Influence of Temperature Upon Permanent Deformation Parameters of Asphalt Concrete Mixes

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ABSTRACT

The performance of asphalt concrete pavement has affected by many factors, the temperature is the most important environmental one which has a large effect on the structural behavior of flexible pavement materials. The main cause of premature failure of pavement is the rutting, Due to the viscoelastic nature of the asphalt cement, rutting is more pronounced in hot climate areas because the viscosity of the asphalt binder which is inversely related to rutting is significantly reduced with the increase in temperature resulting in a more rut susceptible paving mixtures. The objective of this study is to determine the effect of temperatures variations on the permanent deformation parameters (permanent strain (εp), intercept (a), slope (b), Alpha and Mu) as well as resilient strain (εr) and resilient modulus (Mr). To achieve this objective, one aggregate gradation with 12.5mm nominal maximum size, two grades of asphalt cements (40-50 and 60-70) brought form Al- Daurah refinery, limestone dust filler has been used to prepare the asphalt concrete mixtures. 30 Marshall specimens were prepared to determine the optimum asphalt cement content. Thereafter, 30 cylindrical asphalt concrete specimens (102mm in diameter and 203 mm in height) are prepared in optimum asphalt cement and optimum ±0.5 percent. The prepared specimens were used in uniaxial repeated load test to evaluate the permanent deformation parameters of asphalt concrete mixes under the following testing temperature (5, 15, 25, 40 and 60°c). The test result analyses appeared that Mr is decrease 51 percent when temperature increased from 5 °c to 25 °c and then decrease 22 percent with further increase in temperature from 25 °c to 60 °c. Also, the Alpha value decreases by a factor of 1.25 and 1.13 when temperature increases from 5 °c to 25 °c and 25 °c to 60 °c, respectively. Finally, statistical models were developed to predict the Alpha and Mu parameters of permanent deformation.

Key word: Asphalt concrete, Marshall, permanent deformation, Alpha, Mu.

تأثير درجات الحرارة على معاملات التشوهات الدائمية للخلطات الإسفلتية

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المستخلص

أداء التبليط الإسفلت يتأثر بعدة عوامل و درجة الحرارة هي واحدة من العوامل المناخية المهمة التي لها اكبر تأثير على أداء السلوك الانشائي لمواد الرصف المرنة .ان السبب الرئيسي للفشل المبكر للطرق هو التخدد ونظرا لطبيعة الاسفلت اللزجة/المرنة فالتخدد يظهربكثرة في المناطق المناخية الحارة لان لزوجة الاسفلت ترتبط عكسيا مع التخدد

الذي يقل بشكل ملحوظ مع ارتفاع درجات الحرارة وبالنتيجة يعطي حساسيه اكبر للتخدد لطبقات التبليط . ان الهدف من هذه الدراسة هو لتحديد تأثير درجات الحرارة المختلفة على معاملات التشوهات الدائمية ومعامل المرونة ولتحقيق هذا الهدف تم اختيار تدرج واحد للركام بمقاس اسمي اقصى(12.5) ملم ونوعين اسفلت ذو اختراق (40-50)(60-70) من مصفى الدورة وقد تم استخدام الحجر الجيري المطحون كمادة مالئة. استخدمت هذه المواد لتحضير(30) نموذج مارشال لغرض تعيين نسبة الاسفلت المثلى، وكذلك تم تحضير(30) نموذج اسطواني من الخرسانة الاسفلتية (102ملم قطر، 203ملم ارتفاع) تم تهيئتها بنسبه الاسفلت المثلى وكذلك نسبة ±0.5% من النسبةالمثلى . استخدم في الاختبار جهاز الحمل المتكرر لتقييم معاملات التشوه الدائمي لخلطات الاسفلت بدرجات حرارة (60,40,25,10,5)°م .نتائج الفحوصات وتحليل النتائج اظهرت ان معامل المرونة يقل بمقدار 51% عند زيادة درجة الحرارة من5 الى25° م ونقصان 22% مع زيادة درجة الحرارة من 25 الى 60°م وايضا قيمة الفا تقل بمقدار 1.25و1.13 عند زيادة درجة الحرارة (5-25)°م و(25-60)°م على التوالي. واخيرا تم تطوير موديلات احصائية للتنبؤ بقيم المعاملات الفا وMu للتشوهات الدائمية.

1. INTRODUCTION

Asphalt concrete which is also called hot mix asphalt HMA due to its relatively high mixing and compaction temperature is a paving material that consists of asphalt cement (by weight of total mix its content range from 4 to 6 percent while by volume the contents range from 8.8 to 13.3 percent from the entire volume of mix) and mineral aggregate. The aggregate skeleton role is to withstand the traffic load whereas the asphalt cement acts as an adhesive material which holds the aggregate skeleton together. The combination of theses materials forms a mixture that has viscoelastic behavior basically due to the vsicoelastic nature of the adhesive asphalt cement. A viscoelastic material combines the behavior of an elastic solid and a viscous liquid. The proportions of the elastic and viscous components depend on the temperature as well as rate of shear. The viscous nature increases and the elastic nature decreases as the temperature increases and shearing rate decreases, and vice versa.

In the structural design of asphalt concrete pavement system, two climatic factors, temperature and moisture, are considered to influence the structural behavior of the pavement materials. Temperature, either their value which influences the stiffness (resilient modulus) and permanent deformation (rutting) parameters as well as low temperature fatigue behavior or their magnitude fluctuation within a day which can affect thermal fatigue cracking distribution within the asphalt concrete layers. Whereas in the other hand, moisture conditions influence the stiffness and strength of the granular pavement material (subbase course and subgrade). Based on aforementioned, the design procedure requires the determination of pavement temperature values within the asphalt concrete layers of pavement in order to characterize the materials of these layers in the laboratory under condition as close as possible to that anticipated in the field. **Albayati, 2006** conducted a local study to predict the temperature within the asphalt concrete layers at a different depth from the pavement surface and for varying air temperatures. The researcher concluded from the developed relationship at a depth of 2cm below the pavement surface, the asphalt concrete could reach to a temperature of 60°c when the air temperature is 50°c**.** In view of this findings, rutting mode of failure perhaps the most probable cause of failure for local pavement since this type of failure is more prevalent under hot climate condition. The permanent deformation (rutting) is defined as the progressive accumulation of plastic strain in each layers of the pavement system that occurs under each load repetitions. Excessive permanent deformation will eventually result in reduction of pavement serviceability due to loss in riding comfort**, Bazlamit, 2005.**

Rutting is more pronounced in hot climate areas because the viscosity of the asphalt binder which is inversely related to rutting is significantly reduced with the increase in temperature resulting in a more rut susceptible HMA mix. **Fig.1** shows the effect of temperature on log asphalt viscosity for a wide range of asphalt cement grades, **Puzinauskas, 1979**. From this Figure, it is obvious that the viscosity of asphalts vary from less than one poise to more than one trillion poises. Within such 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 .Thus, the gradually changing curvature of plots in **Fig.1** indicates that the viscosity of asphalt tends to change more rapidly at low temperatures, and such change becomes far less pronounced at higher temperatures when the viscous behavior is predominant.

Beside the asphalt consistency which can be characterized by viscosity grading, penetration grading or performance grading, the asphalt cement content also has an effect on the permanent deformation of asphalt concrete. Based on the indirect tensile strength test for dimetral Marshall specimens**, Zhaw, 2011,** concluded that the asphalt cement content variation evaluated in his study has a significant effect on the rutting performance of the mixtures. The mixes with lower binder content showed better rutting performance, he also stated that even deviations within a small range (±0.25 percent) of binder content could significantly have an effect on rutting performance.

Based on the aforementioned preface, it can be postulated that the temperature have a significant effect on the rutting mode of distress in asphalt concrete paving materials, also the asphalt cement types (grades) which control the viscoelastic nature of mixture and asphalt cement content have some specific relations to this type of distress. Therefore, a need has been a rise to conduct a laboratory tests at temperatures approximately close to those which may be encountered in field under local environmental conditions after considering the type and asphalt cement content in consideration.

2. MATERIAL CHARACTERIZATION

The materials used in this study are asphalt cement, aggregate and mineral filler. The properties of these materials were evaluated using routine type of tests and the obtained results were compared with the SCRB **R/9, 2003,** specification requirements. All the materials used are locally available and widely employed in the pavement construction in the Iraq.

2.1 Asphalt cement

Two types of asphalt cement were employed with penetration grade (40-50) and (60-70) obtained from Al-Durra refinery, south-west of Baghdad. The physical properties of these binders are presented in **Table 1**.

2.2 Aggregate

The aggregate used in the laboratory work is crushed quartz from Al-Nibaie quarry which is widely used for asphalt mixes in Baghdad city .The coarse and fine aggregate used in this work were sieved and recombined in the proper proportion to meet the wearing course gradation type III A as required by SCRB specification, **SCRB R/9, 2003**. The gradation of aggregate with a nominal maximum size of 12.5mm (1/2inch) is shown in **Table 2** and the selected gradation with specification limits are presented in **Fig.2**. The physical properties of aggregate used are shown in **Table 3**.

2.3 Filler

The mineral filler is a non-plastic material passing sieve No.200 (0.075mm). The filler used in this work is limestone dust obtained from Amanat Baghdad asphalt concrete mix plant; its source is the lime factory in Karbala Governorate. The physical properties of the filler are presented in **Table 4**.

3.EXPERIMENTAL WORK

The experimental work was started by determining the optimum asphalt content for all the asphalt concrete mixes using Marshall design method and thereafter cylindrical asphalt concrete were prepared to evaluate the permanent deformation parameters using uniaxial repeated loading.

3.1 Marshall mix design

Standard method of Marshall as in (**ASTM D-1559**) specifications was used to find the optimum asphalt content for compacted asphalt concrete specimens. Marshall test was conducted on a cylindrical specimen of 102 mm (4 inch) diameter by 63.5 mm (2.5 inch) height. The optimum asphalt content of the mix (shown below in **Fig.4** and **Fig5**) was calculated as the numerical average of the values of asphalt contents corresponding to the following:

- Asphalt content at maximum unit weight
- Asphalt content at maximum stability
- Asphalt content at 4% air voids

3.2 Uniaxial repeated load

The dimensions of the cylindrical specimen used in this work were 102 mm (4 inch) in diameter and 203 mm (8 inch) in height. The axial compressive repeated loads test were conducted using the pneumatic repeated load system (PRLS) developed by, **Albayati, 2006** (shown below in **Fig.3**) applied in the form of rectangular wave with a constant loading frequency of 60 cycles per minute. A heavier sine pulse of 0.1 sec load duration and 0.9 sec rest period was applied over test duration of approximately 3 hour, history loading results in approximately10,000 load cycles or when the specimen fractured. In these tests ,repetitive compressive loading with a stress level 20 psi and the uniaxial repeated loading tests were conducted at five temperature (5°,15°,25°,40°,and60°c).

The permanent strain (Ɛp) is calculated by applying the following equation:

$$\mathcal{E}p = \frac{pd \times 10^6}{h} \qquad \textbf{(1)}$$

where :
εp = axial permanent microstrain,(in/in)
Pd = axial permanent deformation and
H= specimen height.

The resilient deformation is determined at the load repetition
of 200th , resilient strain (εr) is found according to following equation:

$$\mathcal{E}r = \frac{Rd}{h \times 10^6} \qquad \textbf{(2)}$$

εr = axial resilient microstrain,(in/in)
Rd = axial resilient deformation and

$$Mr = \frac{\sigma}{\mathcal{E}r} \qquad \textbf{(3)}$$

where :

M_r= resilient modulus (psi)
σ = repeated axial stress (psi)
ε_r= axial resilient strain (in/in) , **Huang, Y. H. 2004**.

The permanent deformation test results for this study are represented by the linear log-log relationship between the number of load repetition and the permanent microstrain with the form shown in Eqn.(4) below which is originally suggested by **Monismith et al.,1975 and Barksdale, 1972.**

$$\mathcal{E}\ p = aN^b \qquad \textit{(4)}$$

where :
p = permanent strainƐ

N = number of stress applications
a = intercept coefficient
b = slope coefficient

4. TEST RESULTS AND DISCUSSION

4.1 Marshall properties

To satisfy the requirements of the experimental design, Marshall mix design procedure was performed according to AI`s manual series No.2 (AI, 1981) using 75 blows of the automatic Marshall compactor on each side of the specimen which represent high tire pressure applied to roadway. Based upon this method, the optimum asphalt content is determined by averaging the three values shown below:

- Asphalt content at maximum unit weight.
- Asphalt content at maximum stability.
- Asphalt content at 4% air voids.

For each grade of asphalt cement, 15 Marshall specimens were prepared with a constant increment of 0.3 percent of asphalt cement content (3 replications for each content). The selected asphalt contents to perform the Marshall mix design were (4.3, 4.6, 4.9, 5.2 and 5.5) percent by weight of total mix, these values belong to the mix type IIIA of wearing course.

Fig.4 and **Fig.5** show the plots of the Marshall data for each type of asphalt cement, from these figures the calculated optimum asphalt content is 5 percent for asphalt cement grade (40-50) and 4.6 percent for grade (60-70).

4.2 Effect of temperature

The analysis of the results begins by identifying “sort” variable: i.e., temperature. Therefore, the entire data file is sorted according to test temperature. For example, to clearly show the effect of temperature on both the plastic and elastic properties the entire data is sorted by test temperatures and the mean values of permanent deformation parameters are calculated as presented in **Table 5**.

As may be seen from **Fig.6**, the permanent strain, intercept, slope, resilient modulus, alpha(1-b) and Mu($a^{\times}b/\varepsilon r$) are substantially influenced by temperature. For example, when the temperature increases from 5 to 25°C, the permanent strain and intercept increases by a factor of 6.77 and 1.55, respectively. The corresponding reduction in resilient modulus (Mr) is 51 percent. Further increase in the temperature from 25 to 60°C, results in permanent strain increases by a factor of 6.27 whereas the intercept by a factor 2.57. This findings has the implication that the temperature effects on both the permanent strain and intercept are not linearly varied, i.e., the highest the temperature the more the rate of plastic deformation.

As shown by the values in **Table 5** and **Fig.6** it appears that the temperature influences the slope and the resilient modulus in essentially the same manner.

Furthermore, increase in the temperature from 25 to 60°C, results in the resilient modulus decrease by 22 percent whereas the slope increase by a factor 1.85.

When the temperature increase from 5 to 25°C, Mu increase by a factor of 1.7 and Alpha decreased by a factor 1.25, whilst when the temperature increase from 25 to 60°C Mu increase by a factor of 1.13 and Alpha decrease by a factor 2.12 . These findings besides that related to permanent strain and intercept confirm that the rutting mode of failure is enhanced in asphalt concrete pavement in hot summer temperature.

4.3 Effect of asphalt cement grade

Fig.7 shows the change in resilient modulus as well as the plastic deformation parameters with the variation of asphalt cement type. It can be seen from the presented data in Table 6, the asphalt grade has higher influence on the plastic strain as well as the intercept coefficient than other parameters. The variation of resilient modulus, slope and Mu values changes also with asphalt cement type but to lesser extent. For example, the average value of resilient modulus corresponding to asphalt grade 40-50 is almost 1.13 times the value for asphalt grade 60-70 at 5°C. The same is applicable to the permanent strain which is 1.85 times the value for asphalt grade 40-50 at the same degree.

4.4 Effect of asphalt cement content

Based on the data graphically shown in **Fig.8** and **Fig.9**, it appears that the examined asphalt contents have influence on the plastic response of the material. The higher plastic strain is associated with the increases in asphalt content from 4.5 to 5.5 and from 4.1 to 5.1 percent asphalt for AC (40-50) and AC (60-70) respectively. From **Fig.8** it can be seen that the increment of 1 percent in the asphalt content type (40-50) beyond 4.5 percent will result in 8 percent decrease in alpha value and 35 percent decrease in mu value. Whereas for the asphalt cement type (60-70) that shown in **Fig.9** the change in alpha and mu values are more sensitive for the change in asphalt content, the increasing in asphalt content from 4.1 percent to 5.1 percent resulted in a reduction in alpha value about 12 percent as well as in mu value about 52 percent. from the aforementioned findings, one can be concluded that the asphalt content variations have more effect on permanent deformation parameters alpha and mu when the asphalt cement grade is soft (60-70) as compared to relatively hard grade type (40-50). The resilient modulus decreases approximately 16 percent when there is an increment one percent beyond the 4.5 percent for AC 40-50, for the AC 60-70 the increment of one percent beyond the 4.1 percent resulted in a 15 percent reduction in the resilient modulus value.

4.5 Combined Effect of Variable on Rutting Parameters

Table 7 summarizes the trends in the observed data presented in the preceding sections. This table provides a qualitative description of the influence of the temperature and asphalt cement (type and content) on the resilient modulus and plastic strain as well as the permanent deformation parameters.

As shown in **Table 7**, the resilient modulus, M_r, is heavily dependent on temperature; also it is moderately dependent on asphalt content.

The plastic strain, ε_p , is very highly dependent on temperature, The asphalt content virtually have low effects on the plastic strain of asphalt concrete which is in turn moderately effected by asphalt grade.

The intercept coefficient "a", which is directly related to rutting, is highly affected by temperature, and moderately dependent on asphalt properties (grade and content). Similarly, the slope coefficient "b" or alpha (alpha=1-b) is highly dependent on temperature and to a lesser degree on asphalt properties (grade and content).

Mu appears to be influenced strongly by temperature and asphalt content, asphalt grade have moderate effect on Mu. **Fig.10** through **Fig. 15** show the histogram of collective effects of temperature, asphalt content and asphalt grade on permanent deformation parameters as well as resilient modulus.

4.6 Permanent Deformation Parameters Predictive Models:

Presented in this section, are the statistical models attempted for the permanent deformation parameters alpha and Mu. Stepwise regression technique is used for the purpose of model development using statistical software (SPSS version 19). It's shown that Mu can be predicted with moderate accuracy in terms of the variables citied in this research (R^2=0.85). In contrast to alpha, which is predicted excellently in terms of the test conditions and asphalt cement properties (R^2=0.982). The developed models are:

$$Alpha = -0.009T+0.167Ln\eta-0.06AC$$

$$Mu=0.786-1.211\sqrt{AC}+0.242\sqrt{T}-0.021T+0.256Ln\eta$$

where:

T = test temperature in degree centigrade (°C)
η = viscosity at 135°C (cP)
AC= Asphalt content (percent by weight of total mix)

5.CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

According to the work presented in this research and within the limitation of test program, type of testing tools and type of materials used, the following main points are concluded:

- The asphalt concrete mixture with resilient modulus (Mr) value of 328036 psi at 5°C temperature loses approximately 88 percent of its strength in term of Mr when there is a rise in temperature up to 60° C. The variation in Mr value with temperature was shown to have non-liner trend, the asphalt concrete mix lost about 51 and 22 percentages of its strength when the temperature changed from 5°C to 25°C and from 25°C to 60°C, respectively.

- The results of permanent deformation test support the allegation of "the higher the temperature the more the rate of plastic deformation". When the temperature increases from 5 to 25°C, Mu increases by a factor of 1.7 and Alpha decreases by a factor 1.25, whilst when the temperature increases from 25 to 60°C Mu increases by a factor of 1.13 and Alpha decreases by a factor 2.12.
- The increment of 1 percent in the asphalt content type (40-50) beyond 4.5 percent resulted in 8 percent decrease in alpha value and 35 percent decrease in mu value. Whereas for the asphalt cement type (60-70) the increasing in asphalt content from 4.1 percent to 5.1 percent resulted in a reduction in alpha value about 12 percent as well as in mu value about 52 percent
- Models were developed to predict the permanent deformation parameters alpha and Mu

$$\boldsymbol{Alpha} = -0.009T+0.167\mathrm{Ln}\eta-0.06AC \qquad (R^2=0.982)$$

$$\boldsymbol{Mu}=0.786-1.211\sqrt{AC}+0.242\sqrt{T}-0.021T+0.256\mathrm{Ln}\eta \qquad (R^2=0.85)$$

where:

T = test temperature in degree centigrade (◦C)
η = viscosity at 135◦C (cP)
AC= Asphalt content (%)

As an example when: T =25 C ,η = 498 cP , AC= 4.5 percent by weight of total mix , Alpha =0.64 and Mu =0.642

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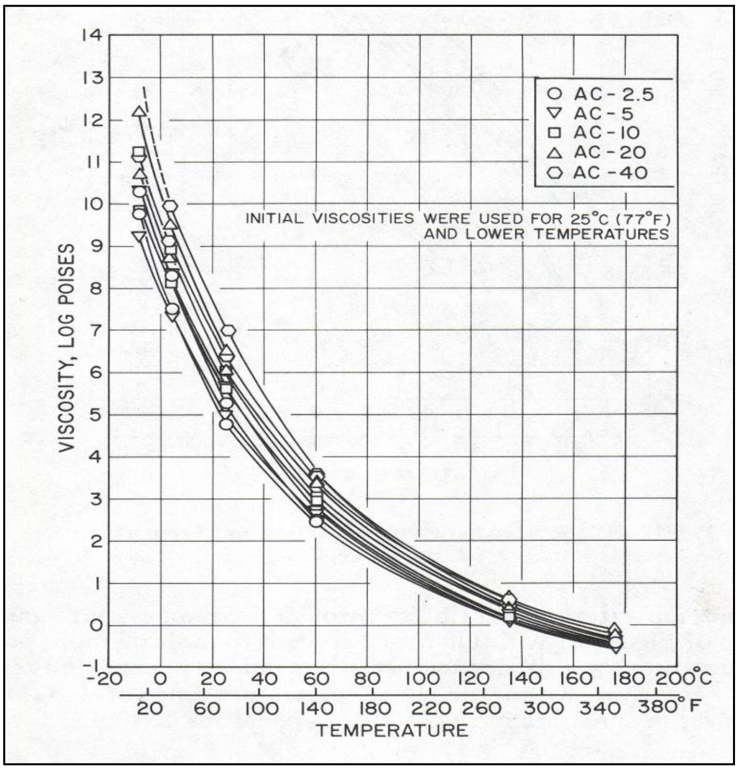

Figure 1. Relationship between viscosity and temperature for asphalt cements, Puzinauskas,1979.

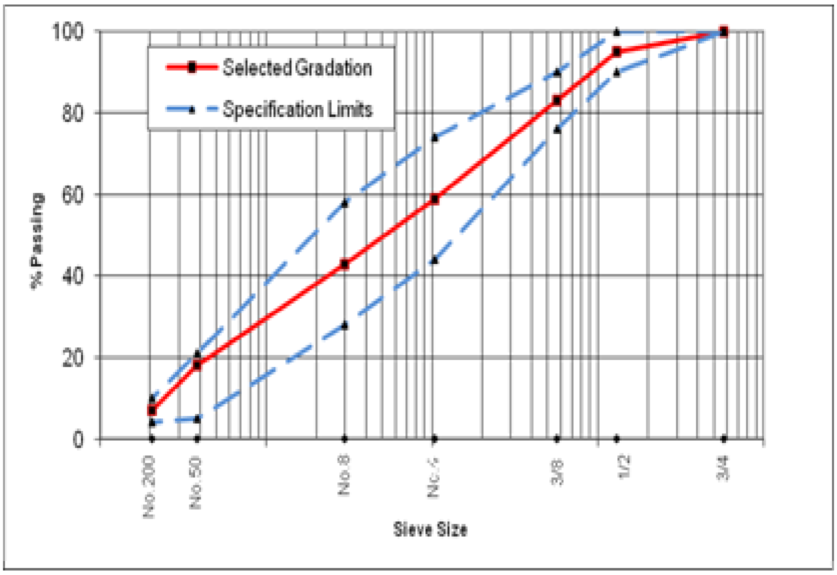

Figure 2. Aggregate Gradation Curve.

Figure 3. Photograph for PRLS.

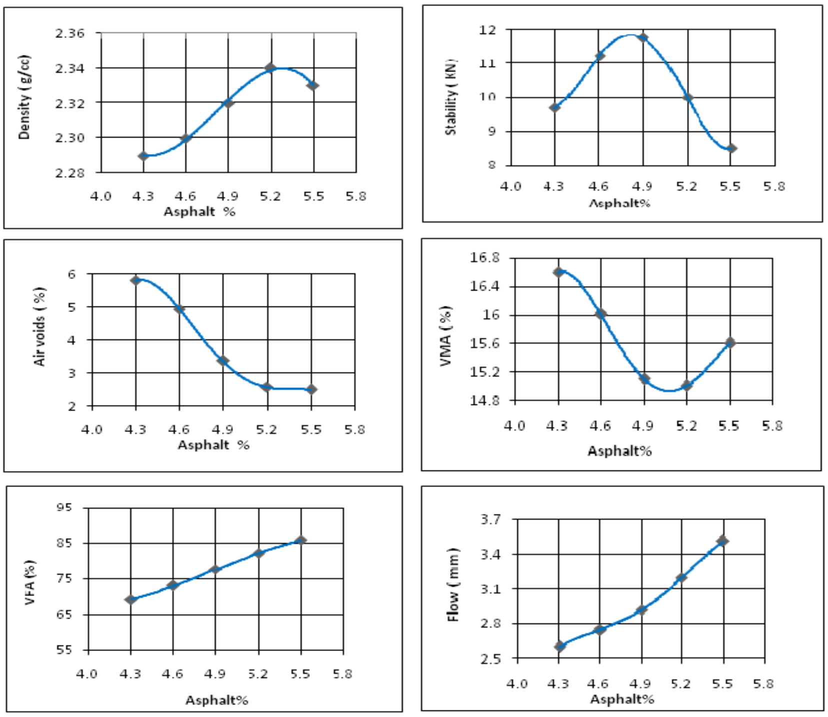

Figure 4. Marshall plots for mixtures with AC (40-50).

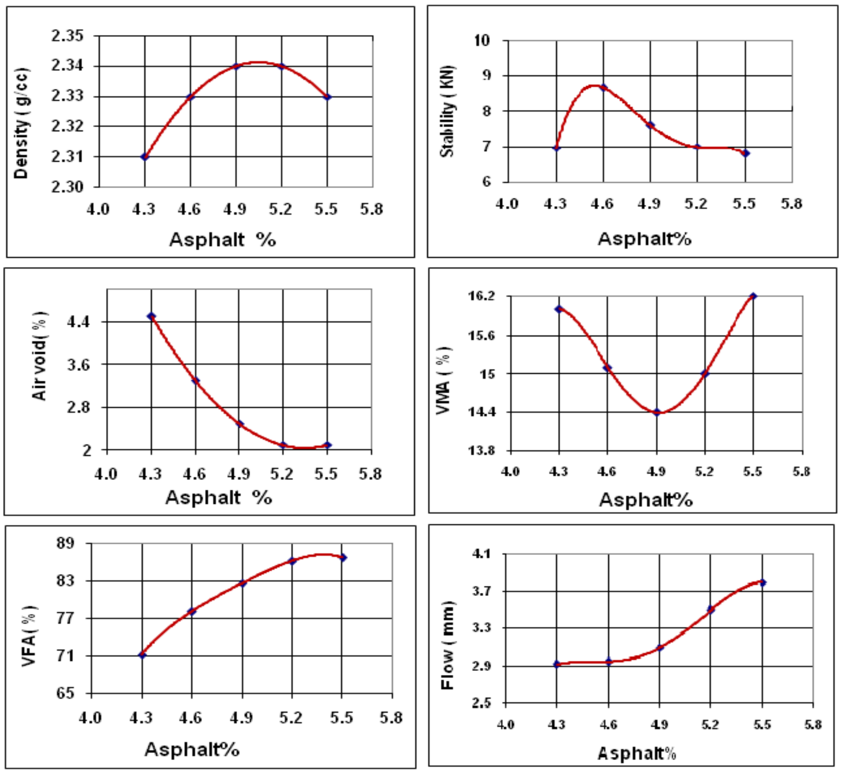

Figure 5. Marshall plots for mixtures with AC(60-70).

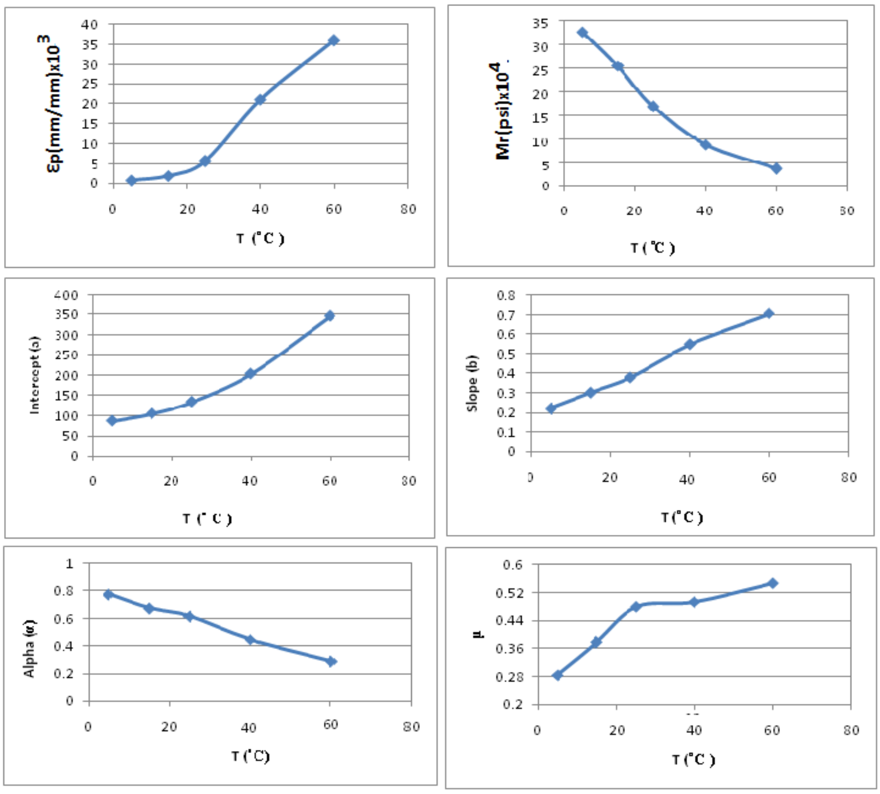

Figure 6. Effect of temperature on permanent deformation parameters.

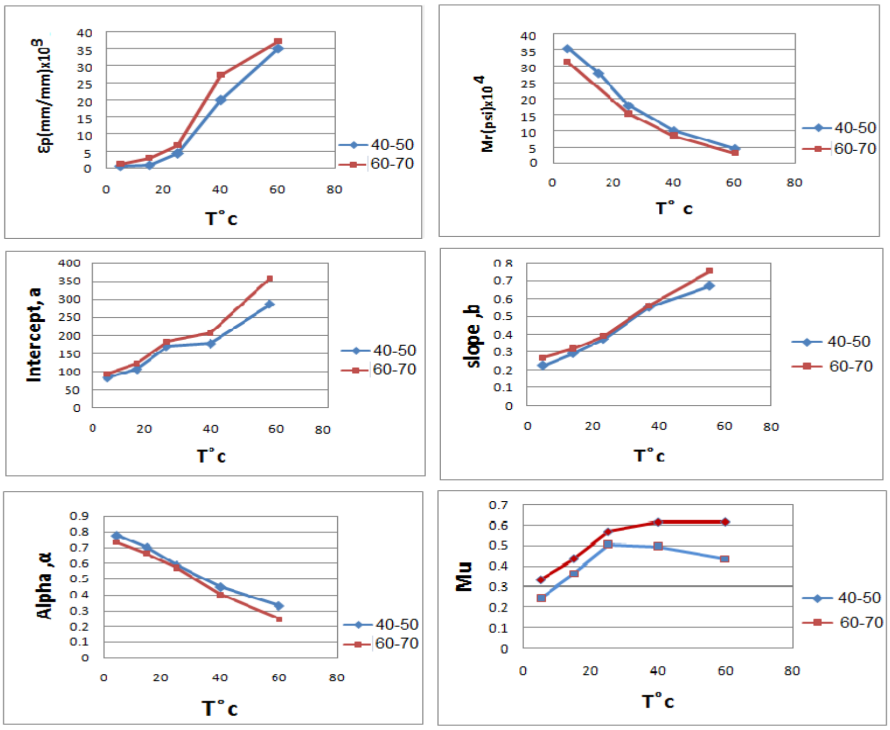

Figure7. Effect of Asphalt Grade on Permanent Deformation Parameters.

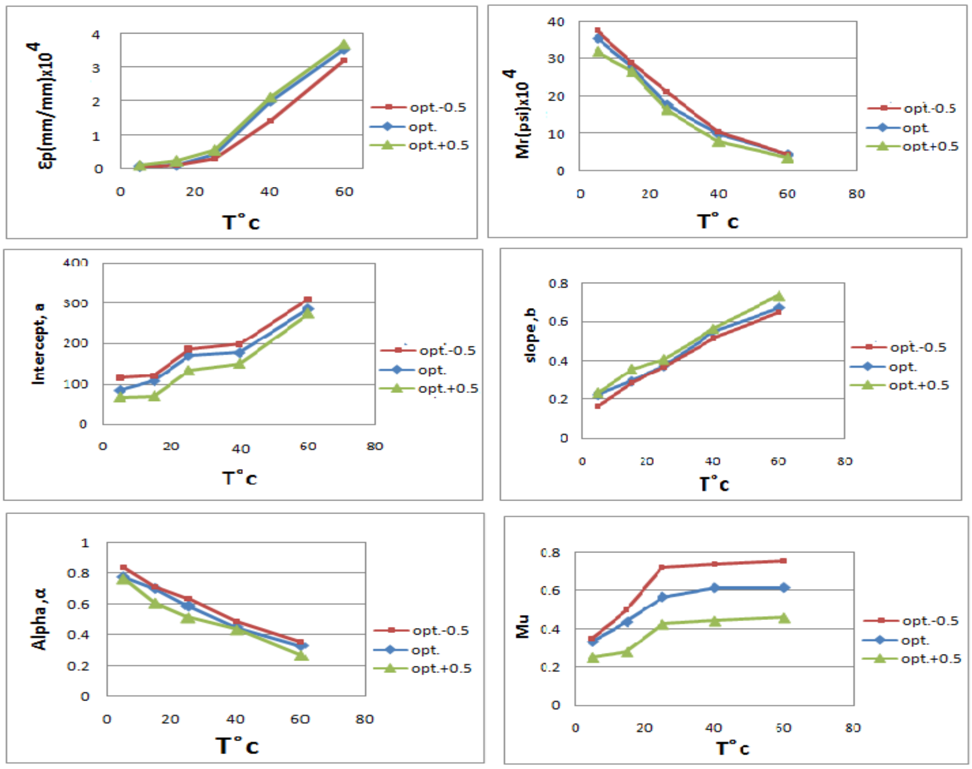

Figure 8. Effect of asphalt content on permanent deformation parameters for AC (40-50).

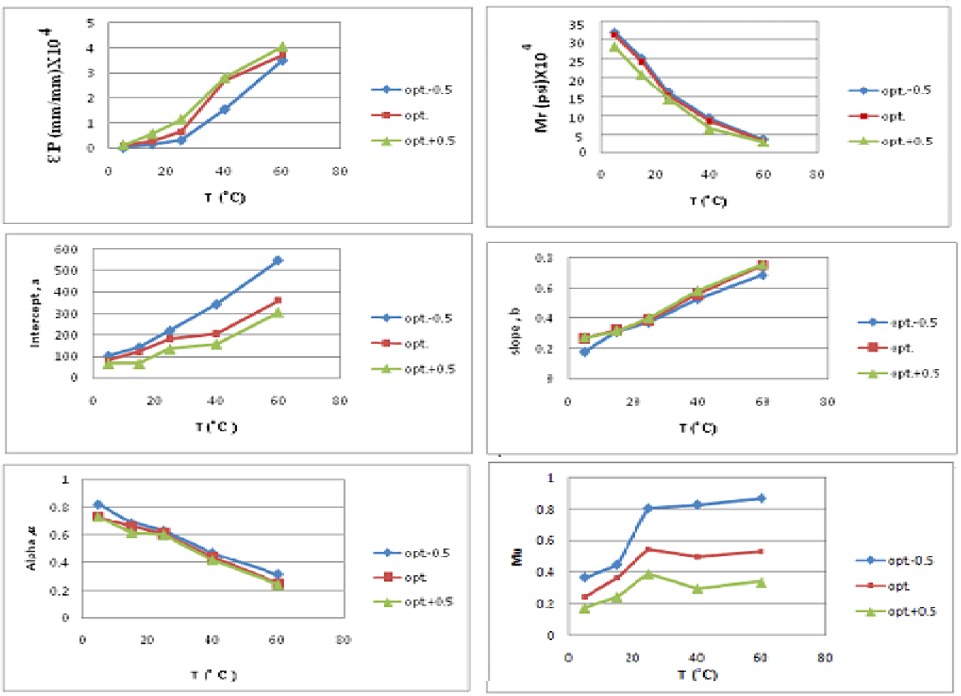

Figure 9. Effect of asphalt content on permanent deformation parameters for AC (60-70).

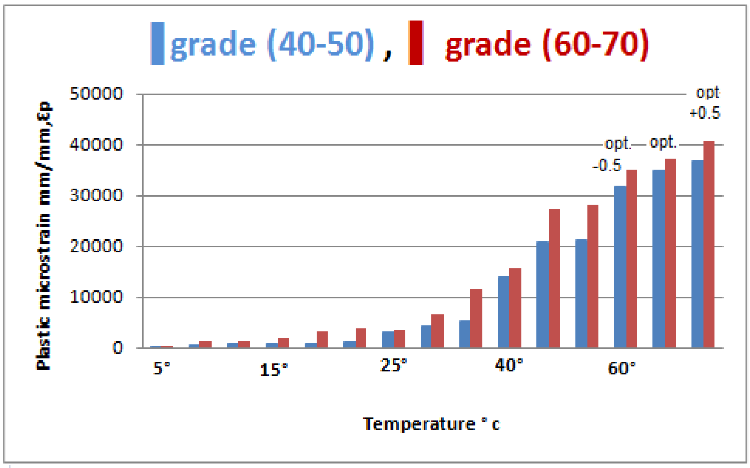

Figure 10. Effect of temperature, asphalt Content, asphalt grade on plastic microstrain.

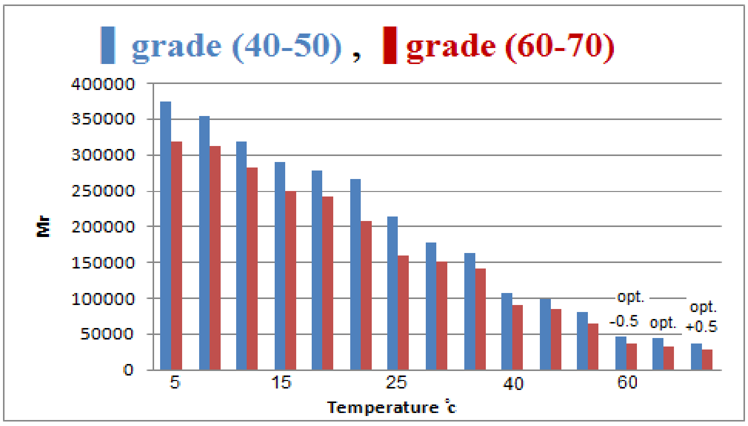

Figure 11. Effect of temperature, asphalt content, asphalt grade on Mu.

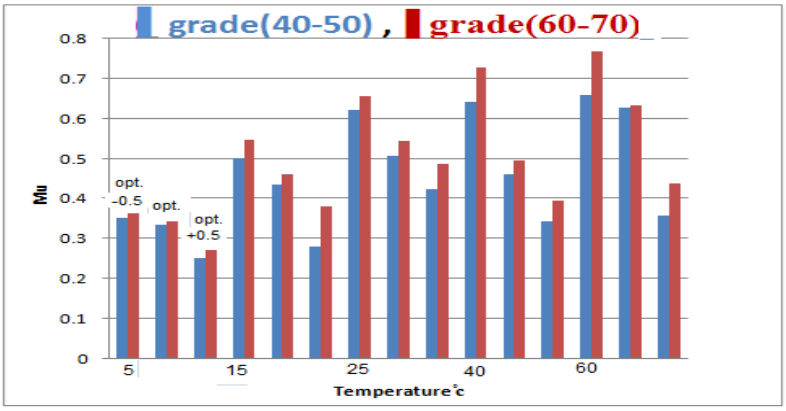

Figure 12. Effect of temperature, asphalt content, asphalt grade on Mu.

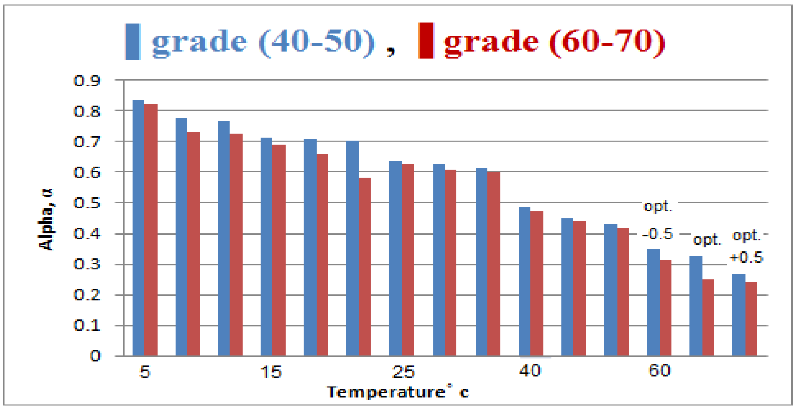

Figure 13. Effect of temperature, asphalt content, asphalt grade on alpha (α).

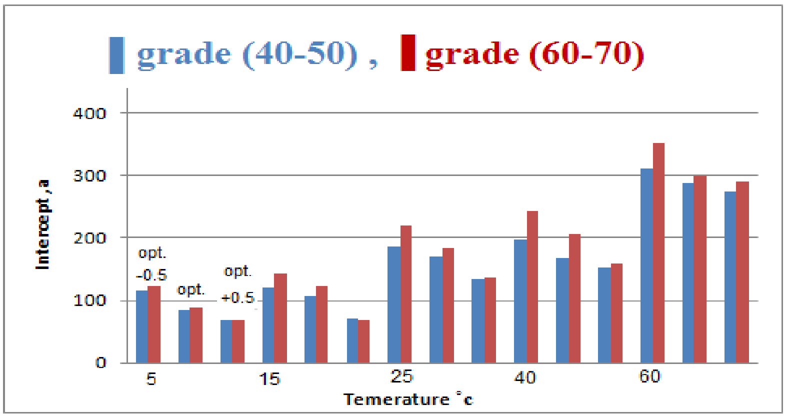

Figure 14. Effect of temperature, asphalt content, asphalt grade on intercept (a).

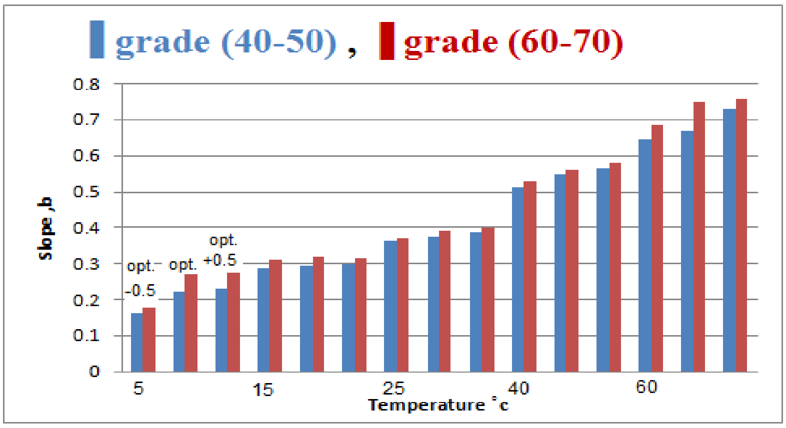

Figure 15. Effect of temperature, asphalt content, asphalt grade on slope (b).

Table 1. Physical properties of asphalt Cement (Baghdad University Lab).

Test	Test condition	ASTM Designation	Units	Asphalt Cement			
				40-50	SCRB specification	60-70	SCRB specification
Penetration	**100 gm, 25 °C , 5 sec., 0.1 mm**	**D5**	**1/10 mm**	**44**	**40-50**	**63**	**60-70**
Kinematic viscosity	**135°C**	**D2170**	**Cst.**	**433**	**Min 400**	**318**	**Min 300**
Specific Gravity	**25 °C**	**D70**	**-----**	**1.03**		**1.02**	
Ductility	**25 °C , 5 cm/min.**	**D113**	**cm**	**>100**	**>100**	**>100**	**>100**
Flash Point	**----**	**D92**	**°C**	**234**	**232 min**	**245**	**232 min**
Softening Point	**(4±1) °C /min.**	**D36**	**°C**	**48**		**46**	
After Thin Film Oven Test							
Penetration of Residue	**100 gm, 25 °C , 5 sec., 0.1 mm**	**D5**	**1/10 mm**	**29**		**45**	
Ductility of Residue	**25 °C , 5 cm/min.**	**D113**	**cm**	**53**	**>25**	**75**	**>25**
Softening point (Ring & ball) °C	**(4±1) °C /min.**	**D36**	**°C**	**50.6**		**49**	

Table 2. Surface or wearing course type.

Opening (mm)	Size(in)	passing by weight of total % aggregate + filler	Specification limits (SCRB-R9/3)
19	3/4	100	100
12.5	1/2	95	90-100
9.5	3/8	83	67-90
4.75	No.4	59	44-74
2.36	No.8	43	28-58
0.3	No.50	18	5-21
0.075	No.200	7	4-10
Asphalt Cement (% weight of total mix)		5	4-6

Table 3. Physical properties of aggregates (Baghdad University Lab).

No.	Laboratory Test	ASTM Designation	Test Results	SCRB Specification
Coarse Aggregate				
1	Apparent Specific Gravity	C-127	2.678	-
2	Bulk Specific Gravity	C-127	2.61	-
3	Water Absorption,%	C-127	0.21	-
4	Fractured pieces,%	-	96	90 Min.
5	Percent Wear (Los Angeles Abrasion),%	C-131	17.5	30 Max.
6	Soundness Loss by Magnesium Sulfate solution,%	C-88	3.83	18 Max.
Fine Aggregate				
1	Apparent Specific Gravity	C-128	2.683	-
2	Bulk Specific Gravity	C-128	2.621	-
3	Water Absorption,%	C-128	0.4	-
4	Sand Equivalent,%	D-2419	68.45	45 Min.

Table 4. Physical properties of mineral filler (Baghdad University Lab).

Property	Test Result
Specific Gravity	2.72
%Passing Sieve No.200 (0.075 mm)	96

Table 5. Mean values of permanent deformation parameters for different temperatures.

T(℃)	Mr (psi)	ε_p (mm/mm)	a	b	α	μ
5	328036	848.958	86.8617	0.22317	0.77683	0.28538
15	256205	1989.58	105.462	0.30417	0.67583	0.37759
25	168303	5755.21	134.983	0.38183	0.61817	0.48122
40	87904.8	21197.9	204.233	0.5505	0.4495	0.49441
60	37060.1	36125	347.717	0.70817	0.29183	0.5476

Table 6. Mean value of permanent deformation parameters with the variation of asphalt cement grade.

	Ɛp		**Mr**		**a**		**b**		**α**		**μ**	
T °c	**40-50**	**60-70**	**40-50**	**60-70**	**40-50**	**60-70**	**40-50**	**60-70**	**40-50**	**60-70**	**40-50**	**60-70**
5	656.3	1218.75	355555	313333	83.75	94.02	0.224	0.27	0.776	0.73	0.24198	0.333
15	1000	3062.5	278260	242973	107.1	122.6	0.293	0.321	0.7	0.659	0.36157	0.436
25	4344	6687.5	177777	152381	170.9	183.1	0.374	0.391	0.586	0.569	0.50546	0.568
40	19875	27187.5	100000	85333.3	177.6	207.5	0.551	0.56	0.449	0.4	0.49579	0.615
60	35125	37187.5	44444	32000	286.9	359.1	0.671	0.752	0.329	0.248	0.43207	0.616

Table 7. Influence of temperature, mix components on strain and permanent deformation parameters for both grade.

Predictor variable	**Criterion variable**					
	Resilient modulus (M_r)	**Plastic strain (ε_p)**	**Intercept coef. (a)**	**Slope coef. (b)**	**Alpha (α)**	**Mu (μ)**
Temperature	High	Very high	High	High	High	High
Asphalt Content	Moderate	Low	Moderate	Low	Low	High
Asphalt Grade	Low	Moderate	Moderate	Low	Low	Moderate