production plant in Sulaymaniyah governorate and KAT Plant for Asphalt & Lub Oil in Kirkuk). These refineries are petroleum refineries with ability of producing thousands of tons of asphalt per day. These refineries working since 2010 are licensed from concerned institutions of Kurdistan regional government and are specialized in bitumen production.

The historical background of tests is shown in Tables (C-1) to (C-6) in Appendix C. All the tests were done according to Iraqi specifications (SORB, 2003, p R9) and (ASTM, D36, D113, D70, D92, D2872).

All asphalt binders samples for this research are taken from the three mentioned refineries and tested in Hawler Construction Laboratory which owned the required conventional and Super-pave test devices. Figure (3-2) shows the flow chart of experimental program of this part of research work.

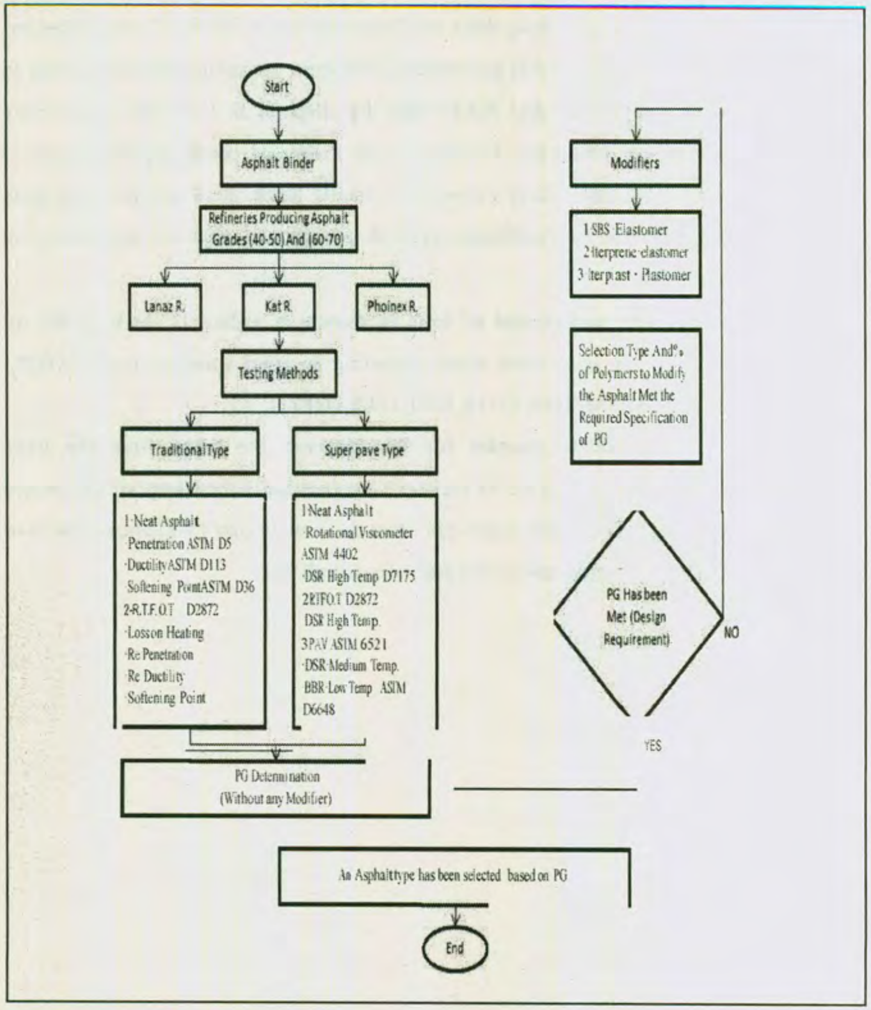


Figure (3-2) Flow Chart of Super-pave Tests

3.2.2 Materials, Resources and Storage

For the purpose of conducting experimental work for the present research, two asphalt grades of 40-50 and 60-70 (as they are used widely in Kurdistan Region-Iraq projects) from three local refineries were selected as first stage for testing. The Iraqi specifications for roads and bridges and its amendment under item R9 puts three penetration grades of bitumen (40-50), (50-60), and (60-70) (SORB, 2003). While AASHTO puts five penetration grades (40-50), (60-70), (85-100), (120-175) and (200-300).

In order to conduct Super-pave tests and find performance grade of local asphalt binders it is important to check asphalt cement through conducting conventional tests. In this regard, the penetration group test considered as mandatory test for asphalt before starting Super-pave tests (Read and Whiteoak, 2003).

3.2.3 Sampling Method

Three groups of asphalt samples were brought from the three refineries Lanaz, Kat and Phoenix. Each group of samples weighted 40 kg for both grades of (40-50) and (60-70). From these samples, approximately 10 kg of asphalt were used for conventional tests, 10 kg for Super-pave performance grade tests for neat asphalt, and 20 kg for Super-pave performance grade tests for polymer modified asphalt. The sampling procedure was according to AASHTO (T40-1) and ASTM (T140-00).

3.2.4 Conventional Tests

Samples were brought to laboratory in August 2015 and conventional tests conducted were; Penetration, Ductility and Softening Point. All the tests were done according to Iraqi specifications (SORB, 2003). Same samples were tested after aging by Rolling Thin Film Oven Test (RTFOT) and according to same Iraqi specifications mentioned before for Loss on Weight, Re-Ductility, Re-Penetration and Softening Point.

3.2.5 Super-pave Performance Grade (PG) Tests

After conventional tests were finished, Super-pave performance grade tests were conducted as second stage of testing according to following procedures:

1- Testing for original bitumen (OB): It includes Flash Point temperature test (AASHTO T48), Rotational Viscometer (RV) test maximum 3 Pa.s (poise) (ASTM4402), and Dynamic Shear Rheometer (DSR) test (T315).

   DSR test will be conducted for original bitumen OB (neat) to determine true grade based on calculation of G*/sin δ value that should not be less than 1.00 kPa, and after aging by Rolling Thin Film Oven Test to determine the true grade based on calculation of G*/sin δ value that should not be less than 2.20 kPa.

2- DSR test, after long aging by Pressure Aging Vessel, was conducted to determine the stiffness value at intermediate temperature based on calculation of G*sin δ value that should not exceed 5000 kPa.

3- BBR test, after long aging by Pressure Aging Vessel, was conducted, to determine both the stiffness and m-value at low temperature based on calculation of stiffness value that should not exceed the 300 MPa and m-value which should not be less than 0.300 Mpa.

It is worth of mentioning that results were compared with performance graded asphalt binder specifications shown in Table (2-1).

3.2.6 Polymer Types Used For Modification of Asphalt

The polymer modified asphalt tests are considered as third stage of testing in this research. Local asphalt samples were used from Lanaz and KAT plant for refineries. The asphalt binders samples were of grades (40-50) and (60-70). Polymers which are used are of two types of Elastomer / SBS and one type of Plastomer. The percentages of 0.5%, 1.0%, 2%, 4% and 6% respectively of polymer by weight were used in asphalt binder modification. The three types of polymer were used in this research are as following:

1- Styrene-Butadiene-Styrene Copolymer SBS (Kraton D1192)

The Kraton D1192 polymer SBS family of polymers (with its series of products; D1118, D1120, D1122, D1133, D1144, D1151, D1153, D1155, D1184, D1190, D1192), is one of common types of polymer which are used in Middle East (Kraton, 2004). This SBS is from elastomers type of polymer and is directly mixed with bitumen before mixing it with other components of asphalt mixture, Kraton D1192 is chemically manufactured (DOĞAN, 2006), with following properties:

The color of the polymer is white
Molecular Weight KM=1 kg/mol
Polystyrene Content KM=3%m
Vinyl Content KM=3%
Triblock Content KM=1% Total
Extractables KM=5%m Volatile
Matter KM=4%m Antioxidant
Content KM=8%m
Specific Gravity according to ISO 2781 should be=0.94 and

Bulk Density according to ASTM D1895 method B should be 0.4 kg/dm^3

2- Iterprene SBS G-L

It is an elastomer type of polymer with linear structure which is composed of SBS in soft granules used for modification of asphalt mix with high performance characteristics in order to provide a high mechanic resistance. The physical properties are (Iterchimica, 2015):

Soft granules

Color-white/pale yellow

Melt Index-<1g/10 min

Specific gravity-0.93 to 0.95 g/cm^3

Stirene-30-32 wt. %

This type of polymer is used for road pavement construction in case of highways with heavy traffic loads, it also improves the characteristics of ring and ball, penetration, spring back (www.Iterchimica.it, 2015).

3- Plastomer/ ITERPLAST 1806;

This type of polymer combines qualities of elastomers and plastic, such as rubber-like properties with processing ability of plastic. It is from Iterchimica productions, having physical properties (www.Iterchimica.it, 2015) as;

Solid appearance

White color

Melting point / freezing point > 100°C

Relative density 0.94-0.96 kg/lit.

The chemical properties (www.Iterchimica.it, 2015) are:

Insoluble in water

Decomposition temperature =260 °C

Does not contain substances harmful to human health

Samples of first type of polymers were brought from Bastore asphalt plant (belong to directorate of road-Ministry of Construction and Housing). The second and third types were brought abroad from Italy / Iterchimica Factory in closed packages. A Figure of each type of these polymers is in Appendix D.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

This chapter discusses the results obtained from the analysis of the observed data. The details of Grade Zoning and Super-pave tests are discussed in the following paragraphs.

4.1 Generals

In this chapter, temperature data collected for grade zoning creation and results of tests will be presented for all three stages of testing, Pre Super-pave tests (Conventional tests), Super-pave tests for neat asphalt and Super-pave tests for polymer modified asphalt. Laboratory test results, material characterization, comparison of each group of tests and relationships were depicted.

4-2 Grade Zoning

The data and information were obtained from General Directorate of Meteorology and Seismology / Ministry of Transportation and Communication, they represent the data from different stations spread over Kurdistan Region-Iraq area. Some data are old with a long historic period while others are new and lasted for 2-4 years.

However, some information of maximum and minimum air temperatures was found from agriculture observation stations and UN-FAO documents, and then they added and merged together. For example, in some cases the first three rows of a specific table (for three years) belong to one source of information, while other rows belong to other sources.

The maximum temperature is counted in attitude of 1.2 m height from the earth surface and minimum temperature very close to earth surface. Appendix A contains all relevant tables for maximum and minimum air temperature for all stations through Kurdistan Region-Iraq. Last column of each table from (A-1) to (A-37) in Appendix A contains both minimum air and the highest maximum air temperatures of the specified year. Table (4-1) shows temperature stations distribution over Kurdistan Region-Iraq, and Figure (4-1) shows the map of air temperature stations.

Table (4-1) Temperature Stations Distribution over Kurdistan Region-Iraq

Governorate	Station Number	Note
Erbil	15	Total = 37 stations
Duhok	11	
Sulaymaniyah	8	
Germyan Administration	2	
Kirkuk	1	

Figure (4-1) Map of Kurdistan Region-Iraq, Location of Air Temperature Stations

4.2.1 Mean and Standard Deviation for Maximum and Minimum Air Temperatures

Mean and standard deviation of maximum and minimum values were counted. Tables (A-70) to (A-79) in Appendix A show calculation of mean and standard deviation for each region. Classification and distribution of stations to create regions for each governorate of Kurdistan Region-Iraq and Kirkuk governorate is shown in Table (4-2).

Table (4-2) Governorate, Region and Stations Classification

Governorate	Region	Stations
Duhok	One	Cani Masi, Bamerni, Batufa, Sharya and Amediye.
	Two	Duhok Center, Zhako, Atrosh, Denarta, Mangysh and Akre.
Erbil	One	Choman, Rawanduz, Haji Umeran, Shyrwan Mazn, Sidekan and Mergasur.
	Two	Pirmam, Shaqlawa, Koye and Soran.
	Three	Hawler Center, Khabat, Qushtepa, Ankawa and Makhmur.
Sulaymaniyah	One	Pynjween.
	Two	Halsho, Mawat and Qaladeza.
	Three	Sulaymaniyah Center, Bazian, Chamchamal and Halabje
Germiyan Administration	One	Kalar and Midan.
Kirkuk	One	Kirkuk center.

The mean and standard deviation of temperatures for regions were collected and presented in Table (4-3).

Table (4-3) Mean and Standard Deviation for Maximum and Minimum Air Temperatures

Name of Governorate	Region	Maximum air temperature		Minimum air temperature	
		Mean	Standard deviation	Mean	Standard deviation
Duhok	Region one	35.479	3.099	-3.875	4.959
	Region two	43.487	2.095	1.509	3.286
Erbil(Hawler)	Region one	33.263	3.103	-3.19	4.360
	Region two	40.4	2.012	0.72	2.903
	Region three	44.543	1.454	3.734	1.884
Sulaymaniyah	Region one	37.047	2.239	-17.483	4.299
	Region two	37.42	1.927	-0.90	3.882
	Region three	43.137	1.143	-0.17	3.395
Germyain Administration	Region one	45.95	2.568	-1.56	2.223
Kirkuk Governorate	Region one	47.03	1.208	-0.873	1.642

4.2.2 Reliability

The methodology for finding reliability is depending on the amount of information, the concerned meteorology institutions extend their scope of work in terms of establishing new stations, which were started just few years ago.

Many stations have worked for 2 years while they are very important for this research and ignoring them will narrow down understanding of performance grade in Kurdistan Region-Iraq area. However, high number and uniform distribution of stations are used to overcome this shortage.

The 98% reliability would be found by the following practical equations based on (Patrick, 2003):

$$T_{Max} \text{ at } 98\% = T_{Max} \text{ at } 50\% + 2.055 \times \sigma \text{ high Temp} \qquad \text{……….} (4\text{-}1)$$

T_{Min} at 98% = T_{Min} at 50 % - 2.055 ×σ low Temp............ (4-2)

Where:

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

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

σ 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.

σ low Tem = Standard deviation of low air temperature.

2.055 = Multiplier for 98% reliability.

For Erbil governorate (as an example):

Region 1; T_{max} at 98%; 33.26275+2.055* 3.102601= 39.6385 °C

T_{min} at 98%; -03.19-2.055*4.360194 = -12.15 °C

Region 2; T_{max} at 98%; 40.40+2.055*2.012091 = 44.534 °C

T_{min} at 98%; 0.72-2.055* 2.903078 = -5.24 °C

Region 3; T_{max} at 98%; 44.543+2.055*1.4542 = 47.531 °C

T_{min} at 98%; 3.734-2.055*1.883793 = -0.137 °C

Details of calculations for other regions are obtained in Appendix B. Table (4-4) shows 98% reliability for maximum and minimum air temperatures.

Table (4-4) Maximum and Minimum Air Temperatures (98% reliability).

Governorate	Region	Maximum Air Temperature(° C)	Minimum Air Temperature(°C)
Duhok	Region one	41.847	-14.06656
	Region two	47.7925	-5.243
Erbil	Region one	39.6385	-12.15
	Region two	44.534	-5.24
	Region three	47.531	-0.137
Sulaymaniyah	Region one	41.6492	-26.31
	Region two	41.379	-8.8775
	Region three	45.485	-7.148
Germyain	Region one	51.224	-6.127
Kirkuk	Region one	49.511	-4.2474

4.2.3 Pavement Temperature

According to Super-pave method, the high pavement temperature measured at 20 mm beneath the pavement surface and the following equation is used for this purpose (Patrick, 2003).

$$T_{20\ mm} = 0.9545\ [T_{air} - 0.00618\ lat^2 + 0.2289\ lat + 42.2] - 17.78 \quad \text{........ (4-3)}$$

Where:

T_{20mm}= 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.

-Calculation of maximum pavement temperature for Erbil (as an example) is as follow:

Region 1:

$T_{20\ mm}$=0.9545[39.6385-0.00618*(36.75)^2+0.2289(36.75) +42.2]-17.78 = 60.139 ° C.

Region 2:

$T_{20\ mm}$=0.9545[44.534-0.00618*(36.25)^2+0.2289(36.25) +42.2]-17.78 = 65.176 ° C

Region 3:

$T_{20\ mm}$ =0.9454[47.531-0.00618*(36)2 +0.2289(36) +42.2]-17.78 = 68.016 ° C

The low pavement temperature is calculated by the following equation (Patrick, 2003).

$$T_{pave.} = 1.56 + 0.72T_{air} - 0.004\ Lat^2 + 6.26\ \log_{10}(H+25) - Z\ (4.4 + 0.52\ \sigma^2_{air})\ ½ \quad \text{.... (3-4)}$$

H=0 (near to surface)

Z=2.055 for 98% reliability

σ ;standard deviation for low air temperature

Summary of maximum and minimum value of pavement temperatures are shown in Table (4-5), and the detail of calculations are available in Appendix B.

Table (4-5) Maximum and Minimum Pavement Temperatures.

Governorate	Region	Maximum pavement temperature ,(° C)	Minimum pavement temperature , (° C)
Duhok	Region one	63	-14
	Region two	69	-6
Erbil	Region one	61	-12
	Region two	66	-5
	Region three	69	-1
Sulaymaniyah	Region one	63	-22
	Region two	63	-9
	Region three	67	-7
Germyain	Region one	72	-5
Kirkuk	Region one	71	-3

The latitude values of the Kurdistan Region-Iraq and Kirkuk are shown in Table (4-6).

Table (4-6) The Latitude Values of (Kurdistan Region-Iraq & Kirkuk)

Governorate	Latitude Range (the x-coordination)	
Duhok	36.5	37.5
Erbil	35.5	37.5
Sulaymaniyah	35	36.5
Germyain	34.5	35
Kirkuk	35.5	35.5

4.2.4 Kurdistan Region-Iraq Zoning

Performance grades are shifted by 6°C. For high temperature, it covers (46, 52, 58, 64, 70, 76, and 82) C° and for low temperature (-10, -16, -22, -28, -34, -40 and -46) °C (AASHTO, 2007). In this regard, maximum pavement temperature range will be (46 to 82) °C and minimum pavement temperature range will be (-10 to -46) °C. A summary of PG specifications from AASHTO is shown in Table (4-7).

Table (4-7) Super-pave Binders Performance Grades (AASHTO M320)

#	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

Values of maximum and minimum pavement temperatures were closed approximately to values shown in Table (4-7). This is to match with international standard of performance grade. In this manner, values of maximum and minimum pavement temperatures for Kurdistan Region-Iraq in Table (4-5) rearranged as shown in Table (4-8).

Table (4-8) Suggested Performance Grade for Kurdistan Region –Iraq (In Terms Of Regions)

Governorate	Region	Maximum pavement temperature ,(° C)	Minimum pavement temperature , (° C)
Duhok	Region one	64	-16
	Region two	70	-10
Erbil	Region one	64	-16
	Region two	70	-10
	Region three	70	-10
Sulaymaniyah	Region one	64	-22
	Region two	64	-10
	Region three	70	-10
Germyain	Region one	76	-10
Kirkuk	Region one	76	-10

To deal practically with this distribution, the above table will be simplified and rearranged to express as zones in Table (4-9). The Figure (4-2) represents map of Kurdistan Region-Iraq explains all PG zones.

Table (4-9) Suggested Performance Grade Zones for Kurdistan Region-Iraq

Zones	Maximum pavement temperature, (° C)	Minimum pavement temperature, (°C)	(Region included)
Zone -1-	64	-16	Duhok-Region one, Erbil -Region one, Sulaymaniyah Region two.
Zone -2-	70	-10	Duhok-Region two, Erbil -Region two &three Sulaymaniyah Region three.
Zone -3-	76	-10	Germyain-Region-one, Kirkuk - Region one,
Zone -4-	64	-22	Sulaymaniyah Region one.

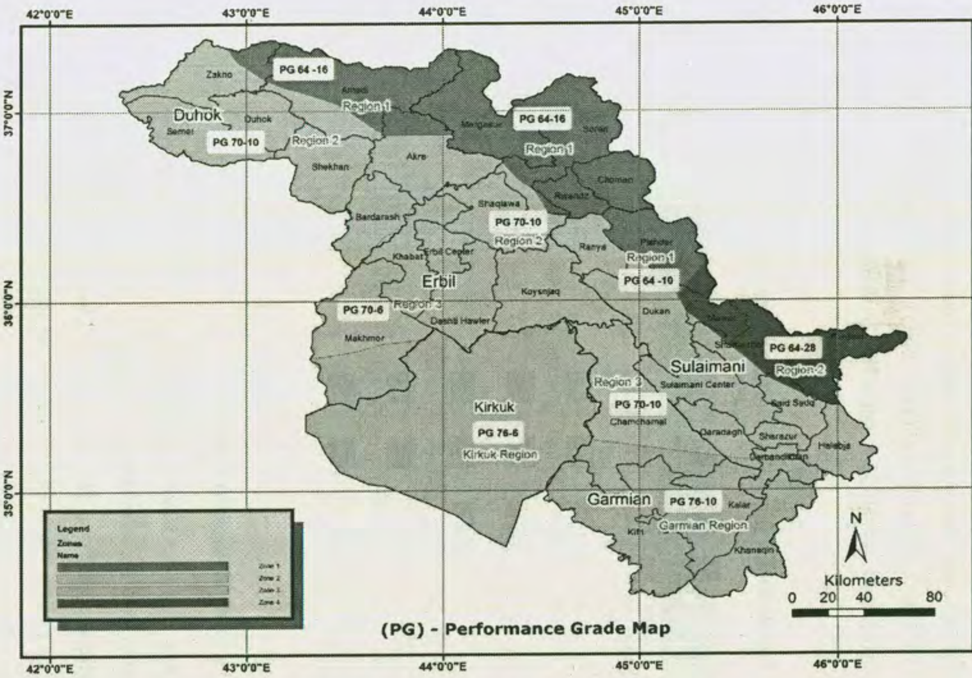


Figure (4-2) Map of Kurdistan Region-Iraq with PG Zone

4.3 Conventional Tests

Conventional tests were made for asphalt binders samples according to Iraqi specifications of roads and bridges (SORB, 2003); the results are shown in Table (4-10). All properties of asphalt were according to standard specifications (SORB, 2003).

Table (4-10) Conventional Properties of Samples of Asphalt for Different Refineries & Grades

Grade of Bitumen	40-50			60-70			*Standard Specification*	
Test Type	Lanaz	Kat	Phoenix	Lanaz	Kat	Phoenix	SORB / R9-07	
Penetration ASTM D5	44	47	47	66	69	69	40-50	60-70
Ductility ASTM D113	>100cm	>100cm	>100cm	>100cm	>100cm	>100 cm	>100cm	>100cm
Softening ASTM D36	53	53.6	53	48.5	48	48.2	51-62	48-58
Testing on Aged Sample (RTFO) ASTM D2872								
Loss on Weight	0.29%	0.35%	0.34%	0.37%	0.45%	0.48%	-	-
Re- Ductility	>26	>26	>26	>51	>51	>51	>25cm	>50cm
Re -Penetration	29	32	31	36	43	41	>55%	>52%
Softening	61	59.8	56	56.8	53	53.7	-	-

4.4 Super-pave Tests of Asphalt Binders

4.4.1 Super-pave Tests for Neat Asphalt Binders

Super-pave tests are conducted according to AASHTO (M320) and ASTM 6373 specifications procedure. The results of neat asphalt binder tests are shown in Tables (4-11) to (4-16). Table (4-11) shows the grade values of all three asphalt refineries samples which fixed to a high grade of 70°C.

Table (4-11) Super-pave Test Results for Penetration Grades (40 – 50)/ DSR for Original and after RTFO Test

Bitumen Reference	Testing condition	True Grade	Grade	DSR test - G*/ Sin δ , Kpa	
				Confirm Spec.	Not Confirm Spec.
Phoenix	Neat	71.3	70	1.2477 @70 °C	0.60474 @76 °C X
Phoenix	After RTFO	71.8	70	2.6002 @70 °C	1.21330 @76 °C X
Lanaz	Neat	72.7	70	1.3983 @70 °C	0.66210 @76 °C X
Lanaz	After RTFO	74.6	70	4.1151 @70 °C	1.82370 @76 °C X
Kat	Neat	73.3	70	1.5109 @70 °C	0.71841 @76 °C X
Kat	After RTFO	72.8	70	3.1016 @70 °C	1.50760 @76 °C X
Specifications				-For neat asphalt; G*/sin δ, Minimum, 1.00 kPa Test Temperature @ 10 rad/s, °C -For after RTFO; G*/sin δ, Minimum, 2.20 kPa Test Temp @ 10 rad/sec, °C	

<u>*Note;*</u>
A-The abbreviation (x) means fail.
B-True grade is the exact value read by DSR test equipment.
C-rad; stand for radian.

Table (4-12) shows that Lanaz refinery sample has G*sinδ ≤ 5000 kpa at 19 °C, kat and phoenix samples reaching 25 °C & 31 °C respectively. This test gives indication about fatigue failure in asphalt that leads to fatigue crack in asphalt pavement layer.

Table (4-12) Stiffness Results for Penetration Grades (40 – 50), DSR after PAV.

Bitumen Reference	DSR test- G*. Sin δ – after PAV					
Phoenix	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	4499.1	6218.6 X	-	-	-	-
Lanaz	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	-	-	4403.2	5646.3 X
Kat	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	4842.6	5650.9 X	-	-
Specifications	G*sin δ, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C					

Table (4-13) shows stiffness value and m-value of BBR test. Phoenix asphalt sample has low temperature value of (-12 °C). Lanaz and Kat asphalt sample have low temperature value of (-18 °C), this value is added by (-10°C) for PG calculation.

Table (4-13) Stiffness Results for Penetration Grades (40 – 50)/BBR test-after PAV

Bitumen Reference	Stiffness (S) value MPa.	m-value
Phoenix	133.9464@ -12 °C	0.344537 @ -12 °C
	296.1589@ -18 °C	0.298127 @ -18 °C X
Lanaz	244.5840@ -18 °C	0.329180 @ -18 °C
	517.0517@ -24 °C X	0.328791 @ -24 °C
Kat	222.3745@ -18 °C	0.307354 @ -18 °C
	434.1060@ -24 °C X	0.291273 @ -24 °C X
Specifications	S, Maximum, 300 MPa m-value, Test Temp, @ 60 sec, °C	Minimum, 0.300 Test Temp, @ 60 sec, °C

Note; the temperature showed in the table are temperatures which values of stiffness and m-value are calculated when tested by BBR.

Table (4-14) shows that phoenix asphalt sample of grade (60-70) has high temperature performance grade PG of 64°C while other two refineries have high temperatures PG of 70°C. Figure (4-3) shows the true grade results for both neat and after RTFO for different asphalt grade & refineries.

Table (4-14) Stiffness Results for Penetration Grades (60-70)/ DSR for Original and after RTFO test.

Bitumen Reference	Testing condition	True Grade	Grade	DSR test - G*/ Sin δ, Kpa	
				Confirm Spec.	Not Confirm Spec.
Phoenix	Neat	66.2	64	1.3020 @64 °C	0.62766 @70 °C X
Phoenix	After RTFO	67.7	64	3.5974 @64 °C	1.60750 @70 °C X
Lanaz	Neat	73.0	70	1.4005 @70 °C	0.70378 @76 °C X
Lanaz	After RTFO	72.6	70	3.0768 @70 °C	1.39890 @76 °C X
Kat	Neat	72.4	70	1.3320 @70 °C	0.64470 @76 °C X
Kat	After RTFO	70.0	70	2.2049 @70 °C	1.08100 @76 °C X
Specifications				-For neat asphalt; G*/sin δ ≥ 1.00 kPa Test Temperature @ 10 rad/s, °C -For after RTFO; G*/sin δ ≥ 2.20 kPa Test Temp @ 10 rad/sec, °C	

Note;

A-The abbreviation (x) means fail.

B-True grade is the exact value read by DSR test equipment.

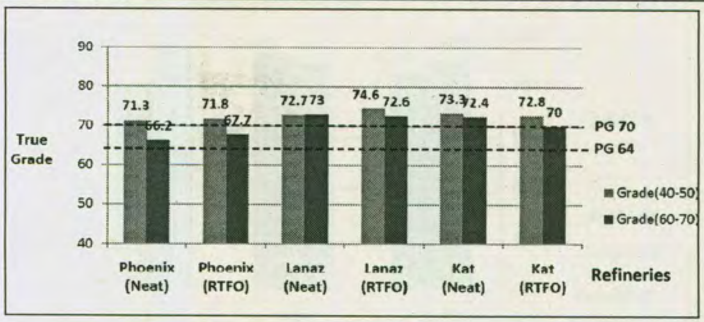


Figure (4-3) Grade Variation for Different Refineries

Table (4-15) shows values of DSR test after PAV for grade (60-70). Lanaz refinery sample has value of G*sinδ ≤ 5000 kpa, at 19 °C. Kat and phoenix samples were 25 °C. Figure (4-4) clarifies the DSR results for both grades and refineries.

Table (4-15) Super-pave Test Results for Penetration Grades (60 – 70) / DSR after PAV.

Bitumen Reference	DSR test- G*. Sin δ – after PAV					
Phonex	34 °C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	-	-	-	-	4279.4	5263.7X
Lanaz	34 °C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	-	-	-	4704.8	6176.6X	-
Kat	34 °C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	-	-	-	4132.9	5382X	-
	G*sin δ, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C					

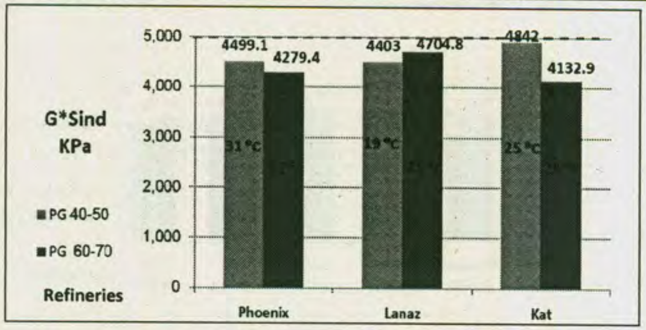


Figure (4-4) DSR after (PAV) Value Variation for Different Refineries

Table (4-16) shows values of stiffness and m-value of BBR test for grade (60-70). Phoenix asphalt sample has both value of stiffness and m-value fixed to low temperature of (-12 °C). Lanaz and Kat asphalt samples have low temperature value of (-18 °C). Figure (4-5) shows results of BBR tests.

Table (4-16) Stiffness Results for Penetration Grades (60 – 70)/ BBR Test after PAV

Bitumen Reference	Stiffness (S) value MPa.	m-value
Phoenix	114.7427 @ -12 °C	0.325502 @ -12 °C
	219.6664 @ -18 °C	0.295512 @ -18 °C X
Lanaz	214.8848 @ -18 °C	0.308178 @ -18 °C
	409.6263 @ -24 °C X	0.258665 @ -24 °C X
Kat	222.9604 @ -18 °C	0.323422 @ -18 °C
	418.1023 @ -24 °C X	0.286953 @ -24 °C X
Specificationss	S, Maximum, 300 MPa, Test Temp, @ 60 sec, °C	m-value, Minimum, 0.300 Test Temp, @ 60 sec, °C

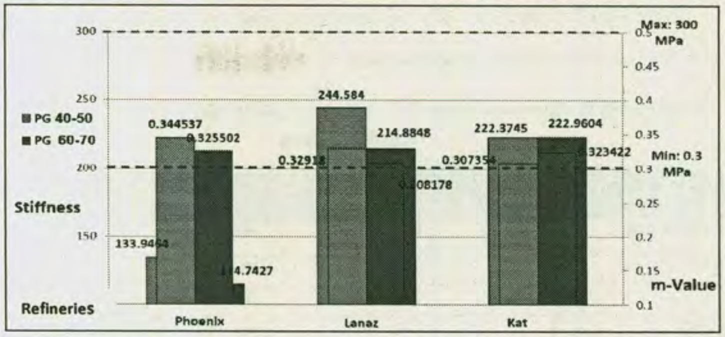


Figure (4-5) Stiffness and m-Value Variation for Different Asphalt Refineries

Table (4-17) shows summery of the three refineries test values. The test results indicate that both Lanaz and kat asphalt samples with grades of (40-50) and (60-70) provides PG (70-28). Phoenix refinery with grades of (40-50) and (60-70) provide PG (70-22), PG (64-22) respectively.

Table (4-17) Summary of properties of Grade, DSR and BBR of Neat Asphalt Product for Both (40-50) & (60-70) Grades

Refineries	Asphalt grade	DSR test - G*/ Sin δ, Kpa.		DSR test- G*. Sin δ – after PAV	BBR test – after PAV	
		For neat	After RTFOT	Kpa.	Stiffness MPa.	m-value
Lanaz	40-50	1.3983	4.1151	4403.2@25 C°	244.58@-18C°	0.329@-18C°
	60-70	1.4005	3.0768	4704.8@25 C°	214.88@-18C°	0.308@-18C°
Kat	40-50	1.5109	3.1016	4842.6@25 C°	222.37@-18C°	0.307@-18C°
	60-70	1.3320	2.2049	4132.9@25 C°	222.96@-18C°	0.323@-18C°
Phoenix	40-50	1.2477	2.6002	4499.1@31 C°	133.94@-12C°	0.344@-12C°
	60-70	1.3020	3.5974	4279.4@22 C°	144.74@-12C°	0.325@-12C°

Table (4-18) represents the performance grade of local asphalt binders for three refineries in Kurdistan Region-Iraq.

Table (4-18) Performance grade PG of Local Asphalt Binders (Neat) Produced in Kurdistan-Iraq

Name of refinery	40-50		60-70	
Temperature range	Maximum °C	Minimum °C	Maximum °C	Minimum °C
LANAZ	70	-28	70	-28
KAT	70	-28	70	-28
PHOENIX	70	-22	64	-22

Table (4-19) shows values of elastic recovery for both grads of (40-50) and (60-70) for the three refineries in Kurdistan Region-Iraq. Among the results, Lanaz shows greater value of elastic recovery for both neat asphalt and after rolling thin film oven test. This test gives indication about asphalt susceptibility and how it recovers after unloading.

Table (4-19) Elastic Recovery of both Neat and After RTFO Test for the Refineries in Kurdistan Region-Iraq

Test name	40-50			60-70			Standard
Refinery	Lanaz	Kat	Phoenix	Lanaz	Kat	Phoenix	
Elastic recovery on neat (%)	6.38	5.53	3.03	4.56	3.86	3.02	ASTM D6083-13
Elastic recovery on RTFO (%)	10.82	9.96	5	9.9	6.5	3.9	ASTM D6083-13

It is important to explain that some conventional tests once done for neat asphalt such as Softening Point, Mass loss (loss on weight) as showed in Table (4-10), and Viscosity showed in Table (4-20), were not repeated again for asphalt polymer modified stages of testing.

The Rotational Viscometer RV test was not related to PG directly, however, it gives an idea about workability and bitumen performance in the pumping, mixing and compaction process. Table (4-20) shows values of RV for asphalt binders samples with both grads of (40-50) and (60-70). This test is applicable for neat asphalt rather than the modified (NCHRP, 2011).

Table (4-20) Value of Rotational Viscometer (RV) Test for both grade (40-50) and (60-70)

Neat					
(40-50)			(60-70)		
Lanaz	Kat	Phoenix	Lanaz	Kat	Phoenix
0.459 Pa.s	0.583 Pa.s	0.535 Pa.s	0.400 Pa.s	0.397 Pa.s	0.360 Pa.s
Aged by (PAV), ASTM D6521					
1,830 Pa.s	2,440 Pa.s	1,926 Pa.s	1,340 Pa.s	1,290 Pa.s	1,240 Pa.s
Specifications M320, (AASHTO,2007) = 3 Pa.s, Max					

4.4.2 Super-pave Tests of Polymer Modified Asphalt

In this stage, tests are conducted for asphalt samples which are modified by different types of polymer (Elastomer and Plastomer) with different percentages. Both (40-50) and (60-70) grades were covered for Lanaz and Kat refineries. The procedure started with Lanaz then Kat with two types of elastomer and one type of plastomer as presented in the following. The values of tests for asphalt binder with polymer modification are shown on Tables (4-21) to (4-47).

Table (4-21) shows stiffness variation of DSR values for Lanaz asphalt sample grade (40-50) which modified by Iterprene -SBS elastomer. Polymer percentages were used from 0.5% to 6%. The results indicated that high percentage of Iterprene increases the asphalt stiffness to abnormal level. Among them 2 percent of Iterprene SBS gives optimum value that provides high temperature of PG 82 °C.

Table (4-21) Stiffness (DSR) Variation with Polymer increments For Lanaz Penetration Grades of (40 – 50) / DSR for Original and after RTFOT

Bitumen Reference	Testing condition	True Grade	Grade	DSR test - G*/ Sin δ, Kpa	
				Confirm Spec.	Not Confirm Spec.
(+0.5% Iterprene SBS G-L)	Neat	78.8	76	2.9532@76 °C	0.6854@ 82 °C X
(+1.0% Iterprene SBS G-L)	After RTFO	79.2	76	3.0542@76 °C	0.8555@ 82 °C X
(+2.0%Iterprene SBS G-L)	Neat	+88	+88	14.0940@ 88 °C	-
(+4.0%Iterprene SBS G-L)	After RTFO	+88	+88	18.2780@ 88 °C	-
(+6.0%Iterprene SBS G-L)	Neat	+88	+88	+20.0000@ 88 °C	-
(+0.5% Iterprene SBS G-L)	After RTFO	78.2	76	2.8820@76 °C	1.02265@ 82 °C X
(+1.0% Iterprene SBS G-L)	Neat	79.1	76	3.2028@76 °C	1.9608@ 82 °C X
(+2.0% Iterprene SBSG-L)	After RTFO	82.8	82	2.4312@ 82 °C	1.1657@ 88 °C X
(+4.0% Iterprene SBS G-L)	Neat	+88	+88	4.8517@ 88 °C	-
(+6.0% Iterprene SBSG-L)	After RTFO	+88	+88	6.6363@ 88 °C	-
Specifications				-For neat asphalt; G*/sin δ ≥ 1.00 kPa Test Temperature @ 10 rad/s, °C -For after RTFO; G*/sin δ ≥ 2.20 kPa Test Temp @ 10 rad/sec, °C	

Table (4-22) shows stiffness variations of DRS after PAV with polymer increments. The value of DSR is fixed to 25°C temperature with Iterprene for optimum 2 percent.

Table (4-22) Stiffness (DSR) Variation with Polymer increments for Lanaz Penetration Grades of (40 – 50) / DSR after PAV.

Bitumen Reference	DSR test- G*. Sin δ – after PAV					
(+0.5% Iterprene SBS G-L)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3378.9	-		-	-
(+1% Iterprene SBS G-L)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3595.1	-	-	-	-
(+2% Iterprene SBS G-L)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	4640.3		-	-
(+4% Iterprene SBS G-L)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	-	-	-	4431.4
(+6% Iterprene SBS G-L	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	-	-	-	1360
Specifications	G*sin d, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C					

Table (4-23) shows results of stiffness and m-values of BBR test, which gives low temperature value of -12°C with optimum percentage of 2% of Iterprene. The summary of test results of Tables (4-21) to (4-23) indicate that asphalt modification with Iterprene polymer using optimum percentage of 2% provides PG (82-22).

Table (4-23) Stiffness and m-value variations with SBS content increments for Lanaz Penetration Grades of (40 – 50)/ BBR test-after PAV.

Bitumen Reference	Stiffness (S) value MPa.	m-value
(+0.5% Iterprene SBS G-L)	237.3185@ -18 °C	0.323115 @ -18 °C
	305.1425@ -24 °C x	0.289912 @ -24 °C x
(+1% Iterprene SBS G-L)	224.5506@ -18 °C	0.302682 @ -18 °C
	310.6750@ -24 °C x	0.271653 @ -24 °C x
(+2% Iterprene SBS G-L)	121.4234@ -12°C	0.329845 @ -12 °C
	212.3750@ -18 °C	0.271426 @ -18°C x
(+4% Iterprene SBS G-L)	116.4502@ -12 °C	0.305797 @ -12 °C
	223.6248@ -18 °C	0.289279 @ -18 °C x
(+6% Iterprene SBS G-L)	108.3773@ -12 °C	0.313430 @ -12 °C
	140.7597@ -18 °C	0.298184 @ -18 °C x
Specifications	S, Maximum, 300 MPa *m*-value Test Temp, @ 60 sec, °C	Minimum 0.300 Test Temp, @ 60 sec, °C

Table (4-24) shows DSR variations with increasing Kraton SBS contents for Lanaz asphalt sample grade (40-50) which was modified by Kraton-SBS. Elastomer polymer percentages were used from 0.5% to 4%. The 2 percent gives optimum value that provides high temperature of PG 82 °C. Figure (4-6) shows these variations of DSR against polymer content clearly.

Table (4-24) Stiffness (DSR) Variation with Polymer Increments for Lanaz Penetration Grades of (40 – 50) / DSR for Original and after RTFO test

Bitumen Reference	Testing condition	True Grade	Grade	DSR test - G*/ Sin δ, Kpa	
				Confirm Spec.	Not Confirm Spec.
(+0.5% Kraton SBS)	Neat	74.8	70	1.6034@70 °C	0.7801@76 °C x
(+1.0% Kraton SBS)	Neat	81.2	76	1.8735@76 °C	0.8085@82 °C x
(+2.0% Kraton SBS)	Neat	84.3	82	2.32541@76 °C	0.9541@82 °C x
(+4.0% Kraton SBS)	Neat	+88	+88	-	-
RTFO(+0.5% Kraton SBS)	After RTFO	72.8	70	2.3888@70 °C	1.4881@ 76 °C x
RTFO(+1.0% Kraton SBS)	After RTFO	79.6	76	3.4968@76 °C	1.6265@ 82 °C x
RTFO (+2.0% Kraton SBS)	After RTFO	85.7	82	3.4199@ 82 °C	1.6609@ 88 °C x
RTFO(+4.0% Kraton SBS)	After RTFO	+88	+88	-	-
Specifications				-For neat asphalt; G*/sin δ ≥ 1.00 kPa Test Temperature @ 10 rad/s, °C -For after RTFO; G*/sin δ ≥ 2.20 kPa Test Temp @ 10 rad/sec, °C	

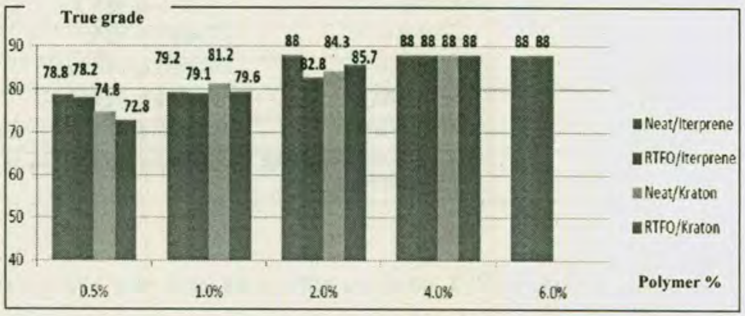


Figure (4-6) Grade Variation against Polymer Content

Table (4-25) shows that the optimum value of stiffness (DSR) fixed at 28 °C temperature with 2 percent content of Kraton SBS. Value of DSR after PAV was not found for Lanaz with (4% Kraton) as DSR value exceeds 88 grades in Table (4-24).

Table (4-25) Stiffness (DSR) Variation with Kraton SBS Content Increments for Penetration Grades Lanaz (40 – 50) / DSR after PAV.

Bitumen Reference	DSR test- G*. Sin δ – after PAV					
(+0.5%Kraton SBS)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3301.7	-	-	-
(+1%Kraton SBS)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3233.8	-	-	-	-
(+2% Kraton SBS)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3698.8	-		-	-
(+4% Kraton SBS)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	-	-	-	-
Specifications	G*sin d, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C					

Figure (4-7) shows the value of stiffness variations for DSR after PAV with Kraton SBS contents.

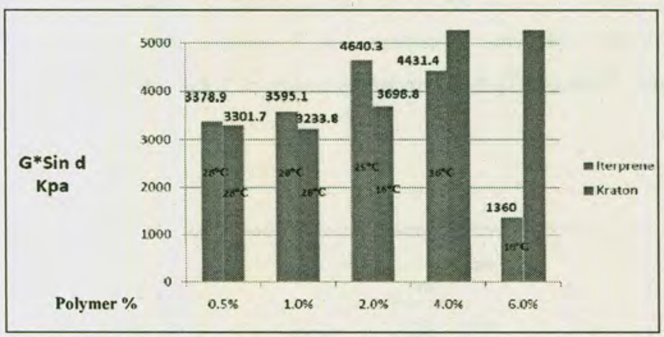


Figure (4-7) DSR (after PAV) Value Variation against Polymer Content

Table (4-26) shows variation of stiffness and m-value with Kraton content increments results for BBR test, which gives low temperature value of -18°C with optimum percentage of 2 percent of Kraton.

Table (4-26) Stiffness and m-Value Variations with SBS Content Increments for Lanaz Penetration Grades of (40 – 50) / BBR test-after PAV.

Bitumen Reference	Stiffness (S) value MPa.	m-value
(+0.5% Kraton SBS)	247.1771@ -18 °C	0.317301 @ -18 °C
	301.7783@ -24 °C x	0.281123 @ -24 °C x
(+1% Kraton SBS)	201.4010@ -18 °C	0.339983 @ -18 °C
	400.0478@ -24 °C x	0.289257 @ -24 °C x
(+2% Kraton SBS)	189.8956@ -18 °C	0.334527 @ -18 °C
	420.6046@ -24 °C x	0.271724 @ -24 °C x
(+4% Kraton SBS)	-	-
	-	-
Specifications	S, Maximum, 300 MPa *m*-value Test Temp, @ 60 sec, °C	Minimum 0.300 Test Temp, @ 60 sec, °C

Figure (4-8) shows profile variation of stiffness for Iterprene and Kraton polymers with percent of polymer contents increments. The summary of test results of Tables (4-24) to (4-26) indicate that asphalt modification with Kraton polymer using optimum percentage of 2 percent provides PG (82-28). Furthermore, Table (4-27) shows summery results of Tables (4-21) to (4-26).

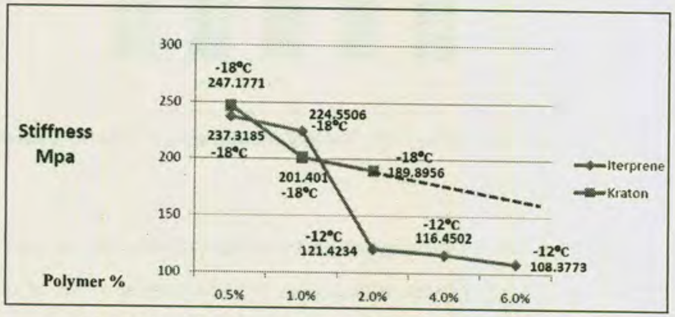


Figure (4-8) Stiffness Variation against Polymer Content

Table (4-27) Summary Results of Polymer Modified Asphalt for Lanaz Product (40-50).

Polymer percentage	DSR test - G*/ Sin δ, KPa		DSR test- G*. Sin δ – after PAV KPa	BBR test – after PAV	
	For neat	After RTFOT		Stiffness MPa	m-value
0.5%Iterprene SBS	2.9532	2.8820	3378.9@28 C°	237.31@-18C°	0.323@-18C°
1.0%Iterprene SBS	3.0542	3.2028	3595.1@28 C°	224.55@-18C°	0.302@-18C°
2.0%Iterprene SBS	14.094	2.4312	4640.3@25 C°	121.42@-12C°	0.329@-12C°
4.0%Iterprene SBS	18.278	4.8517	4431.4@16 C°	116.45@-12C°	0.305@-12C°
6.0%Iterprene SBS	20.000	6.6363	1360.0@16 C°	108.37@-12C°	0.313@-12C°
0.5%Kraton SBS	1.6034	2.3888	3301.7@25 C°	247.17@-18C°	0.317@-18C°
1.0%Kraton SBS	1.8735	3.4968	3233.8@28 C°	201.40@-18C°	0.339@-18C°
2.0%Kraton SBS	2.3254	3.4199	3698.8@28 C°	189.89@-18C°	0.334@-18C°
4.0%Kraton SBS	-	-	-	-	-

Table (4-28) shows DSR variation with increasing Kraton SBS and Iterprene SBS polymer contents for Kat asphalt sample grade (40-50). Polymer percentages were used started from 0.5% to 4%.

The results indicated that high percentage of Elastomer polymer increases the asphalt stiffness (DSR) value to abnormal level. Among them 2 percent of Kraton gives an optimum result that provides high temperature of PG 82 °C.

Figure (4-9) shows the true grade variation with Kraton and Iterprene polymer content (increments) of Kat asphalt samples.

Table (4-28) Stiffness (DSR) Variation with Polymer Increments for Kat Grade Of (40 – 50) /DSR for Original and after RTFO test

Bitumen Reference	Testing condition	True Grade	Grade	DSR test - G*/ Sin δ, Kpa	
				Confirm Spec.	Not Confirm Spec.
(+0.5% Iterprene SBS G-L)	Neat	75.0	70	1.8345@70 °C	0.9225@76 °C X
(+1.0% Iterprene SBS G-L)	Neat	81.1	76	1.9584@76 °C	0.9465@82 °C X
(+2.0%Iterprene SBS G-L)	Neat	85.4	82	1.7428@82 °C	0.8547@88 °C X
(+4.0%Iterprene SBS G-L)	Neat	+88	+88	-	-
(+0.5% Iterprene SBS)	After RTFO	73.1	70	3.1524@70 °C	1.3587@76 °C X
(+1.0% Iterprene SBS)	After RTFO	78.2	76	3.0254@76 °C	1.4568@82 °C X
(+2.0% Iterprene SBS)	After RTFO	84.1	82	2.8565@82 °C	1.6324@88 °C X
(+4.0% Iterprene SBS)	After RTFO	+88	+88	-	-
(+0.5% Kraton)	Neat	77.3	76	1.2546@76 °C	0.7465@82 °C X
(+1.0% Kraton)	Neat	80.6	76	1.8465@76 °C	0.9347@82 °C X
(+2.0% Kraton)	Neat	84.8	82	1.8465@82 °C	0.9347@88 °C X
(+4.0% Kraton	Neat	+88	+88	-	-
(+0.5% Kraton)	After RTFO	74.9	70	3.8123@70 °C	1.7563@76 °C X
(+1.0% Kraton)	After RTFO	78.2	76	2.9658@76 °C	1.4567@82 °C X
(+2.0% Kraton)	After RTFO	83.3	82	2.9658@82 °C	1.4567@ 88 °C X
(+4.0% Kraton)	After RTFO	+88	+88	-	-
Specifications				-For neat asphalt; G*/sin δ ≥ 1.00 kPa Test Temperature @ 10 rad/s, °C -For after RTFO; G*/sin δ ≥ 2.20 kPa Test Temp @ 10 rad/sec, °C	

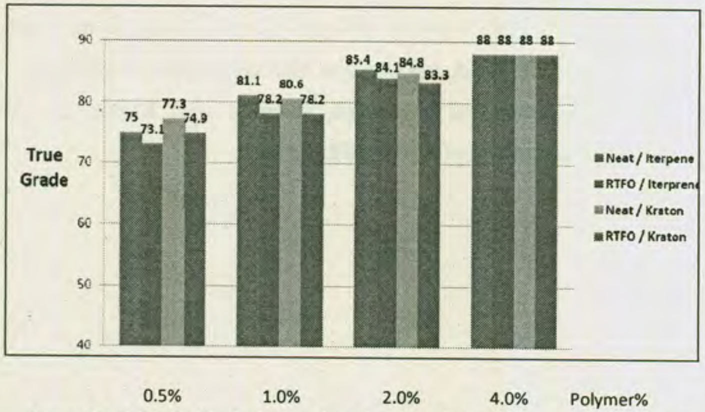


Figure (4-9) Grade Variation against Polymer Content for Kat Asphalt Samples

Table (4-29) represents variation of DSR after PAV at specific temperature. It can be concluded that the optimum content of polymer is 2 percent at 28°C for Iterprene and 34°C for Kraton. . Figure (4-10) shows profile variation with polymer contents.

Table (4-29) Stiffness (DSR) Variation with Kraton & Iterprene SBS content increments for Kat (40 – 50) / DSR after PAV.

Bitumen Reference	DSR test- G*. Sin δ – after PAV					
(+0.5% Iterprene SBS G-L)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3950		-	-
(+1% Iterprene SBS G-L)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	4002.3	-	-	-	-
(+2% Iterprene SBS G-L)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	4201.3	-	-	-	-
(+4% Iterprene SBS G-L)	34 °C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	-	-	-	-	-	-
(+0.5% Kraton)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3311.4		-	-
(+1% Kraton)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3877	-	-	-	-
(+2% Kraton)	34 °C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	4001.2	-	-	-	-	-
(+4% Kraton)	34 °C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	-	-	-	-	-	-
Specifications	G*sin d, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C					

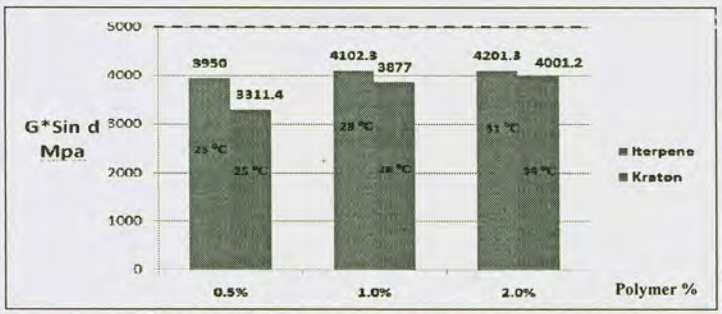


Figure (4-10) DSR (after PAV) Value against Polymer Content.

Table (4-30) shows results stiffness after PAV variation with polymer contents. The optimum content (percent) of polymer is 2 at -12 °C. These values profile are shown in Figure (4-11). The summary of test results of Tables (4-28) to (4-30) indicate that asphalt modification with Iterprene and Kraton polymer using optimum percentage of 2 percent provides PG (82-22).

Table (4-30) Stiffness and m-Value Variations with SBS Content Increments for Kat (40 – 50) / BBR test-after PAV.

Bitumen Reference	Stiffness (S) value MPa.	m-value
(+0.5% Iterprene SBS G-L)	187.2120@ -18 °C	0.311102 @ -18 °C
	299.7571@ -24 °C	0.287444 @ -24 °C x
(+1% Iterprene SBS G-L)	209.2779@ -18 °C	0.361743 @ -18 °C
	323.1797@ -24 °C x	0.290132 @ -24 °C x
(+2% Iterprene SBS G-L)	180.2179@ -12 °C	0.323718 @ -12 °C
	321.8178@ -18 °C x	0.259998 @ -18 °C x
(+4% Iterprene SBS G-L)	-	-
	-	-
(+0.5% Kraton)	190.2135@ -18 °C	0.319091 @ -18 °C
	310.7571@ -24 °C x	0.291333 @ -24 °C x
(+1% Kraton)	200.0020@ -18 °C	0.337390 @ -18 °C
	350.9323@ -24 °C x	0.273037 @ -24 °C x
(+2% Kraton)	178.7365@ -12 °C	0.320012 @ -12 °C
	339.7021@ -18 °C x	0.251052 @ -18 °C x
(+4% Kraton)	-	-
	-	-
Specifications	S, Maximum, 300 MPa *m*-value Test Temp, @ 60 sec, °C	Minimum 0.300 Test Temp, @ 60 sec, °C

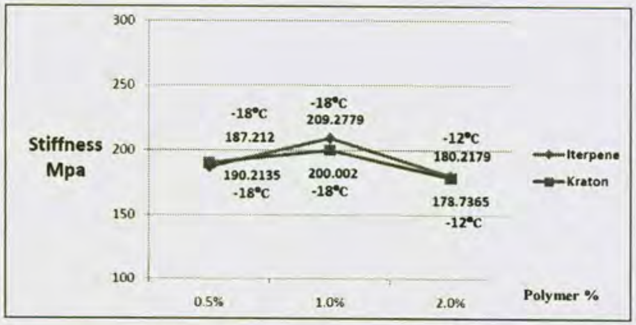


Figure (4-11) Stiffness Variation against Polymer Content

Table (4-31) shows stiffness variation with polymer contents for asphalt of Kat products of grade (40-50).

Table (4-31) Summary Results of Polymer Modified Asphalt for Kat Product (40-50).

Polymer percentage	DSR test - G*/ Sin δ, Kpa		DSR test- G*. Sin δ – after PAV Kpa.	BBR test – after PAV	
	For neat	After RTFOT		Stiffness MPa.	m-value
0.5%Iterprene SBS	1.8345	3.1524	3950.0@25 C°	187.212@-18C°	0.311@-18C°
1.0%Iterprene SBS	1.9584	3.0254	4002.3@28 C°	209.27@-18C°	0.361@-18C°
2.0%Iterprene SBS	1.7428	2.8565	4201.3@28 C°	180.21@-12C°	0.323@-12C°
4.0%Iterprene SBS	-	-	-	-	-
0.5%Kraton SBS	1.2546	3.8123	3311.4@28 C°	190.213@-18C°	0.319@-18C°
1.0%Kraton SBS	1.8465	2.9658	3877.0@34 C°	200.00@-18C°	0.337@-18C°
2.0%Kraton SBS	1.8465	2.9658	4001.2@34 C°	178.73@-12C°	0.320@-12C°
4.0%Kraton SBS	-	-	-	-	-

Table (4-32) shows stiffness variations with polymers for Kat asphalt sample grade of (60-70) which was modified by both Iterprene -SBS elastomer and Kraton-SBS elastomer polymer.

The results indicated that 2 percent gives optimum content that provides high temperature of PG 70 °C with Iterprene. And 4 percent give optimum content that provides high temperature of PG76 °C with Kraton. The variations of grades against polymer contents are shown in figure (4-12).

Table (4-32) Stiffness (DSR) Variation with Polymer Increments for Kat grade of (60 – 70)/ DSR for Original and after RTFO test

Bitumen Reference	Testing condition	True Grade	Grade	DSR test - G*/ Sin δ, Kpa	
				Confirm Spec.	Not Confirm Spec.
(+0.5% Iterprene/ SBS G-L)	Neat	71.0	70	1.2032@ 70 °C	0.7201@ 76 °C x
(+1% Iterprene/ SBS G-L)	Neat	75.6	70	2.213@ 70 °C	0.94937@ 76 °C x
(+2% Iterprene/ SBS G-L)	Neat	77.4	76	1.1707@ 76 °C	0.57701@ 82 °C x
(+4% Iterprene/ SBS G-L)	Neat	+88	+88	-	-
(+1% SBS / kraton)	Neat	76.6	76	1.0536@76 °C	0.63753@ 82 °C x
(+2% SBS/ Kraton)	Neat	79.4	76	1.4292@ 76 °C	0.75515@ 82 °C x
(+4% SBS/ Kraton)	Neat	82.1	82	1.0037@ 82 °C	0.59626@ 88 °C x
(+0.5% Iterprene/ SBS G-L)	After RTFO	70.2	70	2.0888@ 70 °C	1.0721@ 76°C x
(+1% Iterprene/ SBS G-L)	After RTFO	73.3	70	3.2684@ 70 °C	1.582@ 76°C x
(+2% Iterprene/ SBS G-L)	After RTFO	73.8	70	3.4541@ 70 °C	1.6913@ 76 °C x
(+4% Iterprene/ SBS G-L)	After RTFO	+88	+88	-	-
(+1% SBS/ Kraton)	After RTFO	74.3	70	3.5481@ 70 °C	1.8201@ 76 °C x
(+2% SBS/ Kraton)	After RTFO	75	70	4.1069@ 70 °C	1.9278@ 76 °C x
(+4% SBS/ Kraton)	After RTFO	80	76	3.3670@ 76 °C	1.7738@ 82 °C x
Specifications				-For neat asphalt; G*/sin δ ≥ 1.00 kPa Test Temperature @ 10 rad/s, °C -For after RTFO; G*/sin δ ≥ 2.20 kPa Test Temp @ 10 rad/sec, °C	

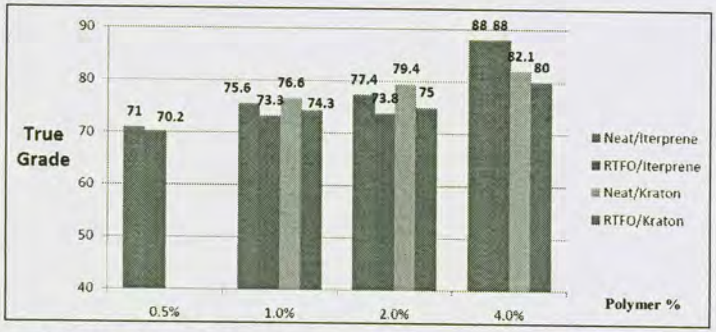


Figure (4-12) Grade Variation against Polymer Content for Kat Asphalt

Table (4-33) shows stiffness variations of DRS after PAV. The optimum values of both polymers give intermediate temperature value of 25°C with Iterprene and 31°C with Kraton respectively. Figure (4-13) shows the value of DSR after PAV against polymer contents.

Table (4-33) Stiffness (DSR) Variation with Kraton & Iterprene SBS content increments for Kat grade of (60 – 70) / DSR after PAV.

Bitumen Reference	DSR test- G*. Sin δ – after PAV					
(+0.5% SBS/ Iterprene)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3001.3		-	-
(+1% SBS/ Iterprene)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	2924.9		-	-
(+2% SBS/ Iterprene)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	--		4110.0	-	-	-
(+4% SBS/ Iterprene)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	--		-	-	-	-
(+1% SBS/ Kraton)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3778.7	-	-	-
(+2% SBS/ Kraton)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	4029.9	-	-	-
(+4% SBS/ Kraton)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	1006.7	-	-	-	-	-
Specifications	G*sin d, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C					

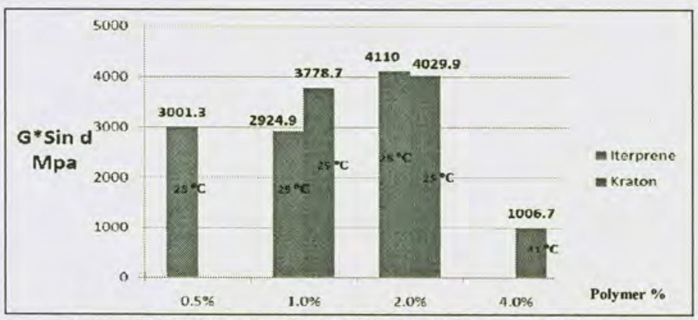


Figure (4-13) DSR (after PAV) Value Variation for Kat Asphalt

Table (4-34) shows values of stiffness and m-value of BBR test, which gives low temperature value of -18°C with optimum percentage of 2 percent of Iterprene and gives -12 °C with 4 percent of Kraton respectively. Figure (4-14) shows BBR test results. Based on summary of test results, it is clear that asphalt modification with 2% Iterprene and 4% Kraton polymer provides PG (70-28) and PG (76-22) respectively.

Table (4-34) Stiffness and m-Value Variations with SBS Content Increments for Kat Grade of (60 – 70) / BBR test-after PAV

Polymer Content	Stiffness (S) value MPa.	m-Value
(+0.5% SBS/ Iterprene)	201.7134@ -18 °C	0.311227 @ -18 °C
	236.9137@ -24 °C x	0.281997 @ -24 °C x
(+1% SBS/ Iterprene)	196.4894@ -18 °C	0.361156 @ -18 °C
	418.4209@ -24 °C x	0.285514 @ -24 °C x
(+2% SBS/ Iterprene)	226.4637@ -18 °C	0.306756 @ -18 °C
	374.4861@ -24 °C x	0.270775 @ -24°C x
(+4% SBS/ Iterprene)	-	-
	-	-
(+1% SBS/ Kraton)	274.4019@ -18 °C	0.343814 @ -18°C
	418.2111@ -24 °C x	0.288942 @ -24°C x
(+2% SBS/ Kraton)	174.7594@ -18 °C	0.319439 @ -18°C
	210.7681@ -24 °C	0.295203 @ -24°C x
(+4% SBS/ Kraton)	183.5341@ -12 °C	0.316797 @ -12°C
	210.7703@ -18 °C	0.295392 @ -18°C x
Specifications	S, Maximum, 300 MPa *m*-value Test Temp, @ 60 sec, °C	Minimum 0.300 Test Temp, @ 60 sec, °C

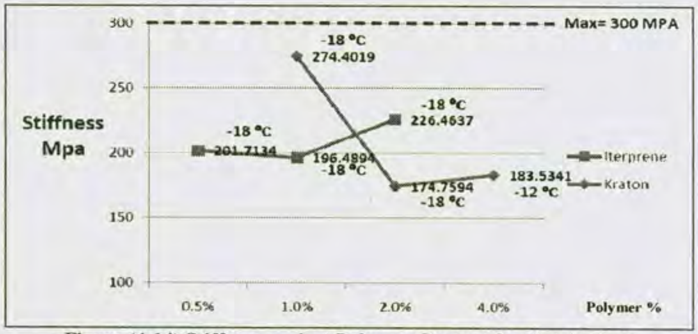


Figure (4-14) Stiffness against Polymer Content for Kat Asphalt

Table (4-35) shows summery results of three main Super-pave tests for Kat asphalt samples for Tables (4-32) to (4-34).

Table (4-35) Summary Results of Polymer Modified Asphalt for Kat Product (60-70).

Polymer percentage	DSR test - G*/ Sin δ, KPa.		DSR test- G*. Sin δ – after PAV KPa.	BBR test – after PAV	
	For neat	After RTFOT		Stiffness MPa.	m-value
0.5%Iterprene SBS	1.2032	2.0888	3001.3@25 C°	201.71@-18C°	0.311@-18C°
1.0%Iterprene SBS	2.213	3.2684	2924.9@25 C°	196.48@-18C°	0.361@-18C°
2.0%Iterprene SBS	1.1707	3.4541	4110.0@25 C°	226.46@-18C°	0.306@-18C°
4.0%Iterprene SBS	-	-	-	-	-
1.0%Kraton SBS	1.0536	3.5481	3778.7@25 C°	274.40@-18C°	0.343@-18C°
2.0%Kraton SBS	1.4292	4.1069	4029.9@25 C°	174.75@-18C°	0.319@-18C°
4.0%Kraton SBS	1.0037	3.3670	1006.7@31 C°	183.53@-12C°	0.316@-12C°

Table (4-36) shows test value of grades and DSR with accordance of polymer contents for Lanaz asphalt grade of (60-70), which was modified by both Iterprene -SBS and Kraton polymer. The results indicated that 2 percent gives optimum content that provides high temperature of PG 82°C with both Iterprene and Kraton. Figure (4-15) shows grade variation with polymer content both Iterprene SBS and Kraton SBS for Lanaz asphalt samples grade of (60-70).

Table (4-36) Stiffness (DSR) Variation with Polymer Increments for Lanaz Grade of (60 – 70) / DSR for Original and after RTFO test

Polymer Content	Testing condition	True Grade	Grade	DSR test - G*/ Sin δ, Kpa	
				Confirm Spec.	Not Confirm Spec.
(+0.5% Iterprene/ SBS G-L)	Neat	72.5	70	1.3112@ 70 °C	0.7211@ 76 °C x
(+1% Iterprene/ SBS G-L)	Neat	78.2	76	1.4781@ 76 °C	0.7030@ 82 °C x
(+2% Iterprene/ SBS G-L)	Neat	82.5	82	1.1500@ 82 °C	0.6999@ 88 °C x
(+4% Iterprene/ SBS G-L)	Neat	+88	-	-	-
(+0.5% SBS / kraton)	Neat	73.5	70	1.7121@70 °C	0.8522@ 76 °C x
(+1% SBS / kraton)	Neat	76.2	76	1.2011@76 °C	0.6707@ 82 °C x
(+2% SBS/ Kraton)	Neat	84.6	82	1.8501@ 82 °C	0.9100@ 88 °C x
(+4% SBS/ Kraton)	Neat	+88	-	-	-
(+0.5% Iterprene/ SBS G-L)	After RTFO	70.1	70	2.2251@ 70 °C	1.1931@ 76°C x
(+1% Iterprene/ SBS G-L)	After RTFO	76.8	76	2.2555@ 76 °C	1.1311@ 82°C x
(+2% Iterprene/ SBS G-L)	After RTFO	82	82	2.2222@ 82 °C	1.0009@ 88 °C x
(+4% Iterprene/ SBS G-L)	After RTFO	+88	-	-	-
(+0.5% SBS/ Kraton)	After RTFO	71.3	70	2.4211@ 70 °C	1.3000@ 76 °C x
(+1% SBS/ Kraton)	After RTFO	73.8	70	2.6618@ 70 °C	1.4010@ 76 °C x
(+2% SBS/ Kraton)	After RTFO	82.5	82	2.4351@ 82 °C	1.5050@ 82 °C x
(+4% SBS/ Kraton)	After RTFO	+88	-	-	-
Specifications				-For neat asphalt; G*/sin δ ≥ 1.00 kPa Test Temperature @ 10 rad/s, °C -For after RTFO; G*/sin δ ≥ 2.20 kPa Test Temp @ 10 rad/sec, °C	

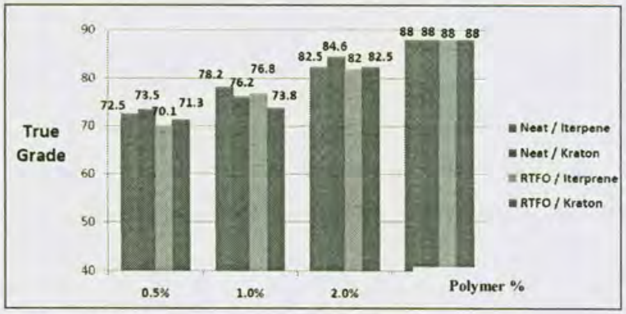


Figure (4-15) Grade Variation against Polymer Content

Table (4-37) represents the DRS after PAV variation with polymer contents. The stiffness (DSR) value with optimum polymer content fixed to 34 °C temperature.

Table (4-37) Stiffness (DSR) Variation with Kraton & Iterprene SBS content increments for Penetration Grades Lanaz (60–70) / DSR after PAV.

Polymer Content	DSR test- G*. Sin δ – after PAV					
(+0.5% SBS/ Iterprene)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3800.5		-	-
(+1% SBS/ Iterprene)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3305.7	-	-	-	-
(+2% SBS/ Iterprene)	34°C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	2487.3	-	-	-	-	-
(+4% SBS/ Iterprene)	34°C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	-	-	-	-	-	-
(0.5% SBS/ Kraton)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3400.7	-	-	-
(+1% SBS/ Kraton)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3211.1	-	-	-	-
(+2% SBS/ Kraton)	34°C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	2725.3	-	4029.9	-	-	-
(+4% SBS/ Kraton)	34 °C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	-	-	-	-	-	-
Specifications	G*sin d, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C					

Figure (4-16) shows the value of DSR after PAV against polymer contents both Iterprene and Kraton.

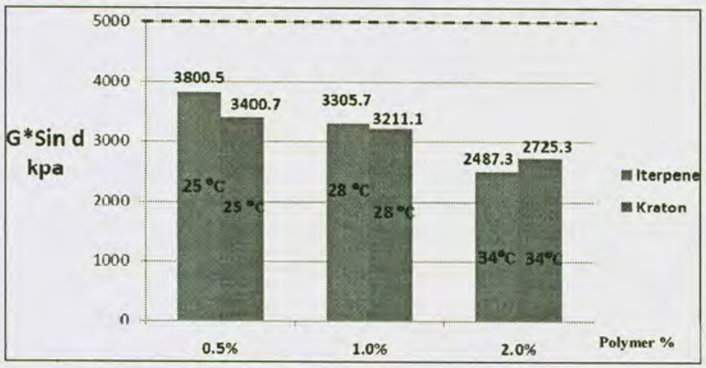


Figure (4-16) DSR (after PAV) Value Variation against Polymer Content for (Lanaz asphalt)

Table (4-38) represents of stiffness and m-value variations with polymer contents increments. The optimum content of both polymers fixed to -12 °C.

Table (4-38) Stiffness and m-Value Variations with SBS Content Increments for Lanaz (60 – 70) / BBR test-after PAV

Polymer Content	Stiffness (S) value	m-value
(+0.5% SBS/ Iterprene)	205.1167@ -18 °C	0.389117 @ -18 °C
	350.1211@ -24 °C x	0.335414 @ -24 °C
(+1% SBS/ Iterprene)	290.0000@ -18 °C	0.320791 @ -18 °C
	367.7370@ -24 °C x	0.309097 @ -24 °C
(+2% SBS/ Iterprene)	205.6582@ -12 °C	0.337917 @ -12 °C
	320.1176@ -18 °C x	0.301079 @ -18°C
(+4% SBS/ Iterprene)	-	-
(+0.5% SBS/ Kraton)	243.2121@ -18 °C	0.323333 @ -18°C
	319.2176@ -24 °C x	0.300121 @ -24°C x
(+1% SBS/ Kraton)	267.3171@ -18 °C	0.3337131 @ -18°C
	330.1591@ -24 °C x	0.301111 @ -24°C x
(+2% SBS/ Kraton)	245.4561@ -12 °C	0.321851 @ -12°C
	389.1027@ -18 °C x	0.299914 @ -18°C x
(+4% SBS/ Kraton)	-	-
	S, Maximum, 300 MPa *m*-value Test Temp, @ 60 sec, °C	Minimum 0.300 Test Temp, @ 60 sec, °C

Figure (4-17) shows BBR test results. Based on summary of test results, it is clear that asphalt modification with Iterprene and Kraton polymer using optimum percentage of 2 percent provides PG (82-22). Table (4-39) shows summary of results for Tables (4-37) to (4-39).

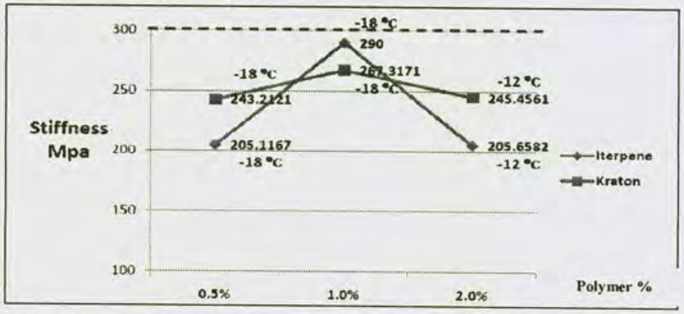


Figure (4-17) Stiffness Variation against Polymer Content for Lanaz Asphalt

Table (4-39) Summary Results of Polymer Modified Asphalt for Lanaz Product (60-70).

Polymer Percentage	DSR test - G*/ Sin δ, Kpa		DSR test- G*. Sin δ – after PAV Kpa.	BBR test – after PAV	
	For neat	After RTFOT		Stiffness Mpa.	m-value
0.5%Iterprene SBS	1.3112	2.2251	3800.5@25 C°	205.11@-18C°	0.389@-18C°
1.0%Iterprene SBS	1.4781	2.2555	3305.7@28 C°	290.00@-18C°	0.320@-18C°
2.0%Iterprene SBS	1.1500	2.2222	2487.3@34 C°	205.65@-12C°	0.337@-12C°
4.0%Iterprene SBS	-	-	-	-	-
0.5%Kraton SBS	1.7121	2.4211	3400.7@25 C°	243.21@-18C°	0.323@-18C°
1.0%Kraton SBS	1.2011	2.6618	3211.1@28 C°	267.31@-18C°	0.333@-18C°
2.0%Kraton SBS	1.8501	2.4351	2725.3@34 C°	245.45@-12C°	0.321@-12C°
4.0%Kraton SBS	-	-	-	-	-

Table (4-40) shows grade and DSR variations with polymer content for Lanaz and Kat asphalt samples grade of (40-50) which was modified by Plastomer-Iterplast polymer. The results indicated that 2 percent gives optimum result that provides high temperature of PG 82°C. This variation profiles for grades shown in Figure (4-18).

Table (4-40) Stiffness (DSR) Variation with Polymer Increments with Plastomer for Grade (40 – 50) / DSR for original and after RTFO test

Asphalt & Polymer Content	Testing condition	True Grade	Grade	DSR test - G*/ Sin δ, Kpa	
				Confirm Spec.	Not Confirm Spec.
Lanaz (+0.5%plastomer, Iterplast)	Neat	75.8	70	1.9785@ 70 °C	0.95320@ 76 °C x
Lanaz (+1%plastomer, Iterplast)	Neat	81.7	76	2.1057@ 76 °C	0.95548@ 82 °C x
Lanaz (+2%plastomer, Iterplast)	Neat	87.7	82	1.8764@ 82 °C	0.96146@ 88 °C x
Lanaz (+0.5%plastomer,Iterplast)	After RTFO	73.2	70	2.3917@ 70 °C	1.2007 @ 76°C x
Lanaz (+1%plastomer, Iterplast)	After RTFO	84	82	2.7787@ 82 °C	1.3658 @ 88 °C x
Lanaz (+2%plastomer, Iterplast)	After RTFO	+88	88	2.9841@ 88 °C	-
Kat (+0.5%plastomer, Iterplast)	Neat	76.6	76	1.3546@ 76 °C	0.5345@ 82 °C x
Kat (+1%plastomer, Iterplast)	Neat	81.8	76	1.9876@ 76 °C	0.9545@ 82 °C x
Kat (+2%plastomer, Iterplast)	Neat	84.7	82	1.7087@ 82 °C	0.8240@ 88 °C x
Kat (+0.5%plastomer, Iterplast)	After RTFO	75.1	70	3.8987@ 70 °C	1.9583@ 76 °C x
Kat (+1%plastomer, Iterplast)	After RTFO	80.2	76	3.9148@ 76 °C	1.9012@ 88 °C x
Kat (+2%plastomer, Iterplast)	After RTFO	82.7	82	2.3144@ 82 °C	1.2039@ 88 °C x
Specifications				-For neat asphalt; G*/sin δ ≥ 1.00 kPa Test Temperature @ 10 rad/s, °C -For after RTFO; G*/sin δ ≥ 2.20 kPa Test Temp @ 10 rad/sec, °C	

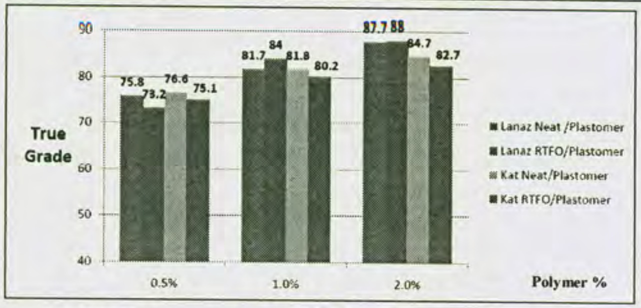


Figure (4-18) Grade Variation against Polymer Content for Lanaz & Kat asphalt

Table (4-41) gives the stiffness DSR variation with polymer content increments. The optimum content of polymer is 2 percent at 28°C for Kat and 34°C for Lanaz. These variations of grade profiles are shown in figure (4-19).

Table (4-41) Super-pave (Polymer Modified) with Plastomer, Test Results for Grade (40 – 50) / DSR after PAV.

Asphalt & Polymer Content	DSR test- G*. Sin δ – after PAV					
Lanaz (+0.5% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3447.2	-	-	-
Lanaz (+1% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	4199	-	-	-	-
Lanaz (+2% /plastomer Iterplast)	34 °C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	1855.8	-	-	-	-	-
Kat (+0.5% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	4100.3	-	-	-
Kat (+1% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3901.5	-	-	-	-
Kat (+2% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3999.2	-	-	-	-
Specifications	G*sin d, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C					

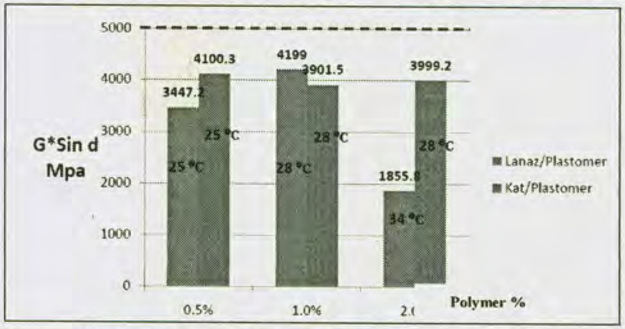


Figure (4-19) DSR (after PAV) Value against Polymer Content

Table (4-42) shows results of BBR test, which gives low temperature value of -12°C with optimum percentages of 2 percent of Iterplast. Figure (4-20) shows Stiffness profile variation with polymer content increments. Based on summary of test results, it is clear that asphalt modification with Iterplast polymer using optimum percentage of 2 percent provides PG (82-22).

Table (4-42) Stiffness Variation with polymer Content Increments for Grades (40 – 50) / BBR test-after PAV.

Asphalt & Polymer Content	Stiffness value (S)	m-value
Lanaz(+0.5%plastomer, Iterplast)	267.7287@ -18 °C	0.310017 @ -18°C
	287.7783@ -24 °C x	0.270339 @ -24°C x
Lanaz (+1%plastomer, Iterplast)	286.6303@ -18 °C	0.335645 @ -18°C
	438.1127@ -24 °C x	0.270496 @ -24°C x
Lanaz(+2%plastomer,Interplast)	148.5529@ -12 °C	0.323174@ -12°C
	304.8174@ -18 °C x	0.286190 @ -18°C x
Kat(+0.5% /plastomer, Iterplast)	270.4625@ -18 °C	0.314567 @ -18°C
	330.4587@ -24 °C x	0.291435 @ -24°C x
Kat (+1% /plastomer, Iterplast)	293.4625@ -18 °C	0.3014568 @ -18°C
	345.4587@ -24 °C x	0.2615670 @ -24°C x
Kat (+2% /plastomer, Iterplast)	199.2172@ -12 °C	0.3278190 @ -12°C
	333.3954@ -18 °C x	0.2657850 @ -18°C x
Specifications	S, Maximum, 300 MPa *m*-value Test Temp, @ 60 sec, °C	Minimum 0.300 Test Temp, @ 60 sec, °C

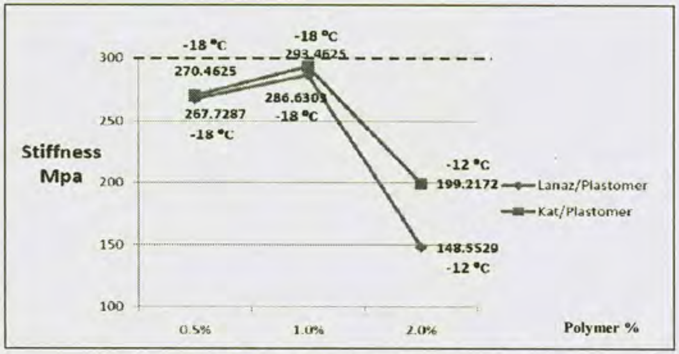


Figure (4-20) Stiffness Variation against Polymer Content

Table (4-43) shows summary of three main Super-pave test results for Tables (4-40) to (4-42).

Table (4-43) Summary of Polymer Modified Asphalt of Lanaz & Kat Products for (40-50) grade.

Polymer Percentage	DSR test - G*/ Sin δ, KPa.		DSR test- G*. Sin δ – after PAV KPa.	BBR test – after PAV	
	For neat	After RTFOT		Stiffness MPa.	m-value
Lanaz0.5%Iterplast	1.9785	2.3917	3447.2@25 C°	267.72@-18C°	0.310@-18C°
Lanaz1.0%Iterplast	2.1057	2.7787	4199.0@28 C°	286.63@-18C°	0.335@-18C°
Lanaz2.0%Iterplast	1.8764	2.9841	1855.8@34 C°	148.55@-12C°	0.323@-12C°
Kat0.5% Iterplast	1.3546	3.8987	4100.3@25 C°	270.46@-18C°	0.314@-18C°
Kat1.0% Iterplast	1.9876	3.9148	3901.5@28 C°	239.46@-18C°	0.301@-18C°
Kat2.0% Iterplast	1.7087	2.3144	3999.2@28 C°	199.21@-12C°	0.327@-12C°

Table (4-44) shows variation of grade and stiffness with polymer content increments for Lanaz and Kat asphalt sample grade (60-70). The results indicated that 2 percent and 4 percent give optimum results that provide high temperature of PG 82°C. Figure (4-21) gives grade variation with polymer content increments.

Table (4-44) Grade and Stiffness Variation with Polymer Content for Grade (60 – 70) / DSR for original and after RTFO test

Bitumen Reference	Testing condition	True Grade	Grade	DSR test - G*/ Sin δ, Kpa	
				Confirm Spec.	Not Confirm Spec.
Lanaz (+0.5% /plastomer Iterplast)	Neat	77.4	76	1.1986@ 76 °C	0.56461@ 82 °C x
Lanaz (+1% /plastomer Iterplast)	Neat	78.8	76	1.3177@ 76 °C	0.6773@ 82 °C x
Lanaz (+2% /plastomer Iterplast)	Neat	83.0	82	1.2289@ 82 °C	0.6425@ 88 °C x
Kat (+0.5% /plastomer Iterplast)	Neat	71.7	70	1.3988@ 70 °C	0.6542@ 76 °C x
Kat (+1% /plastomer Iterplast)	Neat	74.4	70	1.5821@ 70 °C	0.84245@ 76 °C x
Kat (+2% /plastomer Iterplast)	Neat	76.8	76	1.0635@ 76°C	0.68066@ 82 °C x
Kat (+4% /plastomer Iterplast)	Neat	+88	88	1.1457@ 88°C	*
Lanaz (+0.5% /plastomer Iterplast)	After RTFO	75.8	70	3.6413@ 76 °C	1.8232 @ 76°C x
Lanaz (+1% /plastomer Iterplast)	After RTFO	77.0	76	2.3411@ 76 °C	1.3331 @ 82°C x
Lanaz (+2% /plastomer Iterplast)	After RTFO	82.2	82	2.2879@ 82 °C	1.1785 @ 88°C x
Kat (+0.5% /plastomer Iterplast)	After RTFO	70.3	70	2.1117@ 70 °C	1.1007@ 76°C x
Kat (+1% /plastomer Iterplast)	After RTFO	73.9	70	3.7134@ 70 °C	1.6465 @ 76°C x
Kat (+2% /plastomer Iterplast)	After RTFO	74.3	70	3.8684@ 70 °C	1.7660@ 76 °C x
Kat (+4% /plastomer Iterplast)	After RTFO	84.1	82	2.7709@ 82 °C	1.4379@ 88 °C x
Specifications				-For neat asphalt; G*/sin δ ≥ 1.00 kPa Test Temperature @ 10 rad/s, °C -For after RTFO; G*/sin δ ≥ 2.20 kPa Test Temp @ 10 rad/sec, °C	

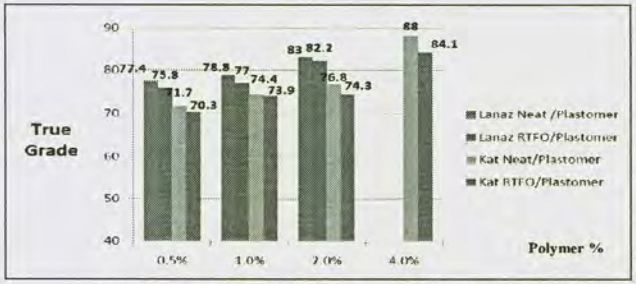


Figure (4-21) Grade Variation against Polymer Content

Table (4-45) shows values variation with polymer content increments of DRS after PAV. The optimum content 2 percent of polymer gives 28°C for Lanaz and 34°C for Kat. Figure (4-22) shows the value of DSR variation with polymer content increments after PAV.

Table (4-45) Stiffness Variation with Iterplast Polymer for Penetration Grade (60 – 70) / DSR after PAV.

Asphalt & Polymer content	DSR test- G*. Sin δ – after PAV					
Lanaz (+0.5% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3696.4	-	-	-
Lanaz (+1% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3574.1	-	-	-	-
Lanaz (+2% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3950.0	-	-	-	-
Kat (+0.5% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3173.3	-	-	-
Kat (+1% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	-	3464.4	-	-	-
Kat (+2% /plastomer Iterplast)	31 °C	28 °C	25 °C	22 °C	19 °C	16 °C
Unit (Kpa)	-	3507.8	-	-	-	-
Kat (+4% /plastomer Iterplast)	34 °C	31 °C	28 °C	25 °C	22 °C	19 °C
Unit (Kpa)	2487.2	-	-	-	-	-
Specifications	G*sin d, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C					

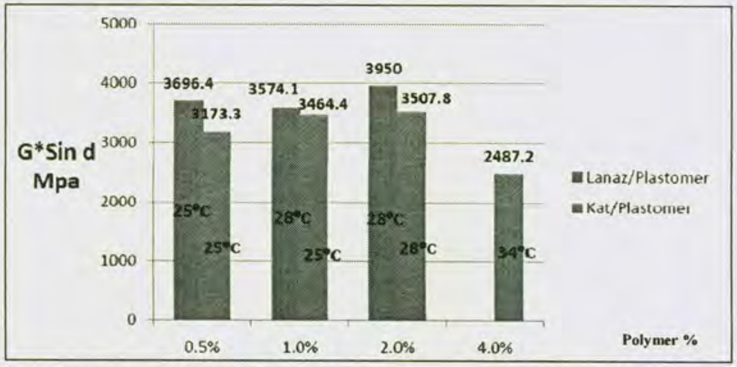


Figure (4-22) DSR (after PAV) Value Variation against Polymer Content

Table (4-46) shows stiffness and m-value variations with polymer content increments. The optimum polymer content with Iterplast 2 percent of Lanaz type fixed at 12°C, and 4 percent of Iterplast of Kat type at the same temperature. Figure (4-23) represents the stiffness variation with polymer content increments.

Table (4-46) Stiffness and m-Value Variations with Polymer Content Increments for Grades (60 – 70) / BBR test-after PAV.

Asphalt & Polymer content	Stiffness value (S) MPa.	m-value
Lanaz(+0.5%/plastomer Iterplast)	267.2615@ -18 °C	0.313006 @ -18°C
	310.5753@ -24 °C x	0.300116 @ -24°C x
Lanaz (+1% /plastomer Iterplast)	279.3127@ -18 °C	0.310000 @ -18°C
	357.1162@ -24 °C x	0.296448 @ -24°C x
Lanaz (+2% /plastomer Iterplast)	180.1777@ -12 °C	0.330397 @ -12°C
	290.2635@ -18 °C x	0.270371 @ -18°C x
Kat (+0.5% /plastomer Iterplast)	211.9342@ -18 °C	0.329373 @ -18°C
	241.3475@ -24 °C x	0.287791 @ -24°C x
Kat (+1% /plastomer Iterplast)	261.1418@ -18 °C	0.312887 @ -18°C
	415.5147@ -24 °C x	0.276484 @ -24°C x
Kat (+2% /plastomer Iterplast)	109.4920@ -12 °C	0.318468 @ -12°C
	317.2359@ -18 °C x	0.339709 @ -18°C
Kat (+4% /plastomer Iterplast)	131.0735@ -12 °C	0.318864 @ -12°C
	279.5762@ -18 °C	0.289310 @ -18°C x
Specifications	S, Maximum, 300 MPa *m*-value Test Temp, @ 60 sec, °C	Minimum 0.300 Test Temp, @ 60 sec, °C

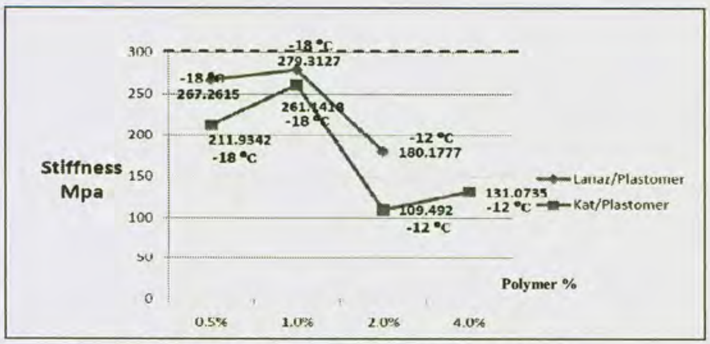


Figure (4-23) Stiffness Variation against Polymer Content

Table (4-47) shows variations of stiffness at different conditions with polymer content increments for Lanaz and Kat products of (60-70) grade.

Table (4-47) Stiffness Variation of Different Conditions with Polymer for Lanaz & Kat Products (60-70).

Polymer percentage	DSR test - G*/ Sin δ, Kpa		DSR test- G*. Sin δ – after PAV Kpa.	BBR test – after PAV	
	For neat	After RTFOT		Stiffness MPa.	m-value
Lanaz0.5%Iterplast	1.1986	3.6413	3696.4@25 C°	267.26@-18C°	0.313@-18C°
Lanaz1.0%Iterplast	1.3177	2.3411	3574.1@28 C°	279.31@-18C°	0.310@-18C°
Lanaz2.0%Iterplast	1.2289	2.2879	3950.0@28 C°	180.17@-12C°	0.330@-12C°
Kat0.5% Iterplast	1.3988	2.1117	3173.3@25 C°	211.93@-18C°	0.329@-18C°
Kat1.0% Iterplast	1.5821	3.7134	3464.4@25 C°	261.14@-18C°	0.312@-18C°
Kat2.0% Iterplast	1.0635	3.8684	3507.8@28 C°	109.49@-12C°	0.318@-12C°
Kat4.0% Iterplast	1.1457	2.7709	2487.2@34 C°	131.07@-12C°	0.318@-12C°

Table (4-48) shows values of elastic recovery for different asphalt binder samples and polymer percentages. Improvement is found after polymer modification was done compared with those values in table (4-19) which includes elastic recovery test of original bitumen (OB). Among the results, 4.0 percent of Kraton for Kat asphalt sample shows optimum value. In most cases, improvement of asphalt elastic recovery after polymer modification is achieved (Zhu et al., 2014).

Table (4-48) Value of Elastic Recovery variations with Polymer Content for Neat Asphalt

Asphalt Source	Polymer content %	Grade (40-50)	Grade (60-70)
Lanaz	(+1% plastomer / Iterplast)	15%	
Lanaz	(+2% plastomer / Iterplast)	35%	
Kat	(+1% SBS/ Iterprene)		15.0%
Kat	(+2% SBS/ Iterprene)		37.5%
Kat	(+1% SBS/ kraton)		28.5%
Kat	(+2% SBS/ kraton)		42.5%
Kat	(+4% SBS/ kraton)		47.5%
Kat	(+1% Plastomer/ Iterplast)		15.0%
Kat	(+2% Plastomer/ Iterplast)		17.5%
Kat	(+4% Plastomer/ Iterplast)		26%

Table (4-49) shows optimum polymer modification percentages among all recent tests in this section. The results categorized into three type temperatures, high temperature for rutting, low temperature for thermal cracking, and intermediate temperature for fatigue cracking.

Table (4-49) Comparison among Best Options of Different Polymer Modification Percentages

Asphalt source	Grade	Polymer Type & % Content	High temperature	Low temperature	Intermediate temperature
Lanaz	40-50	+ 2.0 % Kraton	82 °C	-28 °C	28°C
Lanaz	40-50	+2.0 %Iterprene	82 °C	-22 °C	25°C
Kat	40-50	+ 2.0 % Kraton	82 °C	-22 °C	34 °C
Kat	40-50	+ 2.0 % Iterprene	82 °C	-22 °C	28°C
Lanaz	60-70	+ 2.0 % Kraton	82 °C	-22 °C	34 °C
Lanaz	60-70	+2.0%Iterprene	82 °C	-22 °C	34 °C
Kat	60-70	+ 4.0 % Kraton	76°C	-22 °C	31 °C
Kat	60-70	+ 2.0 % Iterprene	70 °C	-28 °C	25°C
Lanaz	40-50	+ 2.0 % Iterplast	82 °C	-22 °C	34 °C
Kat	40-50	+ 2.0 % Iterplast	82 °C	-22 °C	28°C
Lanaz	60-70	+2.0% Iterplast	82 °C	-22 °C	28°C
Kat	60-70	4.0 % Iterplast	82 °C	-22 °C	34 °C

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Till now, the Iraqi specifications for asphalt binders depend on two methods for asphalt grading system, either on Penetration or on Viscosity. However, these two specifications describe the physical properties at standard test temperature by employing empirical means of testing which cannot simulate the performance of asphalt at field. This problem was existed in other parts of the world. To overcome this shortage, the Super-pave method was invented, which contains evaluation of asphalt binders through performance grade. In this research, evaluation of local asphalt binders is done according to the performance grade (PG) system.

From the result analyses of performance grade zoning for Kurdistan Region-Iraq and experimental works, and through conducting tests of different local asphalt binder samples for neat and after polymer modification with different percentages, the following conclusions are drawn as follows:

1- Performance grade (PG) for Kurdistan Region-Iraq based on Super-pave method divided into four zones as shown in the table below:

Zones	Maximum pavement temperature, (° C)	Minimum pavement temperature, (°C)	(Region included)
Zone -1-	64	-16	Duhok-Region one, Erbil -Region one, Sulaymaniyah Region two.
Zone -2-	70	-10	Duhok-Region two, Erbil -Region two &three Sulaymaniyah Region three.
Zone -3-	76	-10	Germyain-Region-one, Kirkuk - Region one.
Zone -4-	64	-22	Sulaymaniyah Region one.

2- Three local asphalt binders are evaluated according to Super-pave method and there Performance grade (PG) showed in the table below:

Name of refinery	40-50		60-70	
Temperature range	Maximum °C	Minimum °C	Maximum °C	Minimum °C
LANAZ	70	-28	70	-28
KAT	70	-28	70	-28
PHOENIX	70	-22	64	-22

3- Rotational Viscosity of all local asphalt binders are approximately the same. They are according to standard specifications (AASHTO, 2007).

4- Kurdistan Region, being with a sever climate and heavy traffic conditions, causing problems of rutting, shoving…etc., the used asphalt in road construction have to be modified by polymer.

5- Asphalts of (Lanaz bitumen & oil refinery), (kat plant for asphalt & lub oil) and (phoenix bitumen production plant) products are of physical and rheological properties within the specifications.

6- Asphalt binders of (Lanaz bitumen & oil refinery) and (kat plant for asphalt & lub oil) with penetration grades of (40-50) and (60-70) provide performance grade PG (70-28), which could be used directly for zones one, two and four of Kurdistan Region-Iraq.

7- When local asphalt binders modified with polymer optimum percentages is as indicated in the table below:

Asphalt source	Grade	Polymer Type & + 2.0 % Content	High temperature °C	Low temperature °C	Intermediate temperature °C
Lanaz	40-50	Kraton	82	-28	28
Lanaz	40-50	Iterprene	82	-22	25
Kat	40-50	Kraton	82	-22	34
Kat	40-50	Iterprene	82	-22	28
Lanaz	60-70	Kraton	82	-22	34
Lanaz	60-70	Iterprene	82	-22	34
Kat	60-70	Iterprene	70	-28	25
Lanaz	40-50	Iterplast	82	-22	34
Kat	40-50	Iterplast	82	-22	28
Lanaz	60-70	Iterplast	82	-22	28

8- Lanaz refinery sample is superior in rheological properties. It has complex stiffness ($G^*/\sin\delta$) about 3 times more after RTFO aging when compared with neat of the same source. Phoenix and Kat have two times more for the same property.

9- Among results of elastic recovery tests, Lanaz shows greater value for both neat asphalt and after Rolling Thin Film Oven test. Kat, when modified with Kraton, shows greater value.

10-In Super-pave technique stiffness value has a major role in test assessments for all three main tests; DSR, DSR after PAV and BBR.

5.2 Recommendations

1- For all PG zones of Kurdistan Region-Iraq, an increment of 6 °C degrees (one interval) for high temperature is recommended, to avoid asphalt defeats due to sever climate conditions, heavy traffic loads and slow speed trucks.

2- For Phoenix refinery, asphalt product conducting Direct Tension test (DTT) is suggested to assess its rheological properties in low temperature. In this regard, it is suggested for laboratories of Kurdistan Region-Iraq to bring the required apparatus for the purpose of conducting DDT test.
3- Using the penetration grade ranges (40-50) and (60-70) for asphalt binders in mixture design as indicated in AASHTO 2013.
4- Asphalt pavement designer in Kurdistan Region-Iraq can benefit from variety of types and percentage of polymer to modify the local asphalt binders, according to tests results in chapter five in this research.

5.3 Suggestions for Further Studies

As next step, after this research evaluation, the effect of local asphalt binders on asphalt mixture properties through using Super-pave method is suggested.

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Appendices

Appendix A

"Maximum and Minimum Air Temperatures for Stations of Governorates of Kurdistan Region-Iraq and Kirkuk Governorate"

Table (A-1) Hawler Center Station / Erbil Governorate

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1999	Min	5.5	4.78	7.07	11.52	18	23.3	26.4	26.4	20.9	17	9	5.6	5.5
	Max	15.2	15.67	20.09	26.09	38.8	38.8	41.2	42.6	36.2	30.8	20.1	16.8	44.885
2000	Min	3.3	3	4.9	14.2	17.5	23	29.5	27.22	21.27	15.13	9.89	5.9	3
	Max	11.4	13.8	17.8	27.3	38.9	38.9	45	42	36.52	27.96	21.58	14.1	47.228
2001	Min	3.5	5.1	10.3	12.9	16.8	22.6	26.7	26.5	22.5	16.8	8.9	6.8	3.5
	Max	14.3	15.3	21.8	25.9	38.8	38.8	42.6	42.5	37.7	30.3	20	14.8	46.914
2002	Min	3.3	5.1	8.6	12.2	16.6	23.2	27.1	24.7	21.6	18.4	10.3	4.6	3.3
	Max	11.5	16.5	20.6	21.5	39.6	39.6	42	40.3	37.5	31.4	22.5	11.5	44.971
2003	Min	5.1	4.7	6.8	12.9	18.2	23.6	26.1	27.1	21.5	18.3	9.5	4	4
	Max	14.1	12.7	16.3	23.6	33	38.7	41.6	42.9	36.3	31	20.4	13.5	46.057
2004	Min	5.8	4.8	9.2	12.6	18.1	23.1	26.8	25.1	22.5	18.3	10.5	2.7	2.7
	Max	13.3	13.9	21.9	23.8	30.8	38.4	42.4	41	38.3	32.1	18.7	13.2	44.514
2005	Min	4	4.2	8.5	14.4	19	23.9	28.1	28.4	22.4	17.7	9.4	7.7	4
	Max	12.6	12.9	18.7	26.3	31.9	38.5	43.3	42.1	36.9	30.2	21.2	19.4	45.400
2006	Min	4.2	6.4	10	15.5	19.9	25.2	28.1	29.9	23.5	21.7	9.3	3.9	3.9
	Max	11.8	14.8	21.6	25.7	33	41.4	41	43.3	36.8	29.7	19.5	14	45.575
2007	Min	2.9	5.8	8.3	11.3	22.5	25.2	28.2	27.9	23.7	19.3	10.7	5.3	2.9
	Max	11.5	14.2	18.2	21.1	33.2	38.8	41.2	41	37.8	31.1	21.4	15.5	43.771
2008	Min	1.3	5.4	12.8	17.5	19	25	27.8	29.2	24.9	18.1	11.8	5.3	1.3
	Max	10.6	13.9	24.2	28.8	31.2	38.3	41.5	42	36.3	27.9	20.6	15	45.142
2009	Min	3.4	9.6	9.6	13	20.5	26.5	27.6	26.3	22.1	18.49	11.6	15.3	3.4
	Max	13	16.1	17.4	23.3	31.9	37.9	39.9	39.5	33.3	30.21	19.92	9.1	42.814
2010	Min	8.7	8.77	12.3	14.3	20.4	26.1	28.5	29.9	25.3	19.45	13.01	8.2	8.2
	Max	15.02	15.9	20.5	24.3	31.4	38.9	42.2	42.4	38.2	30.1	25.53	18.4	45.814
2011	Min	5.4	6.3	9	14.9	19.8	25.7	29	28.2	23.6	17.3	8.1	5.5	5.4
	Max	12.4	13.8	18.9	23.9	30.3	37.7	41.9	40.7	35.7	27.4	17	16	46.342
2012	Min	4.6	5.6	6.9	16.9	21.7	27.2	30	28.8	24.4	19.1	13.3	7.1	4.6
	Max	11.8	13.5	15.5	27	32.5	39.1	41.8	41.5	37.2	29.8	21	4.9	44.7
2013	Min	2.2	7.7	10	14.5	19.4	24.8	27.3	27.1	22	17.5	12.8	5.6	2.2
	Max	12.7	16.4	19.9	26.2	31.2	38	41.3	41	35.6	28.9	21.9	13.6	43.828
2014	Min	6.1	6.2	11	14.5	20.8	25.1	28.2	27.9	23.1	17.7	9.7	7.6	6.1
	Max	15	16.8	20.7	26.7	33.7	38.5	41.8	42.7	36	27.9	19.5	15.9	45.585

Table (A-2) Makhmur Station / Erbil Governorate

Year	Temperature	Months												Min & max ⊙
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1992	Min	4.9	6.2	6.2	11.7	16.7	23.1	24.2	26.6	22.2	15.8	9.8	4.0	4.0
	Max	13.96	16.35	18.00	24.70	30.40	38.80	42.00	42.70	38.20	32.60	20.20	11.20	42.70
1993	Min	2.9	3.9	6.6	12.9	17.6	23.3	27.3	27.8	22.1	19.0	8.6	7.6	2.9
	Max	12.30	14.10	19.40	24.60	30.40	39.30	44.60	43.50	40.20	33.10	18.70	16.60	44.60
1994	Min	6.8	5.4	9.7	15.8	20.5	24.2	27.4	25.6	26.0	20.1	11.2	3.3	3.3
	Max	15.60	15.60	21.60	29.90	35.50	40.80	43.70	43.40	40.30	32.20	19.50	11.60	43.70
1995	Min	5.7	7.1	7.5	11.5	20.5	25.1	25.5	25.9	22.5	17.1	8.7	3.6	3.6
	Max	14.40	17.30	21.30	26.10	36.00	40.60	43.10	44.00	38.90	32.20	21.70	16.50	44.00
1996	Min	6.7	7.2	9.1	12.5	22.1	24.2	29.3	26.9	22.1	16.5	11.3	9.7	6.7
	Max	13.70	17.80	19.10	25.10	36.60	40.00	46.20	44.50	38.40	31.30	24.50	17.80	46.20
1997	Min	4.8	4.3	9.9	12.2	20.4	25.4	26.7	24.4	21.9	18.5	12.1	6.7	4.3
	Max	14.50	14.50	17.40	25.70	35.70	41.50	43.50	42.20	38.00	31.60	22.80	15.50	43.50
1998	Min	4.2	4.9	8.5	14.4	20.2	27.3	28.8	29.5	23.4	17.5	14.3	8.2	4.2
	Max	11.50	15.80	20.20	28.20	35.80	43.30	45.70	46.60	39.90	33.40	27.70	20.60	46.60
1999	Min	6.3	6.0	10.2	14.7	21.2	25.5	28.2	28.6	23.3	18.9	10.3	6.5	6.0
	Max	16.30	18.40	23.00	29.00	37.00	41.40	43.90	44.90	38.50	32.80	23.10	17.90	44.90
2000	Min	3.5	4.2	7.4	16.8	20.8	25.2	30.5	29.0	23.2	16.6	11.2	6.8	3.5
	Max	12.90	16.10	21.90	30.30	35.10	41.30	47.30	44.40	38.40	29.60	22.80	14.90	47.30
2001	Min	5.2	6.5	11.9	14.5	17.1	22.6	27.7	28.1	24.9	18.3	9.8	6.8	5.2
	Max	15.30	16.60	23.70	27.90	33.70	40.80	44.50	44.60	40.00	32.10	21.90	16.30	44.60
2002	Min	5.3	6.8	10.4	13.9	19.4	24.9	28.9	26.2	24.1	20.3	12.0	4.9	4.9
	Max	14.30	18.30	22.80	24.80	34.10	40.00	44.30	42.40	39.40	33.20	24.50	12.40	44.30
2003	Min	6.0	6.3	7.8	14.3	21.2	25.5	27.2	28.7	23.0	19.2	10.3	6.8	6.0
	Max	14.68	16.30	18.12	26.20	35.58	41.36	43.52	44.95	37.93	32.45	21.85	14.25	44.95
2004	Min	6.6	6.1	10.0	13.3	19.5	25.0	28.3	26.7	24.3	19.6	11.4	3.4	3.4
	Max	14.04	14.89	23.19	26.40	33.26	40.19	44.40	42.80	40.24	33.58	20.05	13.94	44.40
2005	Min	4.2	4.9	9.1	15.6	20.0	24.3	28.8	28.8	22.7	17.3	9.3	8.4	4.2
	Max	14.20	14.60	20.90	29.80	34.20	40.10	44.90	43.60	30.60	31.50	22.30	20.10	44.90
2006	Min	-	-	-	-	-	-	-	-	-	-	8.5	3.7	3.7
	Max	-	-	-	-	-	-	-	-	-	-	21.4	15.8	-
2007	Min	2.9	6.4	9.2	12.0	23.1	26.4	29.0	28.8	23.8	20.0	10.5	5.5	2.9
	Max	12.3	15.9	20.7	24.8	36.3	41.7	43.8	44.4	40.8	34.1	23.5	16.5	44.4
2008	Min	1.6	5.2	13.0	17.3	19.6	24.9	28.1	29.2	25.3	18.1	10.9	5.9	1.6
	Max	11.9	15.3	25.5	30.9	35.4	40.4	43.7	43.7	25.3	30.2	22.2	16.1	43.7

Year	Temperature	Months												Min & max ⊙
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2009	Min	3.3	7.8	10.1	13.9	21.1	27.3	27.3	26.7	21.6	17.9	11.7	9.3	3.3
	Max	14.4	18.0	19.9	25.4	33.9	40.2	42.3	41.6	35.7	32.3	20.8	16.9	42.3
2010	Min	8.3	9.0	12.2	14.7	20.7	26.3	28.8	30.1	19.3	19.3	11.1	7.0	7
	Max	16.4	17.8	22.5	27.5	33.6	41.2	44.7	45.4	40.6	32.8	27.6	18.7	44.7
2011	Min	5.4	5.9	8.7	15.4	19.8	25.7	29.7	27.2	22.5	16.8	8.1	3.4	3.4
	Max	13.8	16.0	21.3	26.1	32.4	40.4	44.8	43.6	38.6	29.8	18.7	17.1	44.8
2012	Min	3.9	5.3	6.3	21.3	21.5	26.2	29.7	28.6	24.2	19.7	14.1	6.6	3.9
	Max	12.9	15.3	18.3	28.8	35.1	41.5	44.4	44.8	39.8	32.0	23.1	15.7	44.8
2013	Min	4.5	8.4	10.1	14.6	20.0	24.7	26.3	27.0	21.9	16.0	12.4	5.0	4.5
	Max	14.0	18.0	21.6	28.9	34.0	40.8	44.2	44.4	38.9	31.2	23.5	14.8	44.4
2014	Min	6.8	-	-	-	-	-	-	-	-	-	-	-	6.8
	Max	15.9	-	-	-	-	-	-	-	-	-	-	-	-

Table (A-3) Soran Station / Erbil Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2008	Min	-	-	-	-	-	18.2	22.2	24.7	13.4	10.2	4.5	-3.2	-3.2
	Max	-	-	-	-	-	41.5	45.3	45.3	41.6	33.7	21	19.7	43.166
2009	Min	-6.8	-0.2	1.6	5.2	9.9	18	-	19.7	9.1	10.4	7.9	-	-6.8
	Max	13.1	17.7	19.1	22.9	35.3	36	-	42.3	38.3	32.8	22.5	-	41.1
2010	Min	-3.2	-3.1	1.7	5	8.3	18.3	20.2	22.9	19.2	10.8	3.8	-0.7	-3.2
	Max	17.6	20	28.3	26	34.5	42.4	44.2	42.9	41.8	33.3	25.7	24.1	42.552
2011	Min	-3.4	-3.4	0.5	2.7	8.4	19	20.2	21.5	13.2	6.4	-	-	-3.4
	Max	13.6	16.8	23.5	28.7	34.1	38.4	43.9	46.1	44.3	33.8	-	-	44.048
2012	Min	-	-	-	-	-	-	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	Min	-	-	-0.9	-	10.8	17.1	21.5	-	13.7	7.7	6.3	-4	-4.0
	Max	-	-	24.4	-	34.3	39.5	42.3	-	40.5	32.1	24.8	14.7	41.861
2014	Min	-1.9	-3.7	0.8	0.6	11.9	15	21.9	22.3	15.4	9.8	1.8	0.4	-3.7
	Max	14.7	21.5	23.4	31.3	36.6	42.4	43.4	43.3	40.6	31.3	20.3	16.7	42.628

Table (A-4) Hajiumeran Station / Erbil Governorate

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2011	Min	-	-	-	-	-	-	23.4	15	13.1	1.2	-3.3	-5.4	-5.4
	Max	-	-	-	-	-	-	33.6	32.6	25.6	20.4	6.2	9.5	-
2012	Min	-	-	-	-	-	-	-	-	16.6	9.1	2.7	-2.7	-2.7
	Max	-	-	-	-	-	-	-	-	21.4	21.5	13.8	9.1	-
2013	Min	-8.5	-2.8	-4.5	3.7	9.4	16.7	22.3	-	14.4	6.1	-	-	-8.5
	Max	3.3	6.7	12.8	17.2	19.8	25.4	28	-	26.7	18.7	-	-	26.77
2014	Min	-7.6	-12.1	-3.2	0.4	12.3	-	-	-	-	-	-	-	-7.6
	Max	3.8	5.1	10.5	17.7	22	-	-	-	-	-	-	-	-

Table (A-5) Choman Station / Erbil Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2012	Min	-	-	-	-	-	-	-	-	-	11.7	6.9	-	-
	Max	-	-	-	-	-	-	-	-	-	23.9	16.5	-	-
2013	Min	-	-	-	-	14	20.6	26.7	27.9	18.1	10	8.1	-	-
	Max	-	-	-	-	24.1	29.6	32	34.2	30.5	21.9	15.7	-	32.985
2014	Min	-1.8	-7	0.3	4.1	16.5	-	-	-	-	-	-	-	-1.8
	Max	6.6	11.2	14.5	20.9	26.6	-	-	-	-	-	-	-	-

Table (A-6) Rewanduz Station / Erbil Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2009	Min	-	-	-	-	-	-	-	-	-	14.1	6.8	4.3	4.3
	Max	-	-	-	-	-	-	-	-	-	23.1	17.9	10.5	-
2010	Min	0.8	0.4	5.5	-	-	-	-	-	-	-	-	4.7	0.8
	Max	11.7	14.6	24.1	-	-	-	-	-	-	-	-	13.2	-
2011	Min	-	-	-	-	-	-	-	24.4	18.7	11.7	5.4	2.6	2.6
	Max	-	-	-	-	-	-	43	39.6	31.9	26.2	12.2	13.3	36.271
2012	Min	-	-	-	-	-	-	-	-	-	14	8	3.4	3.4

Year	Temperature	Months												Min &
	Max	-	-	-	-	-	-	-	-	32.1	30	17.3	10	-
2013	Min	-6.5	0.4	-0.3	8.2	13.4	-	-	-	-	-	-	-	-6.5
	Max	7.6	12.3	16.2	22.5	21.9	-	-	-	-	-	-	-	-

Table (A-7) Mergasur Station / Erbil Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2011	Min	-	-	-	-	-	-	26.8	21	16.9	10.8	4.2	1.1	1.1
	Max	-	-	-	-	-	-	42.1	37.6	29.9	24.2	11.4	12.2	37.5
2012	Min	-	-	-	-	-	-	-	30.5	23.9	12	7.2	2.3	2.3
	Max	-	-	-	-	-	-	-	36.6	33.3	28.7	17.2	11.7	35.814
2013	Min	-7.6	-	-	-	20.1	21.5	21.5	27.7	25	12.2	9.5	-	-7.6
	Max	5.3	-	-	-	24	34.1	34.1	34.8	34.1	27.2	17.2	-	34.057
2014	Min	-	-3.4	-	-	-	-	-	-	-	-	-	-	-3.4
	Max	-	9.4	-	-	-	-	-	-	-	-	-	-	-

Table (A-8) Pirmam Station / Erbil Governorate

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1996	Min	2.3	4.2	4.9	9.7	18.2	21.5	26.5	26.0	20.6	14.6	9.2	6.2	2.3
	Max	8.20	11.70	11.60	17.80	28.10	21.60	38.50	36.90	31.10	23.80	18.50	12.40	38.50
1997	Min	2.6	-0.2	2.5	9.5	16.2	22.4	24.8	22.9	19.8	14.6	9.1	3.7	-0.2
	Max	9.60	7.40	9.40	17.10	25.80	32.80	34.70	35.20	30.40	24.70	16.70	10.00	35.20
1998	Min	-0.2	2.1	5.2	11.5	17.0	24.2	26.8	27.0	21.4	16.0	12.1	7.3	-0.2
	Max	5.60	9.50	12.50	20.10	27.00	33.80	37.40	38.10	32.20	26.50	20.80	15.30	38.10
1999	Min	4	4	6.7	11.6	18.6	22.8	26.7	26.6	20.6	16.1	7.8	6.2	4
	Max	10.9	11.3	14.9	20.8	28.9	33.8	36.7	37.8	31.6	25.3	16.6	14.2	39.96
2000	Min	1.3	2.1	4.4	12.6	16.7	22.2	29.2	26.1	21	13.7	8.6	4.3	1.3
	Max	7.2	9.7	13.7	22.1	27.4	33.4	39.9	37.3	31.8	23.2	17.5	10.3	41.84
2001	Min	3.4	3.6	9.5	12.2	15.9	22.3	26.3	26	21.7	15.7	7.5	4.8	3.4
	Max	10.7	10.5	17.5	20.8	26	33.1	37.4	37.3	32.7	25.2	15.9	11.1	41.54
2002	Min	1.4	4.3	7.9	9.5	15.9	21.9	25.5	24	21.2	17.3	9.5	2.1	1.4

Appendix A

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	Max	7.9	12.5	16.1	17.1	26.2	31.9	34.8	35	32.5	26.5	18.1	7.8	38.82
2003	Min	3.3	1.8	4.1	11.3	18	21.9	24.9	25.7	20.2	16.4	8.1	3.9	1.8
	Max	10.4	7.7	11.6	19.5	26.8	30.4	36.2	37.8	31.5	26.1	16.7	10.1	41.25
2004	Min	2.8	2	9.2	10.6	15.7	21.8	25.1	23.8	21.8	16.4	7.5	2.1	2
	Max	8.9	6.6	17.5	19.1	24.6	32.3	36.5	35.7	32.9	27.2	14	9.6	39.2
2005	Min	2.4	1.8	6.3	12.8	16.6	21.1	26	25	19.9	14.7	7.9	7.2	1.8
	Max	9.1	8.7	13.7	21.5	25.8	31.8	37	36.3	31.1	29.5	17	15.2	39.58
2006	Min	1.1	3.1	7.9	12.2	17.3	23.6	24.6	26.5	20.1	15.2	5.9	1.9	1.1
	Max	7.2	9.8	16.2	20.2	26.7	34.4	35	37.5	31.2	24.4	14.8	9.8	39.58
2007	Min	1.1	3.1	5.7	8.8	19.3	22.9	25.5	25.1	20.9	16.2	8.1	3.3	1.1
	Max	8.2	10.3	13.5	16.9	28	33	35.6	36.2	33.2	26.4	17.1	11.3	38.94
2008	Min	-0.9	1.8	10.5	14.8	15.5	21	24.6	25.6	21.1	14.5	8.3	3.4	-0.9
	Max	6.3	9.3	19.7	23.9	26.2	31.7	36.4	37.2	31.8	24.2	17.9	11.7	40.485
2009	Min	1.7	4.8	6	10.1	16.8	22.7	24.4	23	18.7	15.7	8.41	5.7	1.7
	Max	9.7	12.1	12.9	19.1	27.1	32.8	35.8	35.3	29.4	27.01	16.63	12	38.84
2010	Min	6.4	5.4	9.1	11.3	16.9	22.9	26.03	26.7	22.9	16.3	11.21	7.2	5.4
	Max	11.4	11.9	16.9	19.9	26.1	33.6	37.9	38.6	35.1	26.6	22.87	16.2	40.6
2011	Min	2.49	3	6.53	10.17	16.4	22.97	25.85	24.63	20.54	13.81	4.92	4.92	3
	Max	8.57	9.36	15.07	19.74	26.49	32.87	38.04	37.2	32.04	24.06	13.22	13.16	41.61
2012	Min	1.09	2.98	4.55	13.15	17.07	21.9	23.92	29.15	19.41	14.4	9.54	4.04	1.09
	Max	8.24	9.06	10.91	22.85	27.9	34.18	36.84	36.58	32.74	25.3	17.26	11.35	39.614
2013	Min	1.9	4.5	6.7	11.6	15.8	20.7	23.5	23.5	18.7	13.4	9.4	2.5	1.9
	Max	8.4	12.1	15.2	21.8	26.4	32.8	35.9	36	31	24.2	17.6	9.7	38.185
2014	Min	3.3	3.5	8.2	12.2	18.2	22.0	25.2	25.2	20.3	14.1	7.1	5.6	3.3
	Max	10.5	12.5	16.1	22.3	28.1	32.9	36.6	37.5	31.2	23.1	14.9	12.0	40.014

Table (A-9) Sidakan Station / Erbil Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2011	Min	-	-	-	-	-	-	27.9	20.1	17.3	6.9	-	-	-
	Max	-	-	-	-	-	-	41.9	38	33.4	23.6	-	-	33.82
2012	Min	-	-	-	-	-	-	-	-	23.7	12.6	7.9	1.9	1.9
	Max	-	-	-	-	-	-	-	-	29.5	28.4	16.7	10.4	-
2013	Min	-9.4	0.4	2.8	8.1	14.5	27.1	-	-	-	14.4	-	-	-9.4
	Max	8.2	12.2	16.8	22.4	26.9	32.6	-	-	-	18.3	-	-	31.114

Table (A-10) Shyrwan Mazn Station / Erbil Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2011	Min	-	14.2	-	-	-	-	-	-	-	-	2.8		-
	Max	-	19.3	-	-	-	-	-	-	-	-	12.5		-
2012	Min	-	-	-	-	-	-	-	-	-	13.5	8	2.4	-
	Max	-	-	-	-	-	-	-	-	-	29.2	17.9	14.8	-
2013	Min	-7.2	-0.4	3.2	8.8	14.5	23.1	29.5	29.3	-	14.6	-	-	-7.2
	Max	7.4	13.1	18	23.6	26.5	36.1	37.6	37.2	-	28.6	-	-	35.271
2014	Min	-	-1.2	3.3	6.7	17.5	-	-	-	-	-	-	-	-1.2
	Max	-	14.2	16	22.8	27.8	-	-	-	-	-	-	-	-

Table (A-11) Ankawa Station / Erbil Governorate

Year	Temperature	Months												Min & max ⊙
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2002	Min	1.8	3.7	7.5	10.9	14.3	20.5	24.3	22.7	19.1	16.7	8.5	3.2	1.8
	Max	10.9	16.1	19.8	22.0	32.3	38.9	40.5	40.9	38	31.4	22.5	10.9	40.9
2005	Min	1.9	2.8	7	10.9	15.8	20.5	25.2	33.8	19.6	14.6	6.4	4.6	1.9
	Max	11.5	12.6	18.1	26.1	32.3	38.5	44.3	42.7	37	30.1	20.5	18.6	44.3
2013	Min	2.3	5.8	7.2	11.1	15.7	22.9	25.6	24.7	19.2	13.6	10	2.5	2.3
	Max	11.9	16.1	19.5	25.8	30.9	38.4	42.8	41.5	36.2	29.5	22.1	12.6	42.8

Table (A-12) Koye Station / Erbil Governorate

Year	Temperature	Months												Min & max ⊙
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2002	Min	3.9	6.2	10.3	12.2	17.4	23.6	28.8	26.3	22.7	19.9	11.9	5.5	3.9
	Max	10.9	15.9	19.9	21.2	30.4	36.9	40.9	40.5	37.8	32	21.1	10.4	40.9
2005	Min	5.7	4.4	8.1	12.2	19.1	23.1	27.6	27.8	24.8	18	12.9	10.6	4.4
	Max	10.7	8.9	16.4	25.2	30.4	36.4	44.1	41.9	36.3	28.1	20.7	18.5	44.1
2013	Min	5.5	8.2	10	15.9	21.5	27.4	30.6	29.9	24.4	18.8	1.1	5.8	1.1
	Max	10.9	13.8	17.6	23.2	29.2	36.9	41.5	41.7	35.9	28.3	20	10.3	41.7

Table (A-13) Shaqlawe Station / Erbil Governorate

Year	Temperature	Months												Min & max ⊙
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2002	Min	0.5	3.5	7.8	9.3	15.5	22.1	25.7	24.4	12.7	13.1	9	1.7	0.5
	Max	7.7	11.9	16.5	17.8	26.5	33.7	37.7	36.4	33.2	28	18.4	8.3	37.7

Table (A-14) Qushtepa Station / Erbil Governorate

Year	Temperature	Months												Min & max ⊙
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2010	Min	7.15	6.85	9.99	12.75	18.87	24.14	27.22	28.42	23.53	17.33	10.84	6.63	6.63
	Max	15.26	16.26	21.01	24.76	32.16	39.73	43.06	43.44	39.24	30.86	26.02	18.95	43.44
2011	Min	3.7	4.8	7	13	17.9	24	27.3	26.4	21	15.4	5.7	3.6	3.6
	Max	12.6	14.5	19.3	24.6	31.9	38.6	43	41.4	36.7	28.3	17.1	15.7	43
2012	Min	2.8	4.2	5.5	15.4	19.9	25.6	28.5	26.5	22.6	17.4	12.1	5.8	2.8
	Max	11.7	13.3	15.8	28.5	33.1	39.6	42.1	41.6	37.3	29.9	21.3	14.3	42.1
2013	Min	4.2	6.5	7.9	12.6	18.3	23.1	25.5	25.5	19.9	15.3	11.1	3.3	3.3
	Max	12.3	15.8	19.3	26.4	31.7	38.1	41.4	41.1	35.6	28.5	21.4	13	41.4

Table (A-15) Khabat Station / Erbil Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2002	Min	1.9	3.5	6.7	11	13.1	17.5	21.3	19.2	16.4	14.4	6.3	3	1.9
	Max	13.5	18.1	22.2	23.9	33.4	39.5	43.2	40.9	38.5	32	24	12.8	43.2
2005	Min	2.3	3	6	10.6	14.2	17	20.8	21	16.5	11.2	5.2	4.1	2.3
	Max	14	15	21	28.7	34.2	40.6	45.4	44.1	39.3	32.2	22.7	20.6	45.4
2013	Min	-1	1.9	1.1	7.7	13.5	17.3	21.5	19.3	12.9	8.0	5.4	-1.5	-1.5
	Max	18.4	21.9	29.1	36.8	40.9	45.2	47.5	45.7	45.2	35.3	28.5	21.6	45.05
2014	Min	0.6	-1.6	2.9	1.9	13.0	18.5	21.4	19.6	15.4	12.0	3.9	1.6	-1.6
	Max	18.2	25.8	28.2	36.9	42.6	42.2	48.3	48.1	44.8	36.1	26.2	22.2	47.084

Table (A-16) Duhok Center Station / Duhok Governorate

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2000	Min	1.2	2.3 2	4.1	12.4	16.7	21.9	28.3	26.0	20.9	14.4	8.9	4.8	1.2
	Max	9.0	11. 94	15.4	23.9	30.1	37.3	43.3	39.9	34.9	26.3	19.8	12.6	44.895
2001	Min	3.2	8.7	9.9	11.7	16.3	21.6	26.1	26.9	17.2	15.1	9.3	6.9	3.2
	Max	13.0	13.5	20.4	23.1	28.9	38.6	41.0	40.8	36.4	31.9	20.0	14.3	44.514
2002	Min	2.7	8.7	9.4	11.4	16.8	22.8	27.1	24.7	21.4	18.2	9.7	3.8	2.7
	Max	12.0	13.5	19.5	20.5	30.2	37.1	40.6	38.4	35.6	29.9	22.1	10.8	43.357
2003	Min	5.0	4.8	6.5	12.5	18.3	23.4	26.2	26.4	20.6	17.7	9.5	6.0	4.8
	Max	13.3	11.4	14.8	22.6	31.6	37.4	40.5	41.7	34.8	29.6	19.2	12.7	45.057
2004	Min	5.3	4.3	9.0	11.7	16.3	22.5	26.9	24.6	22.0	17.5	9.9	3.0	3
	Max	11.8	11.6	20.1	23.4	29.3	36.6	41.4	39.7	37.0	30.4	18.3	13.0	43.128
2005	Min	3.7	3.9	8.4	14.1	17.8	22.2	26.4	26.7	21.2	16.1	8.8	8.1	3.7
	Max	12.4	13.1	17.9	24.9	30.7	36.8	41.6	40.0	34.2	27.8	19.6	17.8	45.042
2006	Min	3.8	5.8	9.9	14.7	18.1	24.2	25.9	27.1	27.1	17.6	7.6	3.0	3.0
	Max	10.1	13.6	18.9	23.5	30.5	39.0	39.2	41.4	34.2	27.8	17.3	12.8	43.5
2007	Min	2.0	5.1	7.8	11.0	20.5	23.6	27.4	26.6	22.1	17.8	9.6	3.9	2.0
	Max	11.2	13.4	16.9	20.0	31.3	37.4	40.6	40.3	37.1	30.0	19.9	13.7	43.414
2008	Min	0.0	3.8	11.2	15.7	17.2	23.6	26.2	27.9	23.0	16.4	10.0	4.8	0.0

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	Max	9.7	12.7	22.7	20.0	29.9	37.3	40.8	40.8	35.0	27.9	20.1	14.1	43.757
2009	Min	2.4	6.5	7.9	11.5	17.7	24.5	25.9	24.3	20.2	16.7	9.8	7.4	2.4
	Max	12.5	15.3	16.8	22.3	30.5	36.8	39.3	38.6	32.6	29.5	18.6	14.9	41.585
2010	Min	6.7	6.8	10.5	12.9	17.9	23.5	27.0	28.2	23.5	17.7	10.6	7.4	6.7
	Max	14.0	15.0	20.4	24.4	30.6	38.2	41.8	42.2	37.5	29.2	25.0	18.7	44.085
2011	Min	4.0	4.5	8.1	12.8	17.0	23.0	26.5	26.1	21.3	15.0	6.5	4.7	4.0
	Max	12.4	12.8	18.4	22.7	29.1	36.7	41.2	40.5	35.3	26.9	15.7	15.0	45.628
2012	Min	3.1	3.2	4.3	13.9	17.8	24.0	25.7	24.7	20.7	15.9	11.6	6.0	3.1
	Max	11.0	12.0	14.2	25.4	30.9	37.3	40.4	40.0	35.8	28.5	20.2	13.5	43.514
2013	Min	3.2	5.9	8.9	12.6	17.7	22.1	24.6	24.5	19.9	14.5	10.9	2.8	2.8
	Max	11.1	14.7	18.2	24.6	29.7	36.3	39.7	39.8	34.2	27.0	20.4	12.0	41.940
2014	Min	6.8	8.7	16.4	21.3	25.7	26.0	22.4	18.7	13.6	9.7	4.5	4.4	4.4
	Max	14.4	17.5	25.6	33.9	40.5	40.1	36.5	31.3	24.2	18.9	15.2	13.4	42.857

Table (A-17) Zakho Station / Duhok Governorate

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2000	Min	2.7	3.8	5.7	13.6	17.1	23.2	28.5	26.2	21.3	15.4	9.2	5.5	2.7
	Max	10.0	13.8	17.3	25.5	38.1	38.1	44.0	40.7	35.7	27.8	21.4	13.8	45.84
2001	Min	4.2	8.7	5.7	12.7	15.1	21.7	27.0	26.2	22.2	15.9	8.6	6.3	4.2
	Max	14.3	13.5	17.3	24.5	28.1	37.9	41.8	41.2	36.9	29.2	19.8	13.3	45.471
2002	Min	2.3	8.7	8.8	11.0	15.8	21.8	26.5	24.8	20.9	17.4	10.1	3.4	3.4
	Max	11.6	13.5	19.9	20.4	29.9	36.7	40.6	38.8	35.9	29.7	22.9	10.8	43.014
2003	Min	4.6	8.7	6.0	12.3	18.0	22.6	26.1	26.5	21.0	17.7	9.0	4.5	4.5
	Max	13.9	13.5	15.0	23.1	32.5	37.6	40.9	41.8	35.4	29.6	19.8	11.9	45.028
2004	Min	5.0	3.6	9.2	11.2	16.3	22.5	26.3	24.9	21.9	17.5	9.5	2.2	2.2
	Max	12.1	12.4	21.4	20.0	29.0	37.5	41.2	39.9	37.7	30.9	17.6	13.8	43.328
2005	Min	3.5	3.5	7.7	13.0	17.1	21.9	27.1	26.9	21.3	14.7	8.4	7.5	3.5
	Max	12.9	12.9	18.5	20.0	31.1	36.6	42.2	41.1	36.0	29.4	20.9	18.8	45.042
2006	Min	3.2	5.6	8.9	13.9	17.4	-	26.2	28.1	21.4	17.4	7.0	2.1	2.1
	Max	10.5	13.7	20.4	20.0	31.8	-	40.3	42.9	36.4	28.4	18.8	14.6	45.228

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2007	Min	1.4	4.5	7.4	10.2	19.2	23.4	27.1	26.8	21.7	17.7	9.1	4.2	1.4
	Max	12.6	13.9	17.9	20.0	32.1	38.7	41.2	40.7	37.2	30.7	20.8	14.5	43.414
2008	Min	-0.2	3.5	11.1	15.1	17.3	23.8	27.0	27.8	23.3	17.2	10.2	4.6	-0.2
	Max	11.7	13.4	24.0	20.0	30.4	37.9	41.2	41.3	35.7	28.4	20.5	14.1	43.885
2009	Min	3.2	6.8	8.2	11.2	16.4	24.2	26.4	25.1	20.7	16.5	10.0	7.3	3.2
	Max	13.6	15.2	17.1	20.0	32.1	38.4	40.6	40.0	34.1	30.9	20.2	14.7	43.428
2010	Min	7.1	7.6	10.5	12.9	18.2	23.9	27.6	28.4	23.7	17.7	10.8	7.4	7.1
	Max	14.7	16.3	20.7	25.1	31.0	39.0	42.7	43.3	38.9	30.3	27.1	19.7	45.314
2011	Min	4.0	4.7	8.1	12.9	16.7	22.7	26.3	25.5	20.1	12.9	4.4	2.9	2.9
	Max	13.6	13.7	20.0	23.1	30.1	38.0	42.6	42.0	36.8	28.0	16.8	15.9	46.842
2012	Min	2.6	2.6	4.2	13.9	18.5	24.3	27.2	26.3	22.6	17.8	-	-	2.6
	Max	11.1	13.3	14.9	26.3	32.0	38.8	41.5	41.2	37.3	29.4	-	-	44.971
2013	Min	3.8	6.6	8.8	13.0	17.9	23.0	26.7	26.1	20.7	14.8	11.4	3.3	3.3
	Max	12.0	15.8	19.4	25.9	31.0	38.2	41.3	41.2	35.6	28.0	21.1	12.2	43.457
2014	Min	4.6	5.5	10.3	13.7	18.3	22.9	27.0	26.8	22.2	16.9	9.3	7.1	4.6
	Max	14.3	16.7	20.1	26.4	32.5	38.2	42.1	42.5	35.9	27.1	18.6	15.1	44.957

Table (A-18) Mangush Station / Duhok Governorate

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2013	Min	-7.2	-1.2	0.3	4.7	9.8	14.3	18.3	19	12.4	5.3	-4	-5.5	-7.2
	Max	12	17.3	23.4	30.4	32.2	37.9	40.4	39.4	38.8	30.7	12.5	16.2	42.085
2014	Min	-1.07	-4.7	-3.5	2.1	10.06	12.3	19.6	20.1	12.9	8.9	1.2	0.2	-4.7
	Max	14.3	19.3	22.4	29.7	34.7	39.8	41.7	41.4	38.8	29.02	20.5	17.1	41.037

Table (A-19) Canimasi Station / Duhok Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2010	Min	-	-	-	-	-	-	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	-	-	-	-	8.1	-
2011	Min	-1.6	-6.6	0.5	-	16	19.2	23.2	24.5	15.7	6.8	-0.6	-0.6	-6.6
	Max	4	6.6	6.3	-	23.2	26.8	34.4	31.7	25.3	21.2	9.6	8.2	32.442
2012	Min	-4.5	-3.5	-5.7	9.5	13.8	18.5	22.2	-	-	10.8	5.7	0	-5.7
	Max	4.1	4.3	8.4	18.1	22.3	29.3	31.9	28.5	-	20.7	14.5	13.8	30.371
2013	Min	-	-	-	6.8	12.6	21.6	27.5	-	-	8.3	8.2	-	
	Max	-	-	-	20.2	21.4	31.7	33.1	31.4	-	-	13.5	-	31.328

Table (A-20) Atrush Station / Duhok Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2010	Min	-	-	-	-	-	-	-	-	-	-	-	8.9	-
	Max	-	-	-	-	-	-	-	-	-	-	-	13.3	-
2011	Min	5.7	2.5	8.7	9	15.2	27.7	31.4	31	20.8	14	6.1	7	2.5
	Max	10.5	15.4	18.2	24.5	32.5	36.3	41.7	41.7	32.8	-	-	14.7	41.071
2012	Min	0.3	5.7	-	-	24.9	31.6	34.4	33	24.3	16.7	11	6	0.3
	Max	11.7	11.3	-	-	35.1	41.6	43.7	41.2	34	36.6	22.8	13.5	42.442
2013	Min	0.6	6.3	-	-	-	-	-	-	-	-	-	-	0.6
	Max	13.7	13.9	-	-	-	-	-	-	-	-	-	-	-

Table (A-21) Sharya Station / Duhok Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2010	Min	-	-	-	-	-	25.9	31	33.4	27.2	16.1	12.7	7.3	
	Max	-	-	-	-	31.1	37	38.9	37.2	34.4	28.1	19.6	17.5	38.5
2011	Min	-	2.1	7.5	9.1	15.5	26.8	30	29.5	20	13.8	4	4	2.1
	Max	-	14.4	17.8	25.5	30.7	35.3	39.9	39.8	32.4	28	17	14.2	38.871

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2012	Min	-0.2	4	2.4	15	22.3	26.5	28.5	31.2	26.3	17	9.9	5.2	-0.2
	Max	10.5	13.6	15.8	25.7	32.1	36.5	39.5	36.6	33	28.5	23.5	12.3	37.842
2013	Min	-1.7	5.9	6.4	11.7	18.5	25.4	27.7	24.4	-	16.3	14.2	-	-1.7
	Max	13.8	15.7	19.6	25.2	29.2	36	-	39.2	-	27.7	19.3	-	34.8

Table (A-22) Dinarta Station / Duhok Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2010	Min	-	-	-	-	-	-	-	-	-	-	-	11.6	-
	Max	-	-	-	-	-	-	-	-	-	-	-	17.2	-
2011	Min	5.6	3	8.2	10.9	18.7	29.1	29.2	29.1	20.2	13.1	2.5	-	3
	Max	12.9	15.9	21.7	27.4	39	37.1	39.7	37.2	29.6	26	16.6	-	35.758
2012	Min	-0.9	1.8	-	14.8	20	28	33.1	30	22.4	13.7	9.6	4.7	-0.9
	Max	13.6	11.6	-	24	31.2	38.2	41.2	39.9	31.9	35.7	18.9	12.7	40.442
2013	Min	-3.4	4.7	4.8	9.1	16.5	23.2	28.9	24.5	19.2	-	-	-	-3.4
	Max	11.1	15.2	19	24.2	27.9	37.5	39.3	34.4	33.3	26.4	-	-	37.5

Table (A-23) Batufa Station / Duhok Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2011	Min	3.2	-1.6	4.9	-	-	-	-	29.5	19.3	10.8	4.2	4.5	-1.6
	Max	8.6	12	10.6	-	-	-	-	34	30.2	26.3	13	11.9	31.342
2012	Min	-2.2	-0.6	-3.6	12.8	18.1	24.1	27.3	30.2	-	14.2	7.8	-	-2.2
	Max	8.4	8.3	13.1	22.2	26.5	33.9	36.4	36.6	-	24.8	19.3	-	35.714
2013	Min	-	-	-	9.6	15.7	23.9	31	28.1	-	14.6	10.5	-	-
	Max	-	-	-	24.7	26.9	36.6	36.8	38.4	-	26.6	17.5	-	36.742
2014	Min	-	-	-	-	15.1	-	-	-	-	-	-	-	-
	Max	-	-	-	-	29.2	-	-	-	-	-	-	-	-

Table (A-24) Bamerny Station / Duhok Governorate

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2013	Min	-8.1	-2.8	-1.7	4.7	9	16.2	20.2	20.8	13	8	4.1	-17.6	-17.6
	Max	11.8	15.7	21.4	28.8	30.3	36.6	39.4	39	37.1	30.9	22.5	5.6	40.285
2014	Min	-1.7	-2.6	-3.8	3.9	10.8	12.9	20.8	22.3	13.8	7.4	0.8	-0.1	-3.8
	Max	14.4	18.9	21.7	29	33.6	38.9	40.4	40.1	37.7	28.9	21	16.04	38.934

Table (A-25) Akry Station / Duhok Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2009	Min	-6	1	2	7	11.6	17.9	22.9	22.4	11.8	12.3	4.3	3.5	-6
	Max	16	20	23	28.5	37.8	41.3	42.9	43.4	40.3	35.1	25.5	19.4	42.642
2010	Min	-1.2	-0.8	3.6	6.5	9.8	19.2	22.4	26.4	21.5	9.9	8.2	2.7	-1.2
	Max	19.4	20.6	26.3	28.4	36.7	43.7	46	44.2	42.9	36.7	28.7	28.5	44.271
2011	Min	0.6	-1.8		4.5	9.7	20	26	23.4	18.7	10.6	0	0.6	-1.8
	Max	16	18.9		21.8	28.4	37.3	41.8	40.6	35.4	26.8	15.5	14.6	46
2012	Min	-2	-4	-7	9	14	17	24	26	22	12	5	1	-7
	Max	13	15	20	30	32	38	44	44	40	36	28	19	43.285
2013	Min	-0.5	4.9	6.9	6.6	11.6	19	21.6	23	15.7	8	7.7	-2.6	-0.5
	Max	12.6	14.6	21.3	32.7	36.6	41.3	43.5	43.2	42.1	31.9	25.8	19	44.357
2014	Min	1.4	-1.8	-0.8	1.2	13.8	17.8	24.5	24.1	16.8	11.6	3.4	2.7	-1.8
	Max	16.3	22.9	23.9	33.5	42.4	43.3	45.1	44.8	42	32.3	22.6	19	43.594

Table (A-26) Amydi Station / Duhok Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2011	Min	0.6	-1.4	2.7	4.9	10.4	24	26.3	22.2	16.5	9.3	3.8	-	-1.4
	Max	7.2	8.6	17.1	21.8	25.5	30.6	40.4	36.6	32.1	23.8	10.4	-	36.357
2012	Min	-2.6	-	-	-	-	-	-	27.4	24.5	12	-	1.5	-2.6
	Max	5.7	8.7	-	-	-	-	-	35.4	29.6	22	-	11.5	34.3
2013	Min	-5.2	1.6	1.5	7.4	13.5	22.1	28.7	-	-	13.2	10.3	-	-5.2
	Max	6.7	10.5	17.1	21.8	24.6	34.2	34.7	34.8	33.9	21.3	16.1	-	33.985

Table (A-27) Sulaymaniyah Center Station / Sulaymaniyah Governorate

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1999	Min	5	4.2	7.4	12.4	19.9	24.7	27.2	28.2	21.9	17.4	9	6	4.2
	Max	13.2	14.8	19.3	23.9	31.3	36	38.7	40.5	34	28.7	17.7	14.4	-
2000	Min	1.6	2.2	5.7	13.4	17.9	23.7	29.6	26.3	21	14.5	8	4.7	1.6
	Max	9.3	11.8	15.6	23.9	30	35.9	41.8	39.7	34	25.3	19	12	43.685
2001	Min	4	3.6	9.1	12.2	17.3	23.1	27.4	26	22.1	17.3	7.3	5.1	3.6
	Max	11.9	13.3	19.9	22.6	27.9	36.8	39.3	39.5	34.7	27.4	17.9	11.6	43.528
2002	Min	1.7	4.6	8.8	10.7	16.8	23.6	27.3	25	21.9	18	10.6	3.6	1.7
	Max	8.8	13.4	18.4	19.1	28.3	34.6	38	37.4	34.6	28.9	18.6	9.3	40.771
2003	Min	3.4	2.7	5.7	12.1	18.2	23.4	26.3	27.3	20.9	17.7	8.7	4.7	2.7
	Max	11.1	9.9	13.8	21.7	29.5	35	38.4	39.6	33.7	28.9	17.8	11.4	43.1
2004	Min	4	2.8	9.4	11.2	15.8	22.7	25.8	25	22.9	17.2	8.9	2.9	2.8
	Max	10.8	11.4	19.8	21.1	26.3	34.9	38.1	38.1	35.1	29.5	15.7	10.9	41.442
2005	Min	2.8	2.6	11.8	13	18.9	23.3	28.3	26.7	27.9	15	9	6.2	2.6
	Max	10	10.2	16.1	23.6	29.5	35.6	40.2	38.3	33.5	27.6	19.4	17.1	43.1
2006	Min	1.5	4.3	8.7	13.2	17.8	24.5	26.1	29.5	21.9	17.6	10.1	6.5	1.5
	Max	9.1	12.2	19.7	23.3	29.8	37.6	38.6	40.9	34.6	27.9	16.2	14.3	42.5
2007	Min	1.5	4.4	7.2	10.4	20.3	24	26.9	27.1	22.7	18.3	9.5	4	1.5
	Max	9.5	12.9	19.6	20	31.4	36.9	38.8	38.7	36.2	30	20.5	13.3	41.828
2008	Min	-1	2.5	10.6	15.6	18.2	24.1	26.9	28.6	22.7	16.3	9.3	4.8	-1.0
	Max	7.1	11.9	22.7	27.4	29.7	35.9	39.9	40.8	35.1	27.8	19	14	44.742
2009	Min	1.9	5.7	7.1	11.1	18.3	24.3	26.4	24.8	20.3	16.1	8.8	6.3	1.9
	Max	11.8	14.1	16.8	20.9	29.6	34.7	38.5	38.3	32.2	28.9	17.5	13.4	41.114
2010	Min	6.3	6.1	10	12.4	17.7	25.2	27	28.7	23.9	16.9	10	6.2	6.1
	Max	14.3	14.4	19.5	22.6	28.7	37	40.6	40.5	37.6	29.8	24	17.2	42.928
2011	Min	2.5	3.8	7.5	12.2	17.2	23.7	27.3	25.8	20.9	14.9	6	3.5	2.5
	Max	10.7	12.2	17.9	22.2	28.5	36.4	40.7	39.7	34.9	26.5	15.5	14.8	44.700
2012	Min	1.8	2	4.4	14.3	18.8	24.8	27.1	26.3	22.7	17.7	11.1	5.3	1.8
	Max	10.3	11.8	14.1	25	30.7	37	39.9	40.6	36	28.9	20.1	13.8	42.987
2013	Min	3.2	5.7	8.6	13.5	18.2	23.9	26	25.8	19.9	14.3	10.4	2.7	2.7
	Max	11.7	14.9	19.1	24.9	28.9	36.2	40.4	39.5	34.6	27.4	19.3	11.2	42.428
2014	Min	3.4	3.9	8.9	11.4	18.0	23.1	26.6	26.6	20.9	15.4	8.2	5.8	3.4
	Max	12.0	14.2	17.9	24.0	31.1	36.9	40.2	41.1	35.3	27.5	18.2	15.0	43.085

Table (A-28) Helsho Station / Sulaymaniyah Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2013	Min	-6.8	-1.4	-0.9	4.3	11.2	17.3	22	22.6	24.3	9.8	6.3	-5.6	-6.8
	Max	12.2	16.5	24.3	28.9	31.6	37.4	39.7	38.7	25.7	29.1	21.8	12.6	38.801
2014	Min	-0.7	-7.1	-2.9	0.2	13.4	15.7	22.5	23	17.4	8.2	1	0.5	-7.1
	Max	13	19.6	20.7	28.4	33.9	38.9	40.4	41.1	38	28.6	19	16	40.17

Table (A-29) Halabje Station / Sulaymaniyah Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2013	Min	-2	1.5	1.5	6.7	11.5	18.2	21.8	22.1	15.7	9.4	6.8	-5.6	-5.6
	Max	17.4	20.4	27.6	34.7	39	42.7	45.4	44.1	42.5	35	24.5	12.6	44.388
2014	Min	-0.7	-2.5	2.5	6.4	12.4	18.8	22.5	23.3	17.5	8.5	3.8	1.5	-2.5
	Max	17.4	22.1	24.2	34.6	39.4	43.5	46.2	45.4	43.2	35.6	23.2	18.4	45.384

Table (A-30) Bazyan Station / Sulaymaniyah Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2014	Min	-	-	-0.2	-0.6	7.2	14.2	17.9	18	12.7	9.4	-1.01	-1.8	-1.8
	Max	-	-	24.1	33.1	37.5	42.1	43.7	43.5	41.03	43.6	21.4	5.4	42.942

Table (A-31) Chamchemal Station / Sulaymaniyah Governorate

Year	Temperature	Months												Min & Average max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2004	Min	0.3	-4.5	3.5	3.5	11	18	23	23	19	9.9	0.1	-2.5	-2.5
	Max	14	20	26	28	38	38	43	41	40	34	22	16.2	42.828
2005	Min	-4.6	-5.6	2.9	1.6	7.5	18.7	23	23	17.5	6.5	4.9	-1	-5.6
	Max	16.2	17.5	23.5	33.7	35	40.4	43.5	42.6	38.2	34.7	25.5	25.2	43
2006	Min	0.2	-1	3.5	8.2	12.5	19.7	23	24.2	17	13.1	1.5	-3	-3
	Max	14.5	18.4	23.6	30	37.7	40	42.8	42.7	40.6	34.4	24.4	15	44.528
2007	Min	-3.3	-0.8	2.8	3.8	10	21.2	20.5	23.5	18	12.7	2.4	-2.5	-3.3
	Max	16.9	18.1	23	27	38.3	40.5	45.1	42.8	41.2	33.6	26.4	19	42.071
2008	Min	-5.2	-2.8	3.8	8.5	12.3	18.4	21.8	25.4	16	10.9	6	-1	-5.2
	Max	13.2	16.8	32	36	37.2	42	45.3	45.5	42	35.7	22.3	19.8	42.928
2009	Min	-4.6	1.4	1.7	7	13	20	23.2	26.1	11	11.3	-0.7	2.8	-4.6
	Max	16.9	19	24	27	36.2	40.4	40.6	42.3	38	36.8	24	18.5	41.685
2010	Min	-1.7	-1.6	4.3	7.5	10.8	20.5	22.6	24.5	20.7	11.8	5.7	0.8	-1.7
	Max	19.9	23.8	30.4	29.3	38.6	44.5	45.2	44.6	42.7	36.1	28.3	27.7	44.285
2011	Min	2.7	3.7	7.4	12.8	18.4	24.7	27.9	26.8	21.6	15.1	5.9	2.7	2.7
	Max	11.8	13.1	19.1	23.6	30.1	37.3	41.3	40.4	35.8	27.5	16.9	15.8	45.271
2012	Min	-4.5	-2	-1.8	7.8	16.4	19.2	22.3	22.3	16	11	4.9	0.9	-4.5
	Max	14.9	16.3	23.8	31.7	39.2	42.7	44.6	42.3	41.3	39.1	29.4	20.5	44.271
2013	Min	-1.8	1	3.3	7.6	12.8	19	21.6	21.3	13.5	7.6	5.7	-3.1	-3.1
	Max	17.7	21.6	28	33.2	36.9	41.6	43.9	43	42.3	33.4	24.8	18.7	43.242
2014	Min	-1.2	-4	1.2	2	14	17.6	22.9	22.1	15.9	8.4	2.5	1.6	-4
	Max	17.1	23	25.2	33.8	38.5	43.5	43.6	45.5	41.7	34.5	27.7	20.2	44.242

Table (A-32) Pynjween Station / Sulaymaniyah Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2003	Min	-16.5	-11	-9.5	-3.5	2	7	10.5	-	-	-	-	-	-16.5
	Max	9	8	13	22	28	34	38	-	-	-	-	-	36.928
2004	Min	-6.5	-16	-2.5	0.5	5.5	11.5	20.5	19	9	6.5	-8	-12	-16
	Max	6.5	12.5	19.5	21.5	27	35	37	37	33.5	28	11	10.5	36.957
2005	Min	-19.5	-23	-2.0	2	18	18	23	23.5	13	1.5	-3	-10	-23
	Max	9	8	20	28.5	29.5	35	39.5	38	32.5	28.5	18.5	18	36.571
2006	Min	-19	13	-3	1	10.5	19	24.1	25	-	-	-	-	-19
	Max	5.5	-10.5	16	25.5	32.5	35.5	37	39	-	-	-	-	37.714
2007	Min	-20	-13	-2.0	-0.2	2.5	10	13.2	12	4.2	3	-7.5	-13.5	-20
	Max	5	11.5	15	20.8	33.8	36	37	38.8	37.5	29.9	20	15	37.971
2008	Min	-	-	-	-	-	-	28	16	-	-	-	-	-
	Max	-	-	-	-	-	-	42	42.5	-	-	-	-	41.357
2009	Min	-	-	-	-	-	-	13	12	13.1	10.7	3	2	2
	Max	-	-	-	-	-	-	38.5	38.4	27.8	18.7	14.2	8.5	37.628
2010	Min	-6.9	-4.3	1.5	7.8	9.6	21.8	24.6	26	20.8	5.7	13	1.1	-6.9
	Max	9.4	13.7	22.6	17.1	23	28.8	31.9	30.1	28.5	12.2	21.8	10.8	39.542
2011	Min	-10.4	-2.9	5.2	6.7	-	-	23.5	18.3	15.9	3.1	-	-3.1	-10.4
	Max	6	11.4	17.1	20.4	-	-	40.7	35.7	31.9	13.3	13.3	11.1	34.485
2012	Min	-5	1.4	-	-	-	-	-	31.1	-	10.3	5	0.9	-5.0
	Max	4.9	-	-	-	-	-	-	36.8	-	24.1	14.5	8.9	33.671
2013	Min	-6.3	2.2	4.3	8.8	15.3	24.8	30.3	29.5	21.8	7	11.2	-	-6.3
	Max	8.6	12.8	18.1	21.8	25.8	32.5	35.1	34.8	34.8	24.5	19.6	-	34.7

Table (A-33) Mawet Station / Sulaymaniyah Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2009	Min	-	-	-	-	-	-	-	-	17.2	13	6	5.6	5.6
	Max	-	-	-	-	-	-	-	-	33	25.2	17.3	11.1	-
2010	Min	0.1	0.2	4.2	11.1	12.2	-	-	-	-	14.2	13.4	5.9	0.1
	Max	12.5	15.8	24.1	18.1	24.2	-	-	-	33.3	25.7	20.7	22.3	-
2011	Min	-3.6	0.9	8.1	9.8	-	28.3	28.4	23.3	-	10.2	5.5	1.4	-3.6
	Max	9.2	14.1	19.6	22.8	-	33.6	37.3	34.9	-	24.1	12.1	12.5	35.114

2012	Min	-1.2	0.3	-	-	18.4	25	27.9	29	19.6	13.8	8.3	3.3	-1.2
	Max	8.2	-	-	-	26.2	33.3	35.2	35.3	35.3	30.7	17.9	10	34.642
2013	Min	-0.5		4	8.8	12.3	23.5		30.4	-	14.8	-	-	-0.5
	Max	11.2	14.9	19	24.1	31.1	34.9	37.5	37.6	-	21.2	-	-	36.842
2014	Min	-	-3	4	7.6	19.1	23.3	-	-	-	-	-	-	-3.0
	Max	9.6	13.1	15.9	22.8	27.5	32.4	-	-	-	-	-	-	-

Table (A-34) Qaladzy Station / Sulaymaniyah Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2009	Min	-	-	-	-	-	-	-	-	-	-	8.2	6.8	-
	Max	-	-	-	-	-	-	-	-	-	-	19.4	13.1	-
2010	Min	-	2.4	6.2	12.8	-	-	-	33.6	29.6	15.8	-	7.4	2.4
	Max	-	16.2	22.4	-	-	-	-	39.5	37.5	30.9	24.6	24.5	37.528
2011	Min	-	2.2	-	11	-	-	32.9	26.3	-	13.4	7.9	3.6	2.2
	Max	-	15.4	22.1	25.2	-	-	44.5	41.9	37	27.6	-	13.8	38.9
2012	Min	-	2.9	-	-	21.8	27.5	30.3	32.2	28.4	15.5	10.4	5.8	2.9
	Max	-	-	-	-	29.6	35.9	38	36.7	33.5	20.9	23.2	13.2	36.785
2013	Min	-	4.2	6.5	12.7	18	29.3	32.3	33.6	-	-	-	-	4.2
	Max	-	15.2	20.1	26.3	33	39.6	40.3	38.8	-	-	-	-	38.5
2014	Min	-	-	-	8.9	21.7	-	-	-	-	-	-	-	-
	Max	-	15.3	-	24.3	31	-	-	-	-	-	-	-	-

Table (A-35) Kalar Station / Garmyan Administration

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2001	Min	-	-	5.8	10	11	18.5	21.8	21.4	18.8	10	1.0	-2.0	-2.0
	Max	-	-	31.1	36.5	41.5	45.1	49	49	44	38	32.5	20	48.77
2002	Min	1.0	0	0	7	11	14	19.5	24	19	13	6	-1.0	0.0
	Max	18	22	27	32	44	46.5	48	48.3	44.5	41.8	28.8	24.6	47.84
2013	Min	0.2	3.8	5.7	12.4	16.2	18.2	24.4	24.2	30.4	10.9	9.3	0.9	0.9
	Max	20.9	24.3	31.9	37.7	42.6	42.7	48.5	47.5	32	40	28.6	23	47.472
2014	Min	2	1.8	4.1	9	17.7	20.7	25.2	23.7	21.2	12.4	4.9	3.5	1.8
	Max	20.9	26.6	29.5	43.3	43.1	46.2	48.2	49	46.6	39.3	27.1	23.4	48.367

Table (A-36) Maydan Station / Garmyan Administration

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2013	Min	0.4	3.5	3.2	6.9	41.7	18.3	23.09	21.5	15.6	8.8	7.6	-0.1	-0.1
	Max	17.6	24.4	32.1	38.9	14.3	45.6	48.5	46.3	45	36.6	27.2	21.9	47.028
2014	Min	1.7	-1.8	3.5	1.5	42.5	19.2	23.5	22.7	18.1	8.3	4.5	2.7	-1.8
	Max	19	29.5	30.1	37.8	13.8	46.2	48.7	48.2	45.9	39.1	26.4	22	47.675

Table (A-37) Kirkuk Station / Kirkuk Governorate

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2000	Min	-1.6	0.8	0.2	10.3	15.5	23	27.1	22	19	12.5	6.6	2.9	**-1.6**
	Max	23	23.6	27.5	34	39.2	44.5	49.5	49.6	40.8	36.5	27.6	19.8	**48.91**
2001	Min	0	1.5	8.4	11	16.4	20.7	25.3	25.5	21.6	13.4	2.9	0.2	**0**
	Max	21.4	24.6	30.5	34.9	39.8	44	48.8	48.6	43	39	33.5	21.2	**48.471**
2002	Min	1	2.5	3.4	9.2	15.7	20.6	25.5	24	22.6	15.5	7.2	1	**1**
	Max	17.3	22.8	28.2	32.4	42.2	46	46.7	47	42.2	39.6	28.7	23	**46.271**
2003	Min	-	-	-	-	15.5	20.4	25.4	25	2.2	5.6	2.3	0.7	**0.7**
	Max	-	-	-	-	40.6	45.6	46.8	49.5	43.4	38.3	31.6	18.8	**47.942**
2004	Min	3.7	-1	4.1	2.8	15	20.2	25.5	24.2	19.5	12.5	2.5	-3.8	**-3.8**
	Max	16.6	22.7	30.2	33.3	39.6	42.5	46.5	44.6	44	39	27.4	19.4	**45.528**
2005	Min	0.2	0.5	2.1	8	10.8	20	25.6	25.8	18	9.1	6.4	0.4	**0.2**
	Max	19.8	21.8	28.1	38.3	39.9	45	48.8	46.4	42.3	39.2	26.2	28	**46.785**
2006	Min	-0.5	2	6.2	9.8	16.8	23	26.2	28.1	19.3	15.5	5	-2.2	**-2.2**
	Max	21	22.4	25.8	35.2	42	44.8	45.8	48.3	43.4	37.8	27.2	19.7	**47.457**
2007	Min	-0.3	0.6	5.9	9.8	14.4	24	26.2	26.8	20.2	13.8	4.3	-0.7	**-0.7**
	Max	20.6	21.2	27.9	30.4	44.7	44.6	46.5	48.1	45.1	38.5	29.2	20.9	**46.357**
2008	Min	-2.5	-1.1	7	12	15.4	21.3	24.6	26	18.4	14.4	8	1	**-2.5**
	Max	16.6	23.1	34.2	39.7	40.8	46.3	47.2	47	45.4	37.8	28.8	23	**46.2285**
2009	Min	-2.8	3.2	5.4	10.2	10	21	25.6	22.8	13.2	14.6	6	4.4	**-2.8**
	Max	20.2	23.2	29.4	33.7	41.4	44.4	44.4	46	42.2	37.2	29.2	22.3	**44.9**
2010	Min	1.2	0.8	4.5	8.6	13	23.8	26	27	23.2	12.5	7.3	2.6	**0.8**
	Max	24.3	25	33.4	31.2	41.6	47.6	48.4	48	45.8	38	31.5	30.8	**47.657**
2011	Min	1	-0.4	4.2	9.2	14	20.4	24.8	24	18.3	11	0.5	-0.8	**-0.8**
	Max	20	24	32	34.4	46.3	45	48.4	49.5	42	37	23.6	22	**48.514**
2012	Min	-2	0.8	-0.6	10	14	21.5	24.4	23	19	14.6	8	3	**-2**

Year	Temperature	Months												Min & max
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	Max	16	19.6	25.4	35.2	41.5	46	49	45.6	42.8	40	32	20	**47.7**
2013	Min	-1	2.8	5.6	11	16.5	22.5	24	23.4	16.5	10	9	-1.4	**-1.4**
	Max	20	22.5	33.2	37.5	40.8	45.5	46.2	45.3	45.8	36.2	29	21.2	**45.557**
2014	Min	2	1.5	3.5	6	16	21	26	27.5	19.6	12.5	7	5	**2**
	Max	19.5	26.6	28.5	37.4	43.6	47	47	48.2	45.4	38.8	28.4	25	**47.271**

The 7th Highest Temperature Tables

Table (A-38) Duhok center		Table (A-39) Amydi	
Year	The 7th highest air temperature in Aug. and July. average	Year	The 7th highest air temperature in Aug. and July. average
2000	45.00 + 45.90 + 45.50 + 45.00 + 44.60 + 44.20 + 44.70 = 44.985	2011	40.40 + 37.50 + 36.30 + 36.60 + 35.30 + 34.50 + 33.90 = 36.357
2001	45.00 + 44.60 + 44.50 + 44.50 + 44.50 + 44.50 + 44.00 = 44.514	2012	35.40 + 33.80 + 33.70 + 34.80 + 35.40 + 33.30 + 33.70 = 34.300
2002	44.00 + 43.50 + 43.50 + 43.50 + 43.00 + 43.00 + 43.00 = 43.357	2013	34.70 + 34.70 + 33.80 + 34.80 + 33.80 + 33.10 + 33.00 = 33.985
2003	45.50 + 45.00 + 45.20 + 45.00 + 45.00 + 44.90 + 44.80 = 45.057		
2004	43.50 + 43.00 + 43.50 + 43.40 + 43.00 + 43.00 + 42.50 = 43.128		
2005	48.00 + 45.50 + 45.50 + 44.50 + 44.90 + 43.70 + 43.20 = 45.042		
2006	44.90 + 44.00 + 43.10 + 43.00 + 43.50 + 43.00 + 43.00 = 43.500		
2007	44.20 + 43.50 + 43.50 + 43.00 + 43.20 + 43.00 + 43.50 = 43.414		
2008	45.20 + 44.30 + 44.20 + 43.20 + 43.30 + 43.10 + 43.00 = 43.757		
2009	42.20 + 41.80 + 41.70 + 41.30 + 41.70 + 41.20 + 41.20 = 41.585		
2010	45.00 + 44.70 + 44.60 + 44.00 + 43.50 + 43.50 + 43.30 = 44.085		

Table (A-38) Duhok center		Table (A-39) Amydi	
2011	46.60 + 45.80 + 45.80 + 46.00 + 45.80 + 44.80 + 44.60 = 45.628		
2012	44.50 + 44.40 + 43.20 + 43.70 + 43.20 + 42.80 + 42.80 = 43.514		
2013	43.20 + 42.10 + 41.70 + 41.70 + 41.70 + 41.60 + 41.60 = 41.940		
2014	43.40 + 43.10 + 43.70 + 43.60 + 42.50 + 43.00 + 41.70 = 42.857		

Table (A-40) Atrush		Table (A-41) Batufe	
Year	**The 7th highest air temperature in Aug. and July. average**	**Year**	**The 7th highest air temperature in Aug. and July. average**
2008		2008	--.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- = --.---
2009	--.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- = --.---	2009	--.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- = --.---
2010	41.70 + 41.70 + 41.20 + 40.20 + 39.30 + 41.70 + 41.70 = 41.071	2010	--.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- = --.---
2011	41.2 + 41.20 + 42.60 + 42.50 + 43.70 + 42.70 + 43.20 = 42.4428	2011	31.9 + 32.10 + 31.60 + 31.20 + 31.20 + 30.90 + 30.50 = 31.34
2012		2012	36.6 + 34.3 + 36.30 + 35.40 + 35.60 + 35.20 + 36.40 = 35.714
2013		2013	38.4 + 34.30 + 36.2 + 38.40 + 38.40 + 36.20 + 35.30 = 36.742

Table (A-42) Canimasi		Table (A-43) Dinarte	
Year	**The 7th highest air temperature in Aug. and July. average**	**Year**	**The 7th highest air temperature in Aug. and July. average**
2011	31.7 + 31.50 + 34.40 + 34.40 + 32.70 + 31.10 + 31.30 = 32.442	2011	37.2 + 34.70 + 34.2 + 37.20 + 36.40 + 36.30 + 34.50 = 35.758
2012	31.9 + 31.40 + 30.20 + 30.10 + 29.90 + 29.70 + 29.40 = 30.371	2012	41.20 + 40.80 + 40.40 + 40.10 + 40.20 + 41.20 + 39.20 =

			40.442
2013	31.4 + 30.70 + 33.10 + 31.20 + 31.10 + 31.60 + 30.20 = 31.328	2013	39.3 + 36.60 + 38.50 + 36.5 + 36.70 + 39.30 + 35.60 = 37.500

Table (A-44) Sharya		Table (A-45) Akry	
Year	The 7th highest air temperature in Aug. and July. average	Year	The 7th highest air temperature in Aug. and July. average
2010	38.90 + 38.40 + 38.90 + 38.50 + 38.60 + 38.90 + 37.30 = 38.5	2009	42.40 + 42.2 + 42.70 + 42.30 + 42.70 + 43.40 + 42.8 = 42.642
2011	39.80 + 39.5 + 39.9 + 39.40 + 38.50 + 38.00 + 37.00 = 38.871	2010	46.00 + 45.20 + 44 + 43.60 + 43.90 + 43.60 + 43.60 = 44.271
2012	39.5 + 37.80 + 37.80 + 37.6 + 37.90 + 37.50 + 36.80 = 37.842	2011	47.10 + 46.10 + 45.30 + 47.00 + 45.80 + 45.50 + 45.20 = 46.0
2013	39.20 + 38.50 + 33.20 + 35.70 + 32.60 + 31.50 + 32.90 = 34.8	2012	43.00 + 43.00 + 43.00 + 44.00 + 44.0 + 43.0 + 43.00 = 43.285
		2013	43.30 + 43.30 + 45.50 + 45.10 + 46.30 + 45.00 + 42. = 44.357
		2014	44.58 + 43.6 + 43.25 + 43.34 + 45.14 + 42.51 + 42.72 = 43.59

Table (A-46) Bamerny		Table (A-47) Mangysh	
Year	The 7th highest air temperature in Aug. and July. average	Year	The 7th highest air temperature in Aug. and July. average
2013	39.00 + 38.00 + 37 + 41.90 + 41.20 + 42.70 + 42.20 = 40.285	2013	40.90 + 41.00 + 42.90 + 43.7 + 43.50 + 40.10 + 42.5 = 42.085
2014	38.40 + 38.60 + 38.83 + 38.29 + 40.11 + 40 + 38.31 = 38.934	2014	41.79 + 40.24 + 40.29 + 41.13 + 41.31 + 41 + 41.42 = 41.037

Table (A-48) Zakho			
Year	The 7th highest air temperature in Aug. and July. average	Year	The 7th highest air temperature in Aug. and July. average
2000	45.00 + 45.30 + 46.00 + 47.00 + 47.00 + 45.00 + 45.60 = 45.840		
2001	46.10 + 46.10 + 46.00 + 45.00 + 45.10 + 45.00 + 45.00 = 45.471		
2002	44.00 + 43.00 + 43.00 + 43.60 + 43.00 + 42.30 + 42.20 = 43.014		
2003	46.00 + 46.10 + 45.00 + 45.00 + 44.60 + 44.30 + 44.20 = 45.028		
2004	43.40 + 43.00 + 42.20 + 43.00 + 44.20 + 44.10 + 43.40 = 43.328		
2005	46.00 + 46.00 + 45.20 + 45.00 + 45.00 + 44.10 + 44.00 = 45.042		
2006	45.00 + 45.00 + 45.00 + 45.60 + 46.20 + 45.00 + 44.80 = 45.228		
2007	44.00 + 43.50 + 43.50 + 43.60 + 42.80 + 43.30 + 43.20 = 43.414		
2008	45.00 + 44.30 + 44.30 + 44.00 + 43.60 + 43.00 + 43.00 = 43.885		
2009	43.50 + 43.80 + 43.80 + 44.00 + 43.30 + 43.40 + 42.20 = 43.428		
2010	43.10 + 45.20 + 45.10 + 45.20 + 45.00 + 45.60 + 45.00 = 45.314		
2011	46.30 + 48.10 + 45.90 + 45.40 + 47.70 + 46.00 + 48.00 = 46.842		
2012	46.00 + 46.10 + 45.10 + 44.50 + 44.70 + 44.30 + 44.10 = 44.971		
2013	43.50 + 44.20 + 44.70 + 43.00 + 43.60 + 42.50 + 42.70 = 43.457		
2014	45.90 + 45.80 + 45.20 + 44.00 + 44.50 + 44.70 + 44.60 = 44.957		

Table (A-49) Hawler center		Table (A-50) khabat	
Year	The 7th highest air temperature in Aug. and July. average	Year	The 7th highest air temperature in Aug. and July. average
1999	44.60 + 45.20 + 45.40 + 45.00 + 45.00 + 44.50 + 44.50 = 44.885	2013	45.17 + 45.48 + 45.38 + 44.48 + 44.23 + 44.86 + 45.75 = 45.05
2000	47.30 + 47.20 + 47.40 + 47.90 + 46.90 + 47.90 + 46.70 = 47.228	2014	48.17 + 47.67 + 47.62 + 46.56 + 46.23 + 47.23 + 46.11 = 47.08
2001	48.00 + 47.10 + 47.20 + 46.20 + 46.40 + 47.00 + 46.50 = 46.914	Table (A-51) Soran	
2002	45.00 + 45.00 + 44.70 + 44.70 + 45.10 + 44.70 + 45.60 = 44.971	2008	45.35 + 45.36 + 43.64 + 41.60 + 40.26 + 43.919 + 41.60 = 43.1
2003	45.50 + 44.50 + 44.60 + 45.20 + 46.70 + 48.00 + 47.90 = 46.057	2009	42.33 + 41.22 + 42.33 + 40.90 + 40.75 + 40.77 + 39.35 = 41.1
2004	45.00 + 44.90 + 44.60 + 45.00 + 44.50 + 43.70 + 43.90 = 44.514	2010	45.52 + 42.75 + 42.13 + 42.92 + 42.94 + 42.86 + 41.75 = 42.552
2005	46.60 + 45.90 + 46.30 + 44.90 + 44.80 + 44.20 + 44.60 = 45.400	2011	46.13 + 44.65 + 44.18 + 43.89 + 43.28 + 43.69 + 42.53 = 44.048
2006	45.50 + 45.50 + 46.50 + 46.30 + 46.60 + 45.60 + 44.30 = 45.575	2012	--.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- + --.-- = --.---
2007	44.50 + 44.00 + 44.00 + 43.20 + 43.10 + 43.10 + 44.50 = 43.771	2013	42.33 + 42.24 + 42.08 + 41.47 + 41.40 + 41.5 + 41.92 = 41.861
2008	47.10 + 46.80 + 44.90 + 44.20 + 44.80 + 44.20 + 44.00 = 45.142	2014	43.46 + 42.14 + 41.96 + 41.59 + 43.34 + 43. + 42.84 = 42.558
2009	44.00 + 43.20 + 42.40 + 42.60 + 42.20 + 43.00 + 42.30 = 42.814		
2010	46.90 + 46.20 + 44.60 + 44.30 + 44.80 + 44.30 + 45.50 = 45.228		
2011	47.50 + 46.50 + 45.60 + 45.50 + 45.50 + 46.90 + 46.90 = 46.342		
2012	45.40 + 44.90 + 44.60 + 44.90 + 44.20 + 45.00 + 43.70 = 44.700		
2013	44.80 + 44.70 + 43.60 + 43.60 + 43.40 + 43.30 + 43.40 = 43.828		
2014	46.40 + 46.40 + 45.30 + 44.80 + 45.50 + 45.50 + 45.20 = 45.585		

Table (A-52) Hajiomeran

Year	The 7th highest air temperature in Aug. and July. average
2013	28 + 27.5 + 26.8 + 26.3 + 26.2 + 26.6 + 26 = 26.77

Table (A-54) Choman

Year	The 7th highest air temperature in Aug. and July. average
2013	34.20 + 33.40 + 34.20 + 33.50 + 33.20 + 31.20 + 31.50 = 32.985

Table (A-55) Mergasor

Year	The 7th highest air temperature in Aug. and July. average
2011	42.10 + 42.10 + 35.10 + 37.60 + 37.60 + 34.50 + 33.50 = 37.500
2012	36.60 + 35.30 + 35.80 + 36.60 + 35.80 + 35.40 + 35.20 = 35.811
2013	34.80 + 34.60 + 33.20 + 34.80 + 33.50 + 33.40 + 34.10 = 34.057

Table (A-56) Shyrwanmezn

2013	36.1 + 34.8 + 37.2 + 34.3 + 34.4 + 34.2 + 35.9 = 35.271

Table (A-57) Sidakan

2011	38 + 34.8 + 33.9 + 33 + 33.1 + 32.5 + 31.5 = 33.82
2013	34.8 + 31.2 + 30.1 + 30.5 + 30.7 + 31.4 + 29.1 = 31.114

Table (A-58) Rawanduz

2011	37.70 + 39.40 + 39.60 + 36.40 + 35.50 + 33.90 + 31.40 = 36.271

Table (A-53) Pirmam

Year	The 7th highest air temperature in Aug. and July. average
1999	39.6 + 39.2 + 40 + 40 + 41.1 + 39.4 + 40.4 = 39.9
2000	42.2 + 42.3 + 42.4 + 41.7 + 41.9 + 41.3 + 41.1 = 41.84
2001	42 + 41 + 41.8 + 41.7 + 41.7 + 41.4 + 41.2 = 41.54
2002	38.8 + 38.4 + 38.2 + 38.9 + 39.2 + 39.5 + 38.8 = 38.82
2003	42.2 + 42.9 + 43.2 + 41.4 + 39.2 + 39.8 + 39.9 = 41.25
2004	39.2 + 39.7 + 39 + 39.6 + 39.5 + 38.8 + 38.6 = 39.2
2005	40.1 + 39.1 + 39.2 + 39.4 + 39.9 + 39.6 + 39.8 = 39.58
2006	40.1 + 40.1 + 39.4 + 39.2 + 39 + 39.9 + 39.4 = 39.58
2007	38.5 + 38.6 + 39.4 + 39.2 + 39.2 + 39.3 + 38.4 = 38.94
2008	40.1 + 39.7 + 40 + 42.2 + 41.6 + 40.2 + 39.6 = 40.485
2009	40.2 + 39.1 + 39.2 + 38.6 + 38.6 + 38.6 + 37.6 = 38.84
2010	40.2 + 40.7 + 40 + 40 + 41.8 + 40.7 + 40.8 = 40.6
2011	41.5 + 41.4 + 42.9 + 43.2 + 40.7 + 41.5 + 40.1 = 41.61
2012	40.6 + 40.1 + 39.8 + 38.7 + 39.9 + 39.6 + 38.6 = 39.614
2013	38.6 + 38 + 38.3 + 38 + 38.3 + 38.6 + 37.5 = 38.185
2014	40.3 + 40.2 + 40.4 + 40.2 + 39.6 + 39.6 + 39.8 = 40.01

Table (A-59) Qaladzy	
Year	The 7th highest air temperature in Aug. and July. average
2010	39.50 + 37.50 + 37.00 + 37.90 + 37.00 + 37.20 + 36.60 = 37.528
2011	44.50 + 41.40 + 33.20 + 37.60 + 38.10 + 37.30 + 35.20 = 38.900
2012	37.40 + 38.00 + 37.00 + 36.20 + 36.70 + 36.20 + 36.00 = 36.785
2013	40.30 + 40.30 + 37.90 + 38.30 + 37.60 + 38.30 + 36.30 = 38.500

Table (A-60) Mawat	
2011	37.30 + 35.20 + 34.90 + 34.70 + 34.10 + 34.90 + 34.70 = 35.114
2012	35.20 + 34.70 + 34.20 + 34.60 + 34.90 + 35.30 + 34.10 = 34.642
2013	37.50 + 36.90 + 36.70 + 37.60 + 37.60 + 35.70 + 35.80 = 36.842

Table (A-61) Bazyan	
2014	43.53 + 43.732 + 42.764 + 42.42 + 42.36 + 42.56 + 43.26 = 42.942

Table (A-62) Halabje	
2013	43.62 + 43.64 + 44.00 + 44.15 + 45.49 + 44.69 + 45.13 = 44.388
2014	46.20 + 45.89 + 45.46 + 45.38 + 45.28 + 44.49 + 44.99 = 45.384

Table (A-63) Halsho	
Year	The 7th highest air temperature in Aug. and July. average
2013	38.78 + 38.21 + 39.72 + 38.71 + 38.48 + 39.30 + 38.41 = 38.801
2014	41.13 + 39.96 + 39.84 + 40.44 + 40.32 + 39.93 + 39.57 = 40.170

Table (A-64) Chamchmal	
2004	43.10 + 42.30 + 43.90 + 42. + 42.40 + 42.80 + 43.30 = 42.828
2006	44.90 + 44.30 + 44. + 45.30 + 45.30 + 44.20 + 43.70 = 44.528
2007	43 + 42.40 + 42.20 + 41.90 + 41.80 + 41.70 + 41.50 = 42.071
2008	44.60 + 42.60 + 42.80 + 42.5 + 43.5 + 42.80 + 41.70 = 42.928
2009	43.00 + 42 + 42.00 + 41.90 + 41.40 + 41.40 + 40.10 = 41.685
2010	44.40 + 44.60 + 44.20 + 44+ 43.80 + 45.20 + 43.80 = 44.285
2011	46.50 + 45.50 + 45 + 46.40 + 45.30 + 45.00 + 43.20 = 45.271
2012	44.60 + 44.50 + 44.10 + 44. + 44.40 + 44.10 + 44.20 = 44.271
2013	43.90 + 43.50 + 43.50 + 43.40 + 43. + 42.80 + 42.60 = 43.242
2014	44.80 + 45.50 + 44.6 + 44.20 + 43.8 + 43.50 + 43.30 = 44.242

Table (A-65) Sulaymaniyah Center	
Year	The 7th highest air temperature in Aug. and July. average
2000	42.70 + 44.70 + 44.20 + 43.70 + 43.30 + 43.70 + 43.5 = 43.685
2001	44 + 43.80 + 43.50 + 43.50 + 43.60 + 42.60 + 43.70 = 43.528
2002	42.2 + 41.2 + 40.7 + 40.50 + 40.70 + 40.90 + 39.70 = 40.771
2003	44.50 + 44.00 + 43.70 + 43.70 + 42.40 + 42.40 + 41.00 = 43.1
2004	42.5 + 41.7 + 41.60 + 41.50 + 41.40 + 41.20 + 40.2 = 41.442
2005	43.50 + 43.00 + 43.50 + 43.50 + 43.20 + 42.50 + 42.50 = 43.1
2006	42.30 + 42.50 + 42.70 + 42.60 + 42.20 + 42.50 + 42.70 = 42.5
2007	42.80 + 41.40 + 41.80 + 42.30 + 42.2 + 41.50 + 40.80 = 41.828
2008	45.40 + 45.50 + 44.6 + 44.60 + 44.40 + 44.50 + 44.20 = 44.742
2009	42.3 + 41.50 + 41.70 + 40.60 + 40.90 + 40.30 + 40.50 = 41.114
2010	43.9 + 43.60 + 43.00 + 42.80 + 42.20 + 42.50 + 42.50 = 42.928
2011	44.20 + 46.20 + 45.00 + 45.20 + 45.90 + 44.00 + 43.20 = 44.7
2012	43.40 + 42.80 + 42.7 + 43.70 + 42.50 + 43.50 + 42.60 = 42.987
2013	43.00 + 42.30 + 42.80 + 42.70 + 42.40 + 42.30 + 41.50 = 42.428
2014	43.20 + 43.20 + 43 + 43.50 + 43.20 + 42.50 + 43.00 = 43.085

Table (A-66) Pynjwyn	
Year	The 7th highest air temperature in Aug. and July. average
2003	38.00 + 37.50 + 38. + 37.00 + 37 + 36.00 + 35.00 = 36.928
2004	36.70 + 37.00 + 37.00 + 37.00 + 37 + 37.00 + 37.00 = 36.957
2005	38.00 + 36.50 + 36.50 + 36 + 38.00 + 35.00 + 36.00 = 36.571
2006	39.00 + 38.00 + 38.00 + 37.00 + 37 + 37.50 + 37.50 = 37.714
2007	38.70 + 37.10 + 38 + 38.70 + 38.80 + 37.50 + 37.00 = 37.971
2008	42.50 + 42 + 42.00 + 40.00 + 39.50 + 41.50 + 42.00 = 41.357
2009	38.40 + 38.00 + 38.00 + 38.50 + 37.50 + 37.00 + 36 = 37.628
2010	41.00 + 40.00 + 40 + 39.00 + 39.00 + 39.80 + 39.00 = 39.542
2011	40.7 + 35.9 + 31.6 + 35.70 + 35.70 + 31.60 + 30.20 = 34.485
2012	36.80 + 34.7 + 33.7 + 32.30 + 33.6 + 32.40 + 32.20 = 33.671
2013	35.1 + 35.10 + 34.70 + 34.10 + 34.20 + 35.10 + 34.60 = 34.7

Table (A-67) Maydan	
2013	48.51 + 47.7 + 46.34 + 46.37 + 46.72 + 47.31 + 46.25 = 47.028
2014	48.73 + 48.11 + 46.69 + 48.26 + 47.88 + 47.36 + 46.70 = 47.675

Table (A-68) Kalar		Table (A-69) Kirkuk	
Year	The 7^{th} highest air temperature in Aug. and July. average	Year	The 7^{th} highest air temperature in Aug. and July. average
2001	49 + 49 + 48.6 + 48.4 + 48.4 + 49 + 49 = 48.77	2000	49+49.5+49+48.5+49.6+48.4+48.4 = 48.91
2002	47.1 + 48.3 + 46.6 + 46.7 + 47.5 + 48 + 47.2 = 47.34	2001	48.7+48.6+48.8+48.4+48.2+48+48.6 = 48.471
2013	48.51 + 48.37 + 47.52 + 47.08 + 47.19 + 47.24 + 46.4 = 47.47	2002	46+46.7+46.6+46+46.2+46+46.4 = 46.271
2014	48.29 + 47.73 + 49.04 + 48.57 + 48.37 + 48.63 + 47.99 = 48.367	2003	46.8+48.6+48.9+49.5+49.5+46.4+45.9 = 47.942
		2004	44.3+44.4+46.3+46.5+45+46+46.2 = 45.528
		2005	46.6+47.2+47.2+46+48.8+46.2+45.5 = 46.785
		2006	47.3+48.3+47.4+47.4+47.2+47.1+47.2 = 47.457
		2007	45.9+46+46.2+46+46.5+48.1+45.8 = 46.357
		2008	45.7+45.7+46.6+47.2+47+45.8+45.6 = 46.2285
		2009	45.8+46+44.6+44.6+44.5+44.4+44.4 = 44.9
		2010	48+48+48+47.2+47+47+48.4 = 47.657
		2011	48.4+47.2+48.3+48+49.5+49+49.2 = 48.514
		2012	47+47.2+47+49+47.5+48.2+48 = 47.7
		2013	46.2+45+46.2+46+45.5+45+45 = 45.557
		2014	47.5+47.4+48+48.2+47+46.5+46 = 47.271

In this regard, the Duhok governorate will classify into 2 regions;

-Region one will include: Cani Masy, Bamerni, Batufa, Shary and Amediye stations.

- Region two will include: Duhok Center, Zakho, Atrosh, Denarta, Mangysh and Akre stations.

For Erbil (Hawler) governorate, the classification will include;-

- Region one will include: Choman, Rawandua, Haji Umeran, Shyrwanmezn, Sidekan and Mergasur stations.

- Region two will include: Pirmam, Shaqlawa, Koye and Soran stations.

- Region three will include: Hawler center, khabat, Qushtepa, Ankawa and Makhmur stations.

While for Sulaymani governorate and Germian administration the following regions will recommend;

- Region one: Penjween station.

-Region two; Halsho, Mawat and Qaladeza stations.

- Region three: Sulaymani center, Aazian, Chamchamal and Halabje stations.

For Germyain Administration one region created;

- Region one: Kalar and Midan stations.

For Kirkuk governorate one region is created;

-Region one: Kirkuk center.

The Duhok governorate latitudes are lying between 37.5 and 36.5, while Erbil is lying between (37, 5 and 35, 5), Sulymai is between (36, 5 and 35), and the Germyain administration area is between (35 and 34, 5).

Table (A-70) Duhok Governorate/ Region -1-

{Canimasi, Bamerni, Batufa, Sharyi and Amediye Stations} Districts (2010-2014)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Cani masi	1	-6.6	Sum= -46.5 (Mean)Ẋ= **-3.875** S.D= **4.959495**	1	32.442	Sum= 532.185 (Mean)Ẋ = **35.479** S.D= **3.099262**
	2	-5.7		2	30.371	
				3	31.328	
Batufa	3	-1.6		4	31.714	
	4	-2.2		5	35.714	
				6	36.742	
Bamerni	5	-17.6		7	40.285	
	6	-3.8		8	38.934	
Amediye	7	-1.4		9	36.357	
	8	-2.6		10	34.3	
	9	-5.2		11	33.985	
Sharyi	10	2.1		12	38.5	
	11	-0.2		13	38.871	
	12	-1.7		14	37.842	
				15	34.8	

Table (A-71) Duhok Governorate/ Region -2-

{Duhok Center, Zakho, Mangesh, Akre, Atrush and Denarta Stations} Disricts (2000-2014)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Duhok center	1	1.2	Sum=66.4	1	44.895	Sum=1869.976
	2	3.2		2	44.514	
	3	2.7		3	43.357	
	4	4.8		4	45.057	
	5	3		5	43.128	
	6	3.7		6	45.042	

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
	7	3	(Mean) $\dot{x}$ = **1.509**	7	43.5	(Mean) $\dot{x}$ = **43.487**
	8	2		8	43.414	
	9	0		9	43.757	
	10	2.4	S.D= **3.285756**	10	41.585	
	11	6.7		11	44.085	S.D = **2.09517**
	12	4		12	45.628	
	13	3.1		13	43.514	
	14	2.8		14	41.940	
	15	4.4		15	42.857	
Zakho	16	2.7		16	45.84	
	17	4.2		17	45.471	
	18	3.4		18	43.014	
	19	4.5		19	45.028	
	20	2.2		20	43.328	
	21	3.5		21	45.042	
	22	2.1		22	45.228	
	23	1.4		23	43.414	
	24	-0.2		24	43.885	
	25	3.2		25	43.428	
	26	7.1		26	45.314	
	27	2.9		27	46.842	
	28	2.6		28	44.971	
	29	3.3		29	43.457	
	30	4.6		30	44.957	
Atrush	31	2.5		31	41.071	
	32	0.3		32	42.442	
	33	0.6				
Denarta	34	3		33	35.758	
	35	-0.9		34	40.442	
	36	-3.4		35	37.5	
Mangesh	37	-7.2		36	42.085	
	38	-4.7		37	41.037	
Akre	39	-6.0		38	42.642	
	40	-1.2		39	44.271	
	41	-1.8		40	46	

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
	42	-7.0		41	43.285	
	43	-0.5		42	44.357	
	44	-1.8		43	43.594	

Table (A-72) Erbil Governorate/ Region -1-

{Choman, Rewanduz, Mergesur, Shyrwanmezn, Haji Umeran and Sidekan Stations} Districts (2011-2014)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Choman	1	-1.8	Sum= **-51.1** (Mean)ẋ = **-3.19** S.D= **4.360194**	1	32.985	Sum= **266.102** (Mean)ẋ = **33.26275** S.D= **3.102601**
Rewanduz	2	0.8		2	36.271	
	3	2.6				
	4	3.4				
	5	-6.5				
Mergesor	6	1.1		3	37.5	
	7	2.3		3	35.814	
	8	-7.6		4	34.057	
	9	-3.4				
Sidekan	10	-9.4		5	33.82	
				6	31.114	
Shyrwan Mezn	11	-7.2		7	35.271	
	12	-1.2				
Haji umeran	13	-5.4		8	26.77	
	14	-2.7				
	15	-8.5				
	16	-7.6				

Table (A-73) Erbil Governorate/ Region -2-

{Pirmam, Koye, Shaqlawe and Soran Stations} Districts (1996-2014)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Soran	1	-3.2	Sum= 20.89	1	43.166	Sum=1171.613
	2	-6.8		2	41.1	
	3	-3.2	(Mean)ẋ = **0.72**	3	42.552	(Mean)ẋ = **40.4**
	4	-3.4		4	44.048	
	5	-4.0		5	41.861	
	6	-3.7		6	42.628	
Pirmam	7	2.3	S.D= **2.903078**	7	38.5	S.D= **2.012091**
	8	-0.2		8	35.2	
	9	-0.2		9	38.1	
	10	4		10	39.96	
	11	1.3		11	41.84	
	12	3.4		12	41.54	
	13	1.4		13	38.82	
	14	1.8		14	41.25	
	15	2		15	39.2	
	16	1.8		16	39.58	
	17	1.1		17	39.58	
	18	1.1		18	38.94	
	19	-0.9		19	40.485	
	20	1.7		20	38.84	
	21	5.4		21	40.6	
	22	3		22	41.61	
	23	1.09		23	39.614	
	24	1.9		24	38.185	
	25	3.3		25	40.014	
Koye	26	3.9		26	40.9	
	27	4.4		27	44.1	
	28	1.1		28	41.7	
Shaqlawa	29	0.5		29	37.7	

Table (A-74) Erbil Governorate/ Region -3-

{Hawler Center, Makhmur, Khabat, Ankawa, and Qushtepa Stations} Districts (1999-2014)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Hawler center	1	5.5	Sum=186.73	1	44.885	Sum= 2138.064
	2	3	(Mean)Ẋ = **3.734**	2	47.228	(Mean)Ẋ = **44.543**
	3	3.5		3	46.914	
	4	3.3	S.D=	4	44.971	S.D=**1.4542**
	5	4	**1.883793**	5	46.057	
	6	2.7		6	44.514	
	7	4		7	45.5	
	8	3.9		8	45.575	
	9	2.9		9	43.771	
	10	1.3		10	45.142	
	11	3.4		11	42.814	
	12	8.2		12	45.814	
	13	5.4		13	46.342	
	14	4.6		14	44.7	
	15	2.2		15	43.828	
	16	6.1		16	45.585	
Makhmur	17	4		17	42.7	
	18	2.9		18	44.6	
	19	3.3		19	43.7	
	20	3.6		20	44	
	21	6.7		21	46.2	
	22	4.3		22	43.5	
	23	4.2		23	46.6	
	24	6		24	44.9	
	25	3.5		25	47.3	
	26	5.2		26	44.6	
	27	4.9		27	44.3	
	28	6		28	44.95	
	29	3.4		29	44.4	
	30	4.2		30	44.9	
	31	3.7			-	
	32	2.9		31	44.4	

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
	33	1.6		32	43.7	
	34	3.3		33	42.3	
	35	7		34	44.7	
	36	3.4		35	44.8	
	37	3.9		36	44.8	
	38	4.5		37	44.4	
	39	6.8				
khaAat stations	40	1.9		38	43.2	
	41	2.3		39	45.4	
	42	-1.5		40	45.05	
	43	-1.6		41	47.084	
Ankawa	44	1.8		42	40.9	
	45	1.9		43	44.3	
	46	2.3		44	42.8	
Qushtepa	47	6.63		45	43.44	
	48	3.6		46	43	
	49	2.8		47	42.1	
	50	3.3		48	41.4	

Table (A-75) Sulaymani Governorate/ Region -1-

Penjween District and It's Around {Penjween Station} (2003-2013)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Penjween	1	-16.5	Sum	1	36.928	Sum=407.524
	2	-16	-104.9	2	36.957	(Mean)ẋ = **37.047**
	3	-23		3	36.571	
	4	-19	(Mean)ẋ = **-17,483**	4	37.714	
	5	-20		5	37.971	
	6	-10.4		6	41.357	S.D=
	7			7	37.628	**2.239549**
	8		S.D=	8	39.542	

	9		4.299031	9	34.485	
	10			10	33.671	
	11			11	34.7	

Table (A-76) Sulaymani Governorate / Region-2- {Halsho, Mawat, and Qaladze Stations} (2009-2014)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Halsho	1	-6.8	Sum-9.9 (Mean)Ẋ = **-0.9** S.D= **3.88201**	1	38.801	Sum= 336.78 (Mean)Ẋ = **37.42** S.D= **1.926897**
	2	-7.1		2	40.17	
Mawat	3	0.1		3	35.14	
	4	-3.6		4	34.114	
	5	-1.2		5	36.842	
	6	-0.5				
	7	-3.0				
Kaladze	8	2.9		6	37.528	
	9	2.2		7	38.9	
	10	2.9		8	36.785	
	11	4.2		9	38.5	

Table (A-77)

Sulaymani Governorate / Region -3-

{Sulaymani Center, Bazian, Halabje and Chamchemal Stations} (1999-2014)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Sulaymani center	1	4.2	Sum=-5.1 (Mean)Ẋ = **-0.17** **S.D= 3.395**	1	43.685	Sum=1251.003 (Mean)Ẋ = **43.137** S.D= **1.1428**
	2	1.6		2	43.528	
	3	3.6		3	40.771	
	4	1.7		4	43.1	
	5	2.7		5	41.442	
	6	2.8		6	43.1	
	7	2.6		7	42.5	

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
	8	1.5		8	41.828	
	9	1.5		9	44.742	
	10	-1.0		10	41.114	
	11	1.9		11	42.928	
	12	6.1		12	44.7	
	13	2.5		13	42.987	
	14	1.8		14	42.428	
	15	2.7		15	43.085	
	16	3.4				
Bazian	17	-1.8		16	42.942	
Chamchemal	18	-2.5		17	42.828	
	19	-5.6		18	43	
	20	-3		19	44.528	
	21	-3.3		20	42.071	
	22	-5.2		21	42.928	
	23	-4.6		22	41.685	
	24	-1.7		23	44.285	
	25	2.7		24	43.271	
	26	-4.5		25	44.271	
	27	-3.1		26	43.242	
	28	-4		27	44.242	
Halabje	29	-5.6		28	44.388	
	30	-2.5		29	45.384	

Table (A-78)

Germian Administration / Region -1- {Chamchemal, Kalar and Maidan Stations} (2000-2014)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Chamchemal	1	-2.5	Sum=-15.6	1	42.828	Sum=459.579
	2	-5.6	(Mean)Ẋ = **-1.56**	2	43	(Mean)Ẋ = **45.95**
	3	-3		3	44.528	
	4	-3.3		4	42.071	
Kalar	5	0.9		5	47.472	
	6	1.8	S.D= **2.2227**	6	48.367	S.D= **2.5677**
	7	-2.0		7	48.77	
	8	0		8	47.84	
Maidan	9	-0.1		9	47.028	
	10	-1.8		10	47.675	

Table (A-79)

Kirkuk Governorate/ Region -1-

{Kirkuk Station} (2000-2014)

Station name	No.	Minimum air temperature Xi °C	Note	No.	Maximum air temperature Xi °C	Note
Kirkuk 621	1	-1.6	Sum=-13.1 (Mean)Ẋ = **-0.873** S.D= **1.642066**	1	48.91	Sum=705.5485 (Mean)Ẋ = **47.03** S.D= **1.207735**
	2	0		2	48.471	
	3	1		3	46.271	
	4	0.7		4	47.942	
	5	-3.8		5	45.528	
	6	0.2		6	46.785	
	7	-2.2		7	47.457	
	8	-0.7		8	46.357	
	9	-2.5		9	46.2285	
	10	-2.8		10	44.9	
	11	0.8		11	47.657	
	12	-0.8		12	48.514	
	13	-2		13	47.7	
	14	-1.4		14	45.557	
	15	2		15	47.271	

Appendix B

“Samples calculations”

Finding reliability of air temperature for Kurdistan Region-Iraq depending on tables (A-70) to (A-79) in Appendix –A-

The 98% reliability is founded by the following equation;
T Max at 98% = T Max at 50 % + 2.055 ×σ high Temp

T Min at 98% = T Min at 50 % - 2.055 ×σ low Temp

Duhok; Region 1; T max: 35.479+2.055*3.09926 = 41.847
T min: -3.875-2.055*4.959495 = -14.06656
Region 2; T max: 43.487+2.055*2.09517 = 47.7925
T min: 1.509-2.055* 3.285756 = -5.243

Erbil; Region 1; T max: 33.26275+2.055* 3.102601= 39.6385
T min: -3.19-2.055*4.360194 = -12.15
Region 2; T max: 40.4+2.055*2.012091= 44.534
T min: 0.72-2.055* 2.903078 = -5.24
Region 3; T max: 44.543+2.055*1.4542= 47.531
T min: 3.734-2.055*1.883793 = -0.137

Sulaymani; Region 1; T max: 37.047+2.055*2.239549= 41.6492
T min: -17,483-2.055*4.299031= -26.31
Region 2; T max: 37.42 + 2.055*1.926897= 41.379
T min: -0.9-2.055* 3.88201= -8.8775
Region 3; T max: 43.137+2.055*1.1428 = 45.485
T min: -0.17 -2.055*3.396 = -7.148

Germyain Administration;
Region 1; T max: 45.95+2.055*2.5677= 51.224
T min: -1.56-2.055* 2.2227= -6.127

Kirkuk Governorate;
Region 1; T max: 47.03+2.055*1.207735= 49.511
T min: -0.873-2.055* 1.642066= -4.2474

Pavement Temperature calculations;

Pavement temperature founded by using following equations;

1- T pave @ $_{20}$ mm= 0.9545 [T $_{air}$ – 0.00618 lat^2+0.2289 lat + 42.2] – 17.78 (for high temperature)

1	**Duhok** \ Region-1-
$T_{20\,mm}$=0.9545[41.847-0.00618*(37.25)^2 +0.2289(37.25) +42.2]-17.78 = 62.396	
2	**Duhok** \ Region-2-
$T_{20\,mm}$=0.9545[47.7925-0.00618*(37)^2 +0.2289(37) +42.2]-17.78 = 68.126	
3	**Erbil;** Region-1-
$T_{20\,mm}$=0.9545[39.6385-0.00618*(36.75)^2 +0.2289(36.75) +42.2]-17.78 = 60.139	
4	**Erbil;** Region-2-
$T_{20\,mm}$=0.9545[44.534-0.00618*(36.25)^2 +0.2289(36.25) +42.2]-17.78 = 65.176	
5	**Erbil;** Region-3-
$T_{20\,mm}$ =0.9454[47.531-0.00618*(36)^2 +0.2289(36) +42.2]-17.78 = 68.016	
6	**Sulaymaniyah;** Region-1-
$T_{20\,mm}$=0.9545[41.6492-0.00618*(36.25)^2 +0.2289(36.25) +42.2]-17.78 = 62.422	
7	**Sulaymaniyah;** Region-2-
$T_{20\,mm}$=0.9545[41.379-0.00618(36)^2+0.2289(36) +42.2]-17.78 = 62.2167	
8	**Sulaymaniyah;** Region-3-
$T_{20\,mm}$=0.9545[45.485-0.00618*(35.5)^2 +0.2289(35.5) +42.2]-17.78 = 66.237	
9	**Garmiyan;**Region-1
$T_{20\,mm}$=0.9545[51.224-0.00618*(35)^2 +0.2289(35) +42.2]-17.78 = 71.814	
10	**Kirkuk;** Region-1-
$T_{20\,mm}$=0.9545[49.511-0.00618*(35.5)^2 +0.2289(35.5) +42.2]-17.78 = 70.080	

2- $T_{pave.} = 1.56 + 0.72T_{air} - 0.004\ Lat^2 + 6.26\ log_{10}(H+25) - Z\ (4.4 + 0.52\ \sigma^2_{air})^{1/2}$ (for low temperature

H=0
Z=2.055 for 98% reliability

1	**Duhok** \ Region-1-
T_{air}=1.56 +0.72(-14.06) – 0.004 $(37.25)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*4.959^2)^{1/2}$ = -13.88…………………………………… (-16)	
2	**Duhok** \ Region-2-
T_{air}=1.56 +0.72(-5.243) – 0.004 $(37)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*3.286^2)^{1/2}$ = -5.442………………………………………. (-10)	
3	**Erbil;** Region-1-
T_{air}=1.56 +0.72(-12.15) – 0.004 $(36.75)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*4.36^2)^{1/2}$ = -11.606…………………………………. (-16)	
4	**Erbil;** Region-2-
T_{air}=1.56 +0.72(-5.24) – 0.004 $(36.25)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*2.903^2)^{1/2}$ = -4.8………………………………………… (-10)	
5	**Erbil;** Region-3-
T_{air}=1.56 +0.72(-0.137) – 0.004 $(36)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*1.884^2)^{1/2}$ = -0.107………………………………… (-4)	
6	**Sulaymaniyah;** Region-1-
T_{air}=1.56 +0.72(-26.31) – 0.004 $(36.25)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*4.299^2)^{1/2}$ = -21.579……………………………………. (-22)	
7	**Sulaymaniyah;** Region-2-
T_{air}=1.56 +0.72(-8.87) – 0.004 $(36)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*3.882^2)^{1/2}$ = -8.44……………………………………….. (-10)	
8	**Sulaymaniyah;** Region-3-
T_{air}=1.56 +0.72(-7.148) – 0.004 $(35.5)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*3.395^2)^{1/2}$ = -6.501…………………………………… (-10)	
9	**Garmiyan;**Region-1
T_{air}=1.56 +0.72(-6.127) – 0.004 $(35)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*2.223^2)^{1/2}$ = -4.425………………………………… (-10)	
10	**Kirkuk;** Region-1-
T_{air}=1.56 +0.72(-4.247) – 0.004 $(35.5)^2$ + 6.26*log_{10} (0+25)-2.055 $(4.4+0.52*1.642^2)^{1/2}$ = -2.73……………………………. (-4)	

Appendix –C-

"Conventional Test Results For Asphalt Samples of; Lanaz Bitumen & Oil Refinery, Phoenix Bitumen Production Plant and Kat Plant for Asphalt & Lub Oil"

Table (C-1) Physical Properties of Asphalt Cement Samples (Lanaz Bitumen & Oil Refinery) Grade (40-50)

#	Penetration (0.10 mm)	Softening point (°C)	Ductility (cm)	Flash point (cm)	Residue from thin film oven test		Date
					Retained penetration (%)	Ductility (cm	
L1	49	51	108	238	67	50	24,4,2013
L2	49	52	100	240	69	59	17,11,2013
L3	49	51	100	240	73	60	17,11,2013
L4	49	52	100	240	67	49	17,11,2013
L5	43	53	100	240	72	44	20,11,2013
L6	42	52	100	240	76	45	20,11,2013
L7	42	54	100	240	76	46	20,11,2013
L8	45	55	100	240	80	36	21,11,2013
L9	47	54	100	240	72	36	21,11,2013
L10	46	54	100	240	74	34	21,11,2013
L11	47	52	100	240	74	60	25,11,2013
L12	44	52	100	240	80	60	25,11,2013
L13	48	54	100	240	71	29	2,12,2013
L14	48	53	100	240	79	46	2,12,2013
L15	48	54	100	240	77	60	2,12,2013
L16	48	-	100	240	58	22	21,4,2014
L17	46	-	100	240	57	15	21,4,2014
L18	44	-	100	240	61	26	7,8,2014
L19	47	-	100	240	62	40	7,8,2014
L20	45	-	100	240	58	28	7,8,2014
L21	48	-	100	240	60	33	19,10,2014
L22	45	-	100	240	60	28	7,1,2015
L23	45	-	100	240	58	41	15,1,2015
L24	45	-	100	240	58	44	15,1,2015
L25	45	-	100	240	58	44	15,1,2015
SSRB,(SORB) R9-04 Designation	40-50	51-62	>100	>232	>55	>25	

Note; this tests are made in (Hawler construction laboratory) in Erbil /Kurdistan-Iraq.

Table (C-2) Physical Properties of Asphalt Cement Samples (Lanaz Bitumen & Oil Refinery) Grade (60-70)

#	Penetration (0.10 mm)	Softening point (°C)	Ductility (cm)	Flash point (cm)	Residue from thin film oven test		Date
					Retained penetration (%)	Ductility (cm	
L1	62	52	>100	>230	>50	>50	26,04,2015
L2	61	52	>100	>230	>50	>50	06,05,2015
L3	60	52	>100	>230	>50	>50	11,05,2015
L4	60	52	>100	>230	>50	>50	25,05,2015
L5	60	52	>100	>230	>50	>50	10,06,2015
L6	61	52	>100	>230	>50	>50	15,06,2015
L7	60	52	>100	>230	>50	>50	22,06,2015
L8	61	52	>100	>230	>50	>50	01,07,2015
L9	62	52	>100	>230	>50	>50	07,07,2015
L10	61	52	>100	>230	>50	>50	11,07,2015
L11	60	52	>100	>230	>50	>50	22,07,2015
L12	60	52	>100	>230	>50	>50	08,08,2015
L13	60	52	>100	>230	>50	>50	11,08,2015
L14	60	52	>100	>230	>50	>50	22,08,2015
L15	65	-	>100	>240	57	66	26,08,2015
L16	67	-	>100	>240	57	>50	26,08,2015
L17	65	-	>100	>240	57	>50	26,08,2015
L18	67	-	>100	>240	57	>50	26,08,2015
L19	63	52	>100	>230	>50	>50	06,09,2015
L20	61	52	>100	>230	>50	>50	14,09,2015
L21	62	52	>100	>230	>50	>50	28,09,2015
L22	62	52	>100	>230	>50	>50	04,10,2015
L23	63	52	>100	>230	>50	>50	11,10,2015
SSRB,(SORB) R9-04 Designation	60-70	EN1427	>100	>232	>52	>50	

Note; this tests are made in LANAZ Bitumen & Oil refinery laboratory in Erbil, except for samples (L15, L16, L17 & L18) which performed in (Hawler construction laboratory) in Erbil/Kurdistan-Iraq.

Table (C-3) Physical Properties of Asphalt Cement Samples (Phoenix Refinery) Grade (40-50)

#	Penetration (0.10 mm)	Softening point (°C)	Flash point (cm)	Ductility At 25 C°	Residue from thin film oven test		Date
					Retained penetration (%)	Ductility (cm	
ASTM, Designation	D5-05a	D36-06	D92-05	D113-99	D1754-97	D1754-97	
PH1	49	51	289	150	61	150	16/3/2015
PH2	45	53	291	150	64	77	7/4/2015
PH3	48	52	290	150	63	63	3/5/2015
PH4	46	52	294	150	63	140	5/5/2015
PH5	47	52	295	150	64	118	
PH6	46	53	298	150	63	150	6/5/2015
PH7	46	52	290	150	63	97	
PH8	47	52	288	150	64	79	
PH9	47	52	293	150	62	120	
PH10	45	53	270	150	62	30	7/5/2015
PH11	48	54	270	150	63	26	14/5/2015
PH12	48	53	267	150	65	40	
PH13	48	52	286	150	65	68	19/5/2015
PH14	47	52	294	150	64	133	28/5/2015
PH15	46	51	295	150	65	135	
PH16	47	51	292	150	64	130	
PH17	48	51	295	150	65	140	
PH18	46	53	283	150	65	135	3/6/2015
PH19	47	53	281	150	64	150	
PH20	43	54	287	150	60	46	7/6/2015
PH21	48	51	290	150	63	139	16/6/2015
SSRB Designation	60-70	49-54	>232	>100	>52	>50	

Note; this tests are made in (Sylaimani construction laboratory) /Kurdistan-Iraq.

Table (C-4) Physical Properties of Asphalt Cement Samples (Phoenix Refinery) Grade (60-70)

#	Penetration (0.10 mm)	Softening point (°C)	Viscosity at 135 oC	Flash point (cm)	Ductility	Residue from thin film oven test		Date
						Retained penetration (%)	Ductility (cm	
ASTM	Designation	D5		D113	D36	D1754	D5	
PH1	65	50	495	315	150	62.3	90	24,1,2015
PH2	65	49	460	312	150	68	99	3,2,2015
PH3	66	49	460	305	+150	67	109	5,2,2015
PH4	65	48	455	313	+150	68	106	7,2,2015
PH5	62	50	490	315	++150	64	101	9,2,2015
PH6	66	49	430	311	+150	63.6	105	22,2,2015
PH7	65	50	500	313	+150	62	115	27,2,2015
PH8	62	50	475	312	+150	64.5	105	28,2,2015
PH9	66	49	450	313	++150	67	101	1,3,2015
PH10	62	50	505	309	++150	64	112	7,3,2015
PH11	65	48	430	318	++150	67	115	11,3,2015
PH12	65	50	490	317	+150	62	101	17,3,2015
PH13	67	49	440	310	+150	63	112	29,3,2015
PH14	63	50	510	313	++150	64.3	95	8,4,2015
PH15	66	48	425	320	++150	65	101	15,4,2015
PH16	63	50	485	309	+150	65	105	19,4,2015
PH17	67	49.5	475	313	+150	63.3	95	21,4,2015
PH18	68	49	435	309	+150	65	95	21,4,2015
PH19	62	50	465	319	++150	65	100	22,4,2015
PH20	67	49	450	315	+150	65	110	23,4,2015
PH21	66	49	485	310	+150	63,8	104	24,4,2015
SSRB,(SORB) R9-04 Designation	60-70	49-54	400	>232	>100	>52	>50	

Note; this tests are made in Phoenix refinery laboratory/Kurdistan-Iraq.

Table (C-5) Physical Properties of Asphalt Cement Samples (KAT Plant for Asphalt & Lub Oil) Grade (40-50)

#	Penetration (0.10 mm)	Softening point (°C)	Ductility (cm)	Specific Gravity@25C	Flash point (cm)	Residue from thin film oven test		Date
						Retained penetration (%)	Ductility (cm	
K1	46	-	>100	-	>240	63	>26	04,6,2015
K2	45	-	>100	-	>240	64	>26	28,6,2015
K3	44	-	>100	-	>240	66	>26	10,7,2015
K4	45	53	>150	1.045	300	69	>150	11,08,2015
K5	45	53	>150	1.03	295	68	112	25,08,2015
K6	47	54	>150	1.019	298	69	123	03,09,2015
K7	44	-	>100	1.019	298	69	123	09,09,2015
K8	46	54	>150	1.028	298	69	135	15,09,2015
K9	46	54	>150	1.028	298	69	135	28,09,2015
K10	45	53	>150	1.023	298	68	>150	16,10,2015
SSRB,(SORB) R9-04 Designation, or	40-50	52-60 C ASTM D36	>100 Cm ASTM D113	1.011-1.061 ASTM D70	>250 ASTM D92	>55 ASTM D2872	>25 ASTM D2872	

Note; this tests are performed on (KAT Plant for Asphalt and Lub oil) and in Hawler construction laboratory in Erbil.

Table (C-6) Physical Properties of Asphalt Cement Samples (KAT Plant for Asphalt & Lub Oil) Grade (60-70)

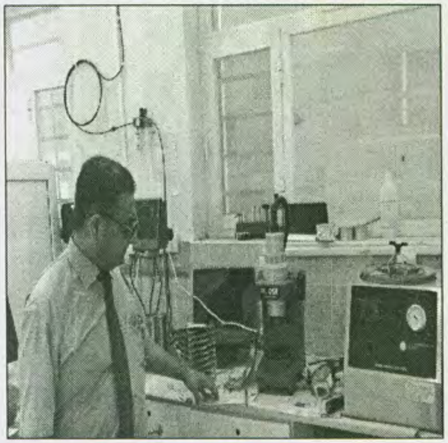
#	Penetration (0.10 mm)	Softening point (^{o}C)	Ductility (cm)	Specific Gravity@25C	Flash point (cm)	Residue from thin film oven test		Date
						Retained penetration (%)	Ductility (cm	
K1	69	-	>100	-	>240	59	>40	30,05,2015
K2	69	-	>100	-	>240	58	>40	15,06,2015
K3	68	-	>100	-	>240	59	>40	15,07,2015
K4	69	-	>100	-	>240	60	>40	10,08,2015
K5	65	50.6	>150	1,025	290	72	>150	11,08,2015
K6	63	51	>150	1,025	295	71	136	25,08,2015
K7	67	50	>150	1,012	290	73	144	03,09,2015
K8	64	49,5	>150	1,021	295	71	140	15,09,2015
K9	64	51	>150	1,021	295	70	140	28,09,2015
K10	65	50	>150	1,018	296	72	>150	16,10,2015
SSRB,(SORB) R9-04 Designation, or ASTM	60-70	49-56 C ASTM D36	>100 Cm ASTM D113	1.011-1.061 ASTM D70	>232	>53 ASTM D2872(RTFO)	>50 Cm ASTM D2872(RTFO)	

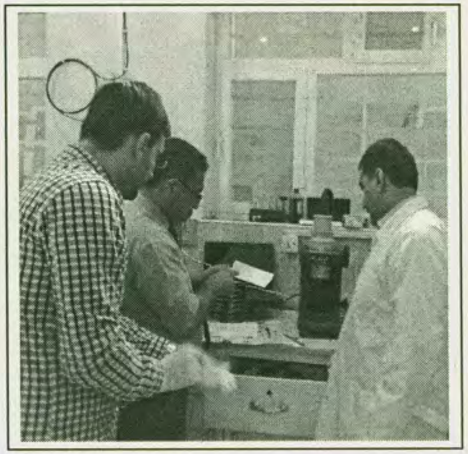
Note; this tests are performed on (KAT Plant for Asphalt and Lub oil) in Hawler construction laboratory in Erbil, Kurdistan/ Iraq.

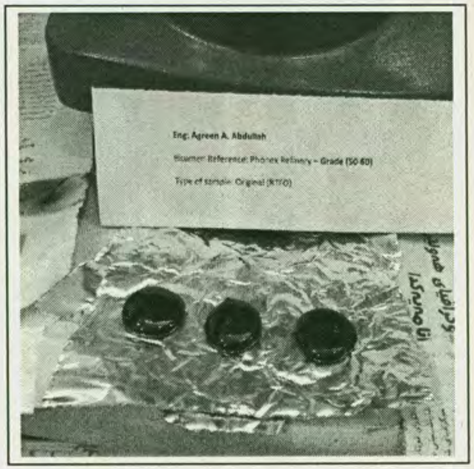
Appendix D

Views on experimental works

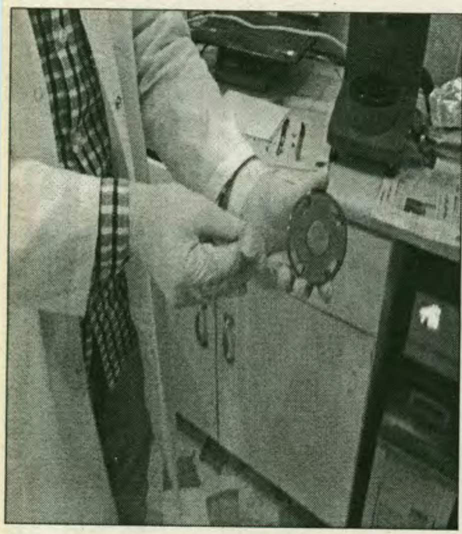
1-Visit on 2/7/2015;



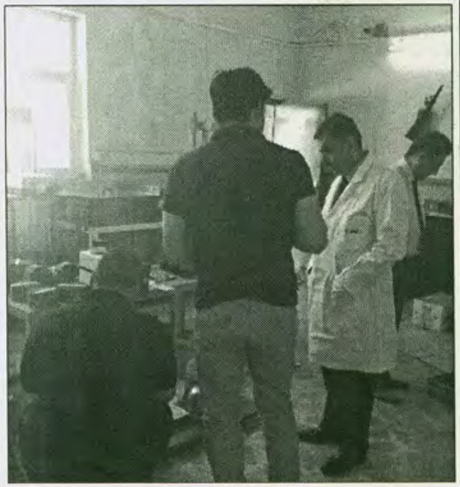


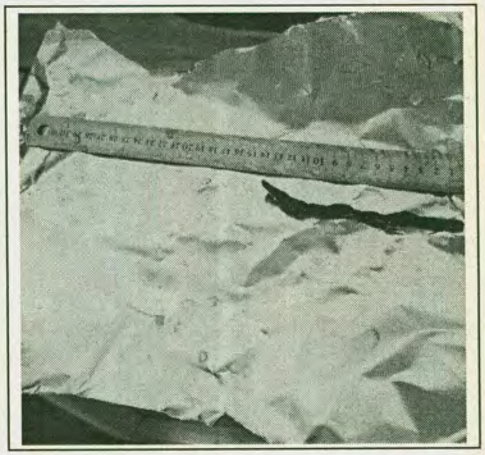


2-Visit on 1/8/2015;

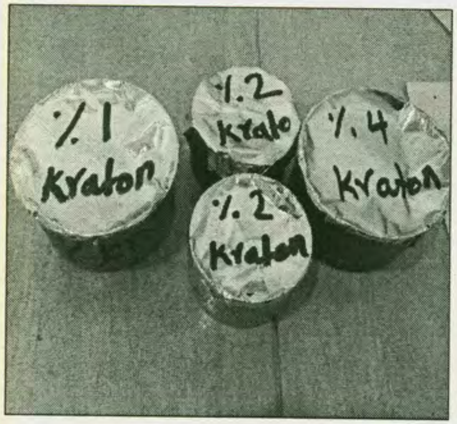


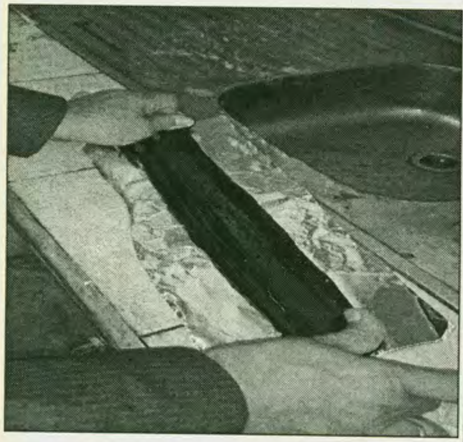
3-Visit on 29/8/2015;



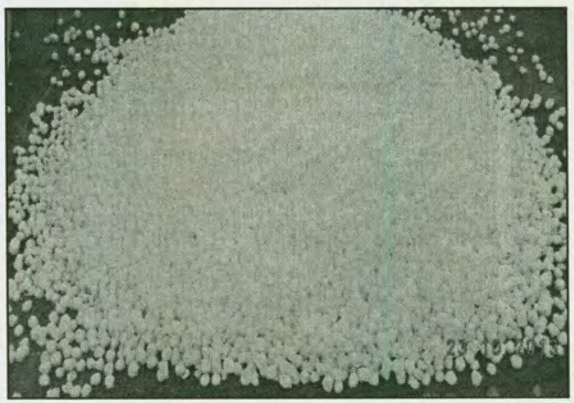


4-Vist of 27 Oct 2015

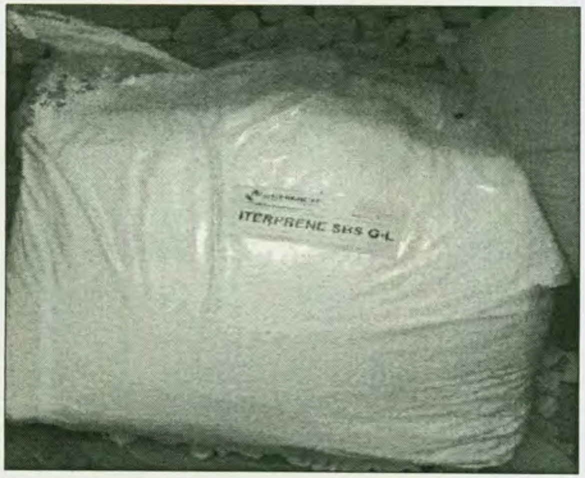




Mixing device for melting polymer with asphalt samples



Kraton D1192 (Source; Bastora asphalt plant-Erbil)



ITERPRENE SBS G-L/ Elastomer, source; Hawler laboratory warehouse

Iterplast 1806 plastomer, (source; Hawler laboratory warehouse)

Agreen Abdoulla Azeez

Educational Statues:

1- Bachelor degree in civil engineering, Salahadin University-Erbil\Iraq (1994\1995).
2- Master in business administration (MBA)\ Lebanese -French University-Erbil\Iraq (2010).
3- Master in road engineering, Erbil Polytechnic University\Iraq (2016).

Positions Possessed:

1- From Augusts 1995, employed in ministry of Construction and Development (Kurdistan Regional Government), as site and project supervisor engineer.
2-(1995-2000), participated in supervision of several projects (small, intermediate and large projects) in road, bridges, building renovation and construction.
3-(2000-2002) become manager of rural water directorate of Erbil.
4-(2003) possessed the position of manager for village reconstruction of Erbil.
5- Worked as director of Road Maintenance of Erbil (2007).
6- Worked as director of Road and Bridges of Erbil (2013).
7-From2014 possessed the position of deputy minister of ministry of Construction and Housing, for Construction & Housing sector.

8- Was member in engineering syndicate leading bureau for 3 years (2000-2004).

Experiences:

1- Worked as site engineer and supervisor engineer in road and building projects.
2- Worked as the head of water and sanitation department under UN 986 SCR program.
3- As manager of different directorate (Rural water, road maintenance and Road construction).
4- Represented ministry of Construction and Housing, in dealing with various organizations as; UNHCR, Habitat, UNICEF.
5- Heading various ministries delegations for different countries for issues related to road projects, bitumen and civil engineering.

Publications:

1- Publishing different articles regarding technical issues in "Engineer" magazine.
2- Own different researches about road maintenance and road pavement with asphalt and road network.
3- Publishing two books about road maintenance and road networks management in Kurdish language.

Evaluation of Local Asphalt Production and Performance Grade (PG) for Kurdistan Region-Iraq

The asphalt layer distresses was the main reason that motivated me to make various research into understanding why this phenomenon occurs on continues basis and finding feasible solutions to solve this problem. Due to this interest, I found myself in the master course at the civil department of the Erbil University of Polytechnic in the Kurdistan region of Iraq. After the completion of the formal course I dedicated myself to seek the best method for strengthening the asphalt pavement, which became my mission with the help of my supervisor Dr. Fars Najer and the support of Erbil Construction Laboratory.

Evaluation of Local Asphalt Production and Performance Grade (PG) for Kurdistan Region-Iraq