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Rotational Viscosity Prediction Models For Asphalt Cement

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Abstract

It is a great importance to know asphalt cement viscosity in order to perform handling, mixing, application processes and asphalt compaction in highway surfacing.

This paper presents the results of rotational viscosity measurement for different asphalt cement sources, grades, and different test temperatures. statistical models were developed to predict the rotational viscosity for any asphalt cement grades that usually used in pavement work in Iraq and for different test temperatures. in this study six types of asphalt cement have been used. All the asphalt cement are locally available and widely employed for the pavement construction in the Iraq. These asphalt cement are: AC(40-50) from Daurah and Baiji refinery, (AC 60-70) from Daurah refinery, AC(50-60) from Daurah and Basrah refinery, AC(85-100) from Daurah refinery.

Also, this paper shows that no change have been observed in rotational viscosity for asphalt cement blow 100 °C, and it is about 12613 mPa.s.

Keywords: Rotational Viscometer, Superpave, Asphalt Cement

التنبؤ بعلاقات رياضية للزوجة المحورية للإسفلت الأسمنتي

الخلاصة

من المهم جدا" معرفة لزوجة الإسفلت الأسمنتي لمعرفة أداء الخلطات الإسفلتية خلال الخلط والنقل وتنفيذ الطبقات السطحية الإسفلتية. في هذا البحث تم إيجاد أقيام اللزوجة المحورية لعدة أنواع من الإسفلت الأسمنتي ولمختلف درجات الفحص المختبرية. لقد تم أيجاد علاقة إحصائية للتنبؤ باللزوجة المحورية لتدرجات الاختراق المستخدمة عادة في تبليط الطرق بالعراق ولعدة درجات حرارة للفحص. في هذا البحث تمت دراسة ستة أنواع من الإسفلت الإسمنتي وهي إسفلت ذو اختراق (40-50) من مصفى الدورة وبيجي, اسفلت ذو اختراق (60-70) من مصفى الدورة, أسفلت ذو اختراق (50-60) من مصفى الدورة والبصرة, واسفلت ذو اختراق (85-100) من مصفى الدورة. أيضا" لقد تم الاستنتاج بأنه لايوجد تغيير ملحوظ باللزوجة المحورية للاسفلت الاسمنتي بدرجات الحرارة اقل من 100 م° وتكون مساوية ل 12613 mPa.s.

Introduction

Asphalt cements are complex materials due to their chemical formulation and physical properties. The asphalt develops viscous behavior when loaded over a long period of time or under high temperatures (> 50 °C) and behaves as an elastic material in a reverse situation.[1] Rheology studies thematerial properties of fluid and semi-solid materials and Determines the relation between force, deformation and time variables. The viscosity is one of the most important rheological characteristics of a fluid which indicates resistance to flow. The known dependence of viscosity to temperature, shear rate and other parameters can be used to predict behaviour of asphalt in various conditions [2]. Superpave (Superior Performing Asphalt Pavements) binder

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specification, which is a widespread methodology in the world, recommends Brookfield Rotational Viscometer to assess rheological properties at high temperatures. The relation between viscosity and temperature is essential to define temperature ranges to pumping, mixing, and compaction of asphalt mixes .[3]

Puzinauskas[4] stated that the viscosity of asphalt binder is significantly reduced with the increased pavement temperature. Within the extreme viscosity range, asphalts are transformed from low viscosity Newtonian liquids to materials exhibiting shear-dependent visco-elastic behavior, where with decreasing temperature the elastic component tends to be predominant. Figure 1 shows the effect of temperature on log asphalt viscosity for a wide range of asphalt cement grades.

ASTM [5] described an equation which was used to develop a standard ASTM viscosity- temperature chart for asphalts shown in Figure 2 .For calculating Viscosity Temperature Susceptibility (VTS) within a given temperature range, the following equation is used:

$$VTS = \frac{\log\log \eta_1 - \log\log \eta_2}{\log T_2 - \log T_1} \qquad (1)$$

Where:

η_1 = absolute viscosity at T_1 (centipoises)

η_2 = absolute viscosity at T_2 (centipoises)

T_1, T_2 = temperatures in degrees Kelvin.

Historically, viscosity values have been used to calculate mixing and compaction temperatures. The Marshall mix design has used capillary viscometers for viscosity measurements since the 1940[6]. In that design, asphalt must be heated to produce a viscosity of 170 ± 20 centistokes and 280 ±30 centistokes to establish mixing and compaction temperatures, respectively[5]. Those values are the same for the Superpave mix design (0.17 ± 0.02 Pa-s and 0.28 ± 0.03 Pa-s).

Materials

The materials used in this study are six grades of asphalt cement. All the asphalt cement are locally available and widely employed for the pavement construction in the Iraq. The penetration grades for these asphalt cement are: AC(40-50) from Daurah and Baiji refinery, (AC 60-70) from Daurah refinery, AC(50-60) from Daurah and Basrah refinery, AC(85-100) from Daurah refinery. The Table1 to 3 shows the physical properties for the different asphalt cement grade.

Test Method

Viscosity measurements were performed in rotational viscometer (Brookfield Viscometer DV-II+). This test was conducted according to AASHTO T 316-06 "Standard Method of Test for Viscosity Determination of Asphalt Binder"[7]. Figure 3 shows a photograph of Brookfield rotational viscometer employed in this study to evaluate binder's viscosity by measuring the torque required to rotate the spindle submerged in a sample of hot asphalt at a constant rotational speed of 20 rpm. The Thermosel system consisting of stainless steel sample chamber, temperature controller and a thermo-container to control the required test temperature. To have adequate mixing and pumping capabilities, Superpave specification (AASHTO M320) requires the binder to have a rotational viscosity less than 3.0 Pa.s at 135°C. The viscometer can also be used to develop Temperature-Viscosity charts by running the viscometer at both 135°C and 165 °C to determine laboratory mixing and compaction temperatures. Furthermore, this test can be performed for both unmodified and modified asphalt binder.

In this research, rotational viscosity for each asphalt cement grade have been taken for the temperatures range (60 °C, 70 °C, 80°C,90 °C,100 °C,110 °C, 120 °C,130 °C,135 °C,140 °C,150 °C,160 °C,165 °C,170 °C,175 °C). The viscosity of each temperature represent the mean of three reading of viscosity for space time one minute.

Results And Discussion

Table4 represent the mean of three reading of viscosity for space time one minute that taken for each temperature. Linear regression is used to develop models for prediction of asphalt viscosity as a function of the temperature. The figure 4 to 10 shows the relationships between asphalt viscosity and the temperatures for different asphalt cement grade.

The developed statistical models are shown in equations below:

For Baiji Asphalt Cement have penetration grade (40-50):

$V(bij40\text{-}50) = 10^{-0.0196T+5.512}$ ......(2)

Where:

V(bij40-50) =Viscosity of Baiji refinery asphalt have penetration grade(40-50),(mPa.s)

T= test Temperature (°C).

This model has an R^2 value of 0.947.

For Daurah Asphalt Cement have penetration grade (40-50) :

$V(dau40\text{-}50) = 10^{-0.01714T+5.2929}$ ...(3)

Where:

V(dau40-50)=Viscosity of Daurah refinery asphalt have penetration grade(40-50),(mPa.s)

T= test Temperature (°C).

This model has an R^2 value of = 0.946.

For Daurah Asphalt Cement have penetration grade (60-70) :

$V(dau60\text{-}70) = 10^{-0.0235T+5.819}$ ....(4)

Where:

V(dau60-70) =Viscosity of Daurah refinery asphalt have penetration grade(60-70),(mPa.s)

T= test Temperature (°C).

This model has an R^2 value of =0.959.

For Daurah Asphalt Cement have penetration grade (50-60) :

$V(dau50\text{-}60) = 10^{-0.0211T+5.6128}$ ..(5)

Where:

V(dau50-60) =Viscosity of Daurah refinery asphalt have penetration grade(50-60),(mPa.s)

T= test Temperature (°C).

This model has an R^2 value of = 0.966.

For Basrah Asphalt Cement have penetration grade (50-60) :

$V(bas50\text{-}60) = 10^{-0.0219T+5.7}$ ......(6)

Where:

V(bas50-60) =Viscosity of Basrah refinery asphalt have penetration grade(50-60),(mPa.s)

T= test Temperature (°C).

This model has an R^2 value of = 0.968.

For Daurah Asphalt Cement have penetration grade (85-100):

$V(dau85\text{-}100) = 10^{-0.0215T+5.597}$ .... (7)

Where:

V(dau85-100) =Viscosity of Daurah refinery asphalt have penetration grade(85-100), (mPa.s)

T= test Temperature (°C).

This model has an R^2 value of = 0.956.

For asphalt cement have any penetration grade from penetratiom40 to penetration 100:

$V = 10^{-0.0208T+5.589}$ .... (8)

Where:

V=Viscosity of asphalt cement have any penetration grade from penetratiom40 to penetration 100, (mPa.s)
T= test Temperature (°C).
This model has an R^2 value of = 0.940.

Conclusions

1- No change have been observed in rotational viscosity for asphalt cement blow 100 °C, and it is about 12613 mPa.s.
2- Models were developed to predict the rotational viscosity of asphalt cement for varying test temperatures(T). It is a linear model with following form:
3- Model was developed predict the rotational viscosity of asphalt cement for varying test temperatures(T) to the penetration grade range from 40 to 100. It is a linear model with following form:
$V= 10^{-0.0208T+5.589}$

Models	Source, Penetration Grade
$V=10^{-0.0196T+5.512}$	Baiji AC(40-50)
$V=10^{-0.01714T+5.2929}$	Daurah AC(40-50)
$V= 10^{-0.0235T+5.819}$	Daurah AC(60-70)
$V= 10^{-0.0211T+5.6128}$	Daurah AC(50-60)
$V= 10^{-0.0219T+5.7}$	Basrah AC(50-60)
$V= 10^{-0.0215T+5.597}$	Daurah AC(85-100)

References

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[6]Martin, J. R., Wallace, H. A., "Design and Construction of Asphalt Pavements", New York, McGraw-Hill Book Company, (1958).
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Table 1 Physical Properties of Asphalt Cement with penetration grade 40-50

Property	ASTM Designation (2000)	Penetration Grade		SCRB Specification
		Baiji Ac(40-50)	Daurah Ac(40-50)	
Penetration at 25°C, 100 gm, 5 sec, (0.1mm)	D-5	42	45	40-50
Softening Point, °C	D-36	57.5	50.5	....
Ductility at 25 °C 5cm/min,	D-113	>100	>100	>100
Flash Point, °C	D-92	292	320	min.232
Specific Gravity	D-70	1.041	1.040	....
Residue from thin film oven test	D-1754			
-Retained penetration, of original	D-5	59.5	61	55+
-Ductility at 25°C, 5cm/min, (cm)	D-113	80	80	25+

Table 2 Physical Properties of Asphalt Cement with penetration grade 50-60

Property	ASTM Designation (2000)	Penetration Grade		SCRB Specification
		Daurah Ac(50-60)	Basrah Ac (50-60)	
Penetration at 25°C, 100 gm, 5 sec, (0.1mm)	D-5	54	52	50-60
Softening Point, °C	D-36	46	47	....
Ductility at 25 °C 5cm/min,	D-113	>100	>100	>100
Flash Point, °C	D-92	295	290	min.232
Specific Gravity	D-70	1.028	1.022	....
Residue from thin film oven test	D-1754			
-Retained penetration, of original	D-5	64	62	53+
-Ductility at 25°C, 5cm/min, (cm)	D-113	82	81	40+

Table 3 Physical Properties of Asphalt Cement withpenetration grade 60-70 and 85-100

Property	ASTM Designation (2000)	Penetration Grade			
		Daurah Ac (60-70)		Daurah Ac (85-100)	
		Test Results	SCRB Specification	Test Results	SCRB Specification
Penetration at 25°C, 100 gm, 5 sec, (0.1mm)	D-5	63	60-70	92	85-100
Softening Point, °C	D-36	45.3	....	42.5	....
Ductility at 25 °C 5cm/min,	D-113	>100	>100	>100	>100
Flash Point, °C	D-92	290	min.232	292	min.232
Specific Gravity	D-70	1.024	....	1.036	....
Residue from thin film oven test	D-1754				
-Retained penetration, of original	D-5	63.5	52+	64	....
-Ductility at 25°C, 5cm/min, (cm)	D-113	83	50+	>100	....

Table4 Rotational Viscosity for Asphalt cement

Baiji (40-50)		Daurah (40-50)		Daurah (60-70)	
Temperature°C	Viscosity(mpa-s)	Temperature°C	Viscosity(mpa-s)	Temperature°C	Viscosity(mpa-s)
60	12613	60	12613	60	12613
70	12613	70	12613	70	12613
80	12600	80	12613	80	12613
90	12600	90	11225	90	12613
100	5962	100	2662	100	2147
110	1256	110	1875	110	1345
120	1243	120	1512	120	1312
130	668	130	1208	130	1196
135	541	135	516	135	400
140	487.5	140	429	140	243
150	431	150	400	150	162.5
160	387	160	356	160	125
165	175	165	281	165	87.5
170	137.5	170	275	170	62.3
175	125	175	245.8	175	42
Daurah (50-60)		Basrah (50-60)		Daurah (85-100)	
Temperature°C	Viscosity(mpa-s)	Temperature°C	Viscosity(mpa-s)	Temperature°C	Viscosity(mpa-s)
60	12613	60	12613	60	12613
70	12613	70	12613	70	12613
80	12613	80	12613	80	12613
90	12613	90	12613	90	12613
100	3616.6	100	4150	100	2050
110	1825	110	1946	110	1412.6
120	906.25	120	937.5	120	766.6

130	531.25	130	525	130	500
135	491.6	135	433.3	135	350
140	376.75	140	362.5	140	281.25
150	268.75	150	225	150	181.25
160	156.25	160	150	160	156.25
165	143.75	165	106.25	165	118.75
170	118.75	170	106.25	170	118.75
175	106.25	175	87.5	175	86

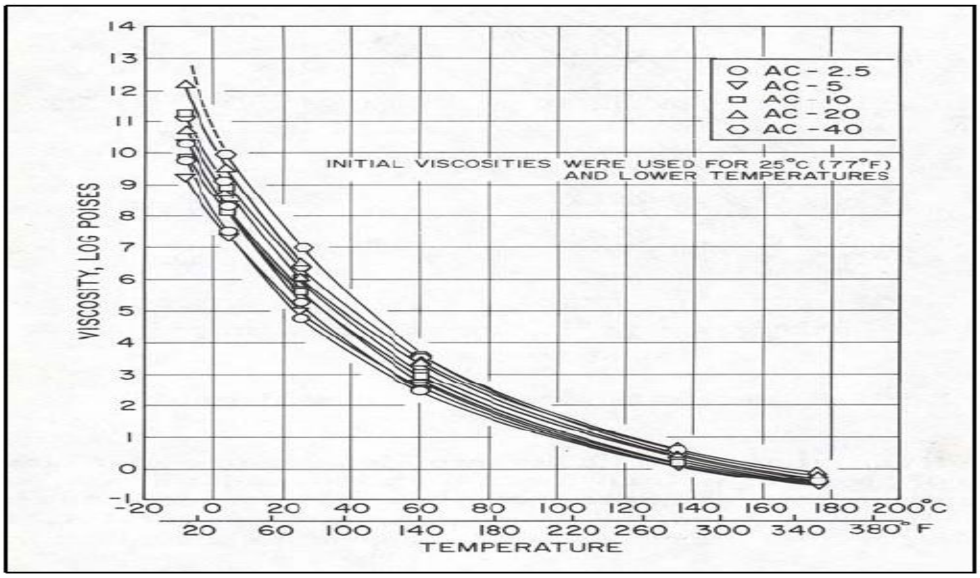
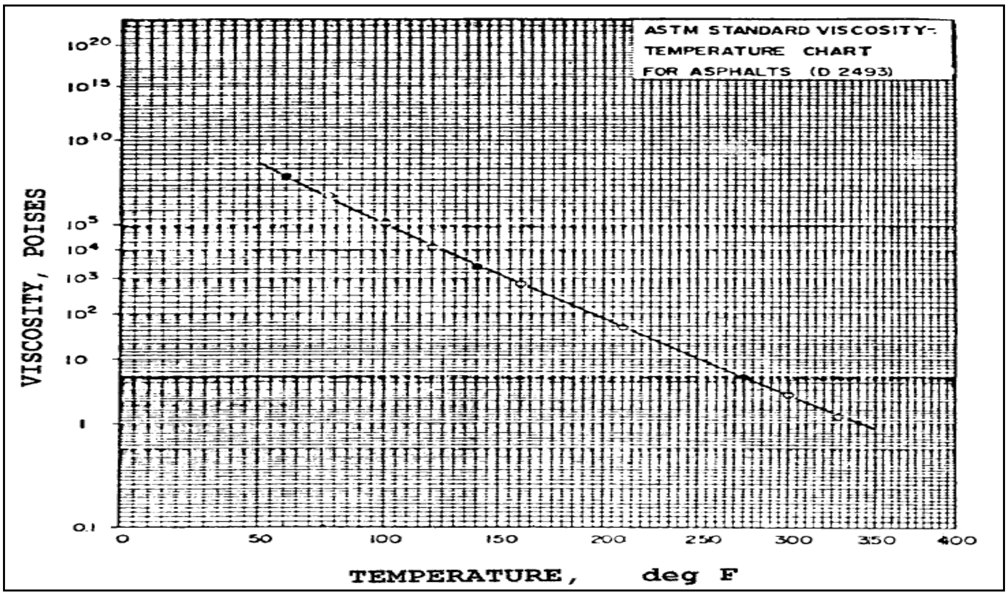


Figure1 Relationship between Viscosity and Temperature for Asphalt Cements



[4]

Figure 2 Temperature-Viscosity Chart [5]

Figure 3 Photograph of Rotational Viscometer Device

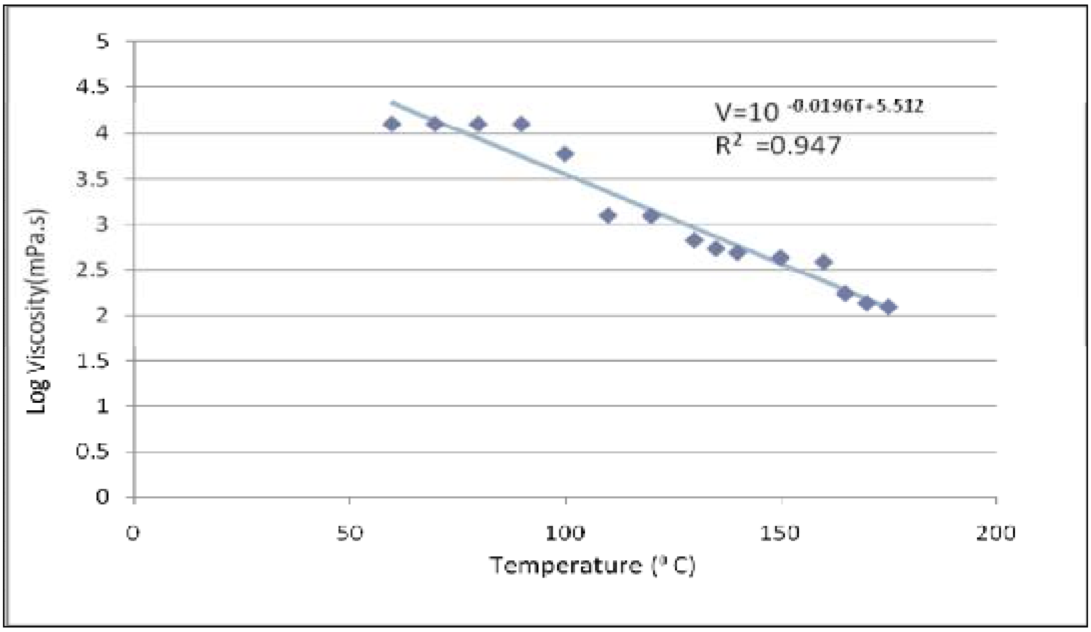


Figure 4 Temperature- Viscosity Relationship for Baiji Asphalt Cement AC (40-50)

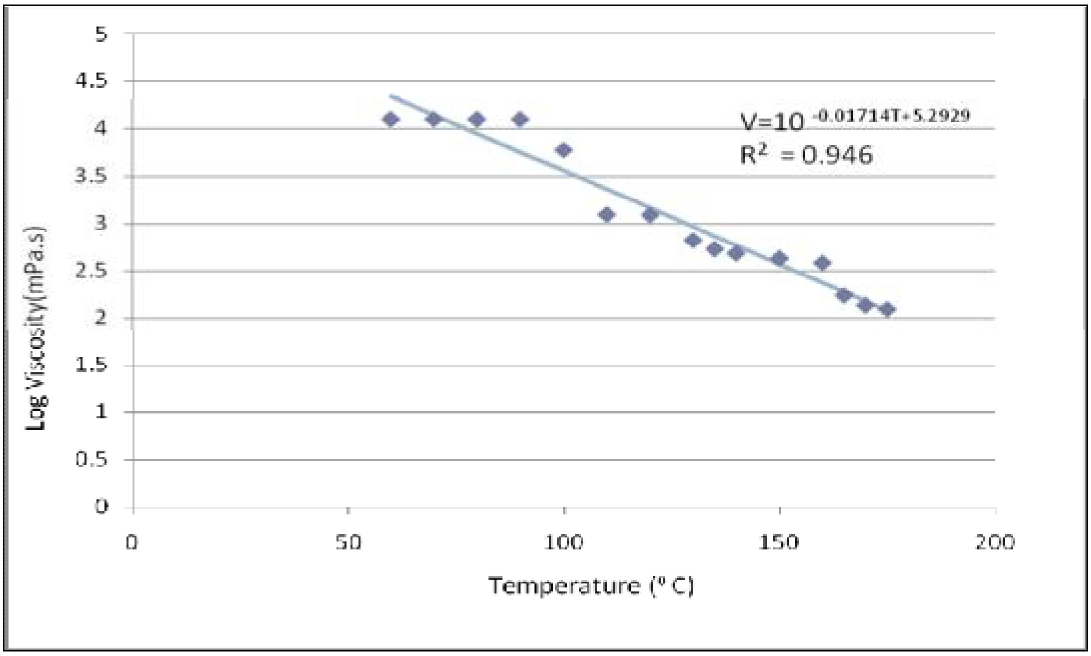


Figure 5 Temperature- Viscosity Relationship for Daurah Asphalt Cement AC (40-50)

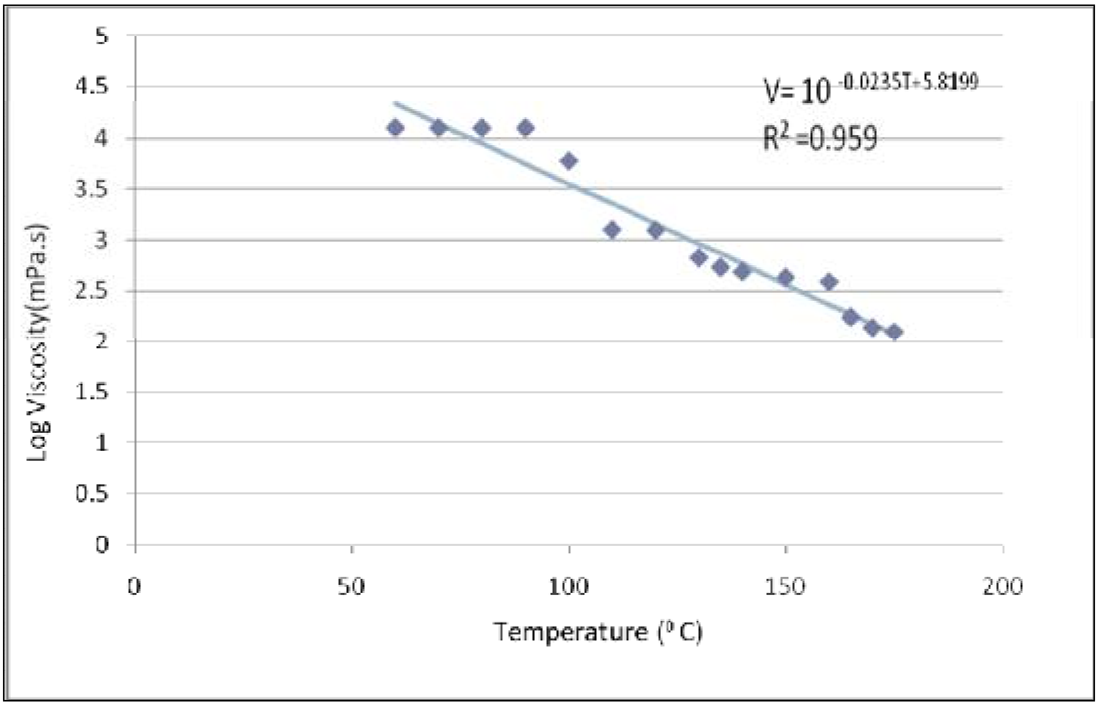


Figure 6 Temperature- Viscosity Relationship for Daurah Asphalt Cement AC (60-70)

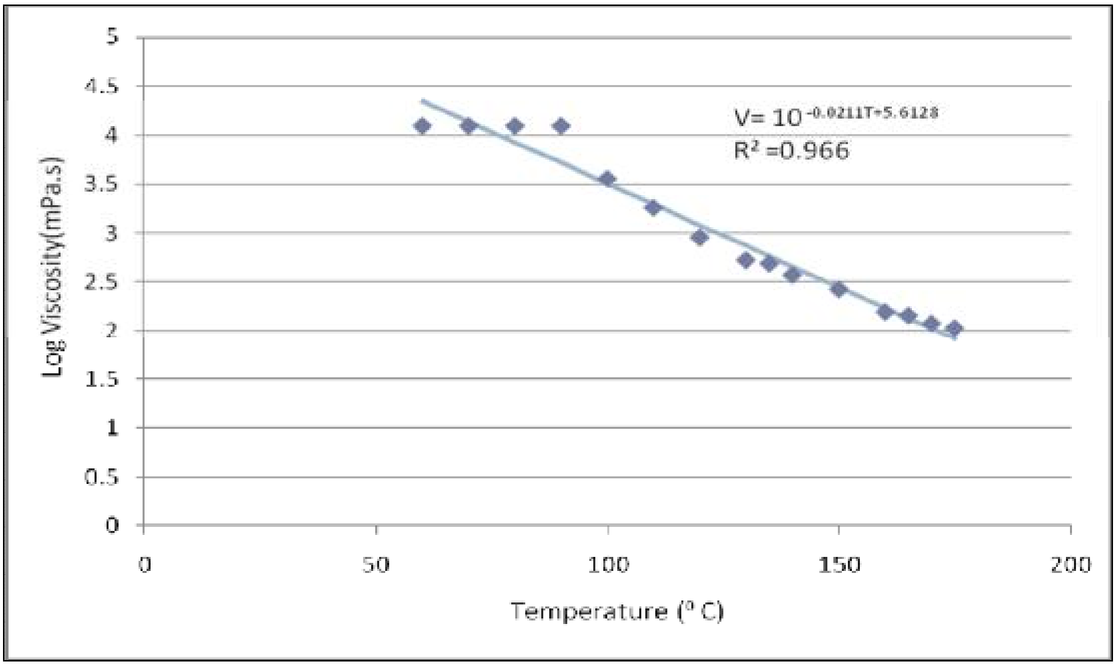


Figure 7 Temperature- Viscosity Relationship for Daurah Asphalt Cement AC (50-60)

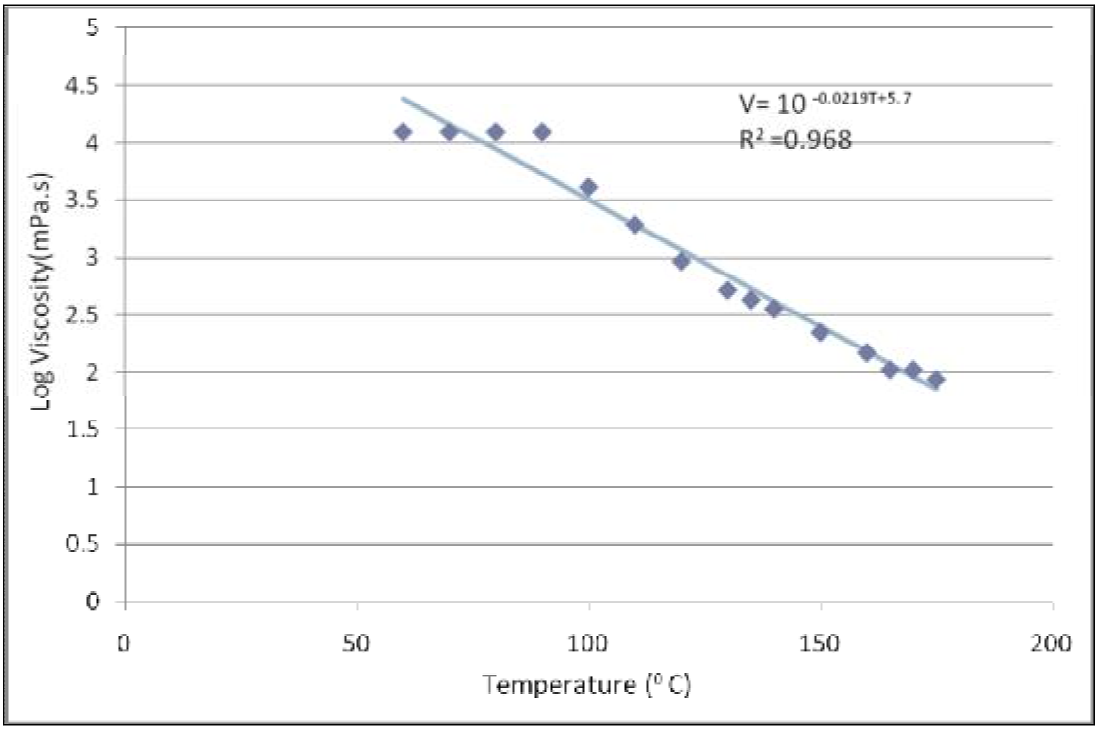


Figure 8 Temperature- Viscosity Relationship for Basrah Asphalt Cement AC (50-60)

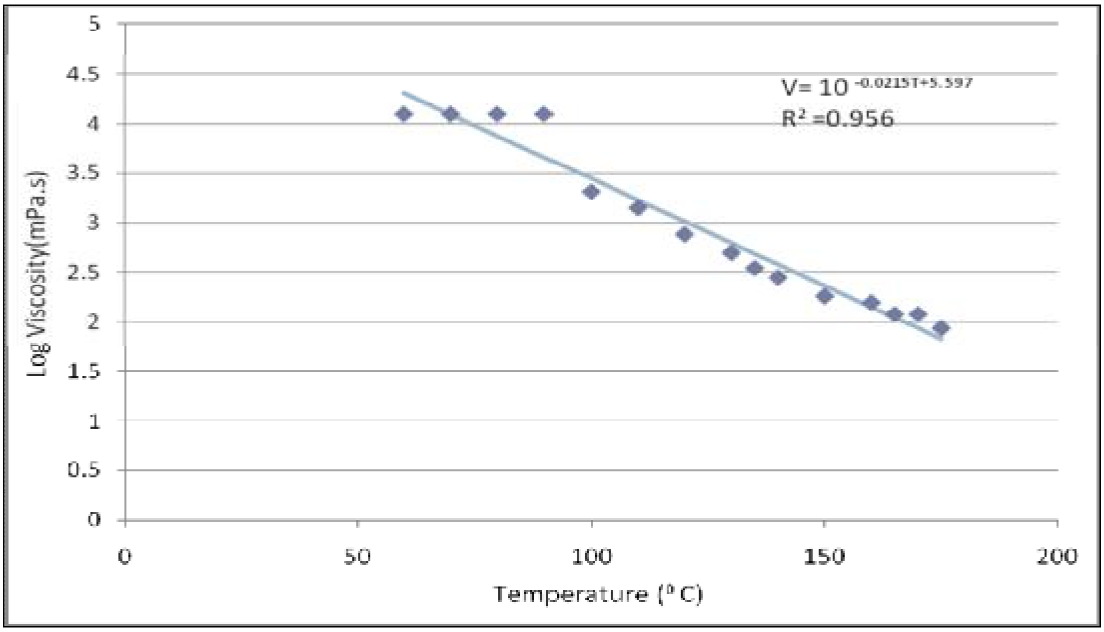


Figure 9 Temperature-Viscosity Relationship for Daurah Asphalt Cement AC (85-100)

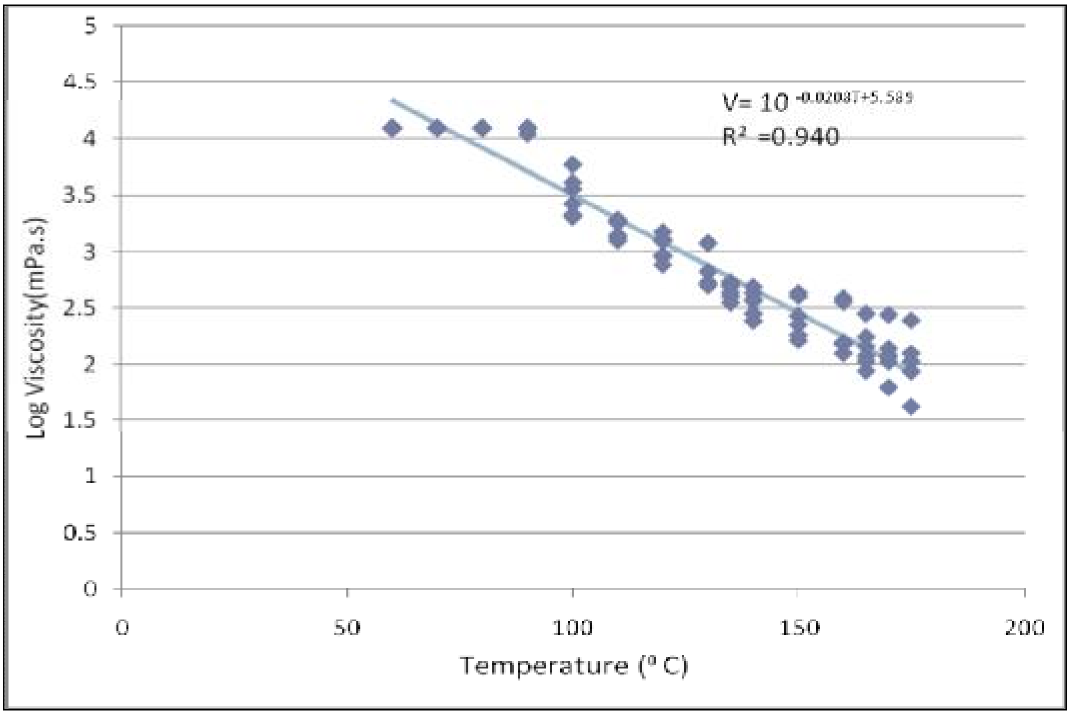


Figure 10 Temperature-Viscosity Relationship for all grades