AMERICAN Journal of Engineering, Mechanics and Architecture
Volume 2, Issue 12, 2024 ISSN (E): 2993-2637

Prediction Models for Compaction and Mixing Temperatures for Asphalt Mixture modified with SBS

Ethar K. Shaker
Assistant Lecture, Civil. Eng. Dept. University of Thi-qar, Nasiriya, Iraq

Abstract: The application of SBS polymer (styrene butadiene styrene) to the mixture to improve the performance results in necessary high temperatures that negatively impact the characteristics of the mixture modified with SBS. The purpose of the study is to forecast models for the compaction temperature and mixing temperature of the mixtures that modifying with SBS and evaluates the impact of filler kind, asphalt content and styrene butadiene styrene content on the temperatures. (3%, 4%and 5%) of the asphalt's weight cement is produced of styrene butadiene styrene and asphalt cement grade (40-50). Asphalt mixtures were tested using two methods: compaction of asphalt mixture test and mix coating test. According to the outcomes of experimental testing, there is a negative association between the asphalt content and the mixing and the compaction temperatures. However, there is a positive association between the content of SBS and the mixing and compaction temperatures. The modified asphalt blend containing lime stone dust has produced high mixing temperature and compaction temperature than the mixture containing Portland cement. In HSRV-O approach the compaction and mixing temperatures of modified bitumen with styrene butadiene styrene decreased in contrast to the super pave method while HSRV-E method showed even greeter decreases.

Keywords: SBS-polymer, mixing and compaction temperatures, superpave, Brookfield.

1-INTRODUCTION

The bitumen's viscosity affects the mixing and compaction procedures. A Fluid's internal friction is measured by its viscosity. During mixing it evaluates the quality of the aggregate coating and during compaction, the ability to combine particles to create a cohesive , resistant, durable with a specified air void content during compaction (Read & Whiteoak, 2003; Yildirim, Solaimanian, & Kennedy, 2000). If the viscosity is too high, it will be very difficult to get the desired density, and the specimen cannot be mixed and compacted properly. It will be difficult to achieve the required density and the specimen cannot be compacted and mixed if the viscosity of asphalt high. Low viscosity might make it difficult to distribute asphalt within the aggregate structure. Modified bitumen was considered Newtonian flow which viscosity is influenced by the rate of shear. Traditional equiviscous methodology ASTM D2493 was used to establish HMA the temperatures of mixing and compaction for unmodified binders and identify very high temperature which can degrade bitumen-polymer bonds and increase energy usage (Micaelo, Santos, & Duarte, 2012). Therefore, other methods are used to find acceptable temperatures.

(DeSombre, Newcomb, Chadbourn, & Voller, 1998) presented the (SSF) the steady shear flow test, technique based on measuring viscosity using dynamic shear rheometer at warm temperatures (76 ºC to 94 ºC).target ranges for viscosity are 0.17±0.02 Pa.sec and 0.35±0.03 Pa.sec .

(Yildirim et al., 2000) "Presented the idea of HSRV-O (High shear rate viscosity original), after computing the shear rate inside the superpave compactor, which was 487s^{-1} and rounded to 490s^{-1}. It stated that utilizing the same viscosity ranges (0.17±0.02 Pa.s and 0.28±0.03 Pa.s), mixing and compaction temperatures should computing using 490s^{-1} rather than 6.8^{-1}".

(Bahia et al., 2001) developed the concept of Low Shear Rate Viscosity (LSRV) by defining the shear rate of 0.001 s^{-1}.

(Khatri, Bahia, & Hanson, 2001) low shear rate viscosity is more crucial for the stage of critical compaction in the superpave compactor, which is recommended for calculation the temperatures of mixing and compaction of modified bitumen. The target viscosity ranges for compaction and mixing were transformed to 6±0.6 pa.s and 3±0.3 pa.s. The approach was known as ZSRV-O, or (zero shear rate viscosity origina)l.

(Reinke, 2003)"introduced (SSF) the steady shear flow test ,a technique based on viscosity measurements utilizing a dynamic shear rheometer at warm temperatures (76 ºC to 94 ºC) .range of viscosity are 0.17±0.02 Pa.s and 0.35±0.03 Pa.s".

(Yildirim, Ideker, & Hazlett, 2006) using a new range for viscosity (0.275-0.55) pa.s and a greater shear rate of 500s-1 lead to lower compaction and mixing temperatures (13-52) ºC compared to the conventional method. This method is called high shear rate viscosity (Evolution) or HSRV-E.

The study aims to evaluate the impact of factors on mixing and compaction temperatures, developing statical models to predict these temperatures and to compare temperatures calculated with different method.

2-MATERIALS

Tests from ASTM standard were used to evaluate the materials and the SCRB R9 specification requirements were compared with them.

2-1 asphalt binders

Asphalt cement AC (40-50) was used in this study. The physical characteristics of asphalt are shown in table (2)

2-2 aggregates

The aggregate used in this work was chosen from the al-Nibaie Quary. Laboratory experiments were used to determine the characteristics of gravel .table 1 illustrated the chemical and physical properties for gravel.

2-3 filler

In this work, two kinds of filler are utilized:

1. Lime stone dust from Karbala

2. Portland cement which is purchased from market

Table (4) and (5) display the physical characteristics of lime stone dust and cement

2-4 additives

SBS polymer (styrene-butadinene-styrene) was the additives used in this research. It was supplied by the state company for mining industries and the ministry of industrial and materials .plate (1) demonstrates the SBS used in this study. Table (3) illustrates the properties of SBS polymer, which added to asphalt at 5%, 4%and 3% by weight.

3- LABORATORY TESTS

3-1 design of a superpave mixture

After ensuring that the (aggregate, asphalt binder and mineral filler)is in accordance with specifications, the asphalt mixture was designed by mixing the materials, then the specimens are prepared for the compaction operations in the SGC in compliance with ASTMD 698.figure(1) shows that in 4% air voids, the design asphalt content was established. The optimum asphalt content was 5% by the total weight of the sample. The procedures for preparing superpave gyratory compactor samples was illustrate in plate 2.

3-2 Asphalt test

The viscosity values of the modified bitumen are measured using a Brookfield viscometer at135 °C and 165°C (ASTM D 4402- AASHTO TP48**.** Using spindle No.27, the viscosity readings were plotted on viscosity versus the rate of shear diagram ranges from 1.7 to 34 s^{-1} with corresponding rpms from (5 to 100). The relationships between them were plotted for 5%, 4% and 3%, SBS. the rate of shear inside SGC is represented by the graph's extrapolation to the rate of shear equal to 500 s^{-1} (Yildirim, 2000; Yildirim et al., 2000). The model of power-law for Ostwald –de waele, the most popular model, was used to compute the viscosity at 500 s^{-1}. The model's equation is provided:

$\eta = k\,\gamma^{n} - 1$ …….. (1)

Where:

n: the pseudeoplacticity that measure by the power-law index

K: the polymer s consistency index.

γ: shear rate.

η: The viscosity.

The value is computed using the power model equation as illustrated below where y refers to log –log viscosity (cp) and x for log temperature (Rankine)

Viscosity measurement at 135 °C for 3% sbs modified bitumen

$$y = 1377.71 * x^{0.909-1}$$

$$= 1377.71 * (500)^{-0.091} = 782.62cp$$

Viscosity measurement at 165 °C for 3% sbs modified bitumen

$y = 525.795 * x^{0.855-1}$

$$= 525.79 * (500)^{-0.145} = 213.53cp$$

In the same way the viscosity was calculated for 4and 5% SBS at 135 and 165 °C. The viscosity at 135°C and 165°C for 3%, 4%, and 5% shows in table (6).

Computing modified bitumen temperatures

The ranges for viscosity of 0.28±0.03 pascal.sec for compaction and 0.27± 0.02 pascal.sec for mixing were used to plot the viscosity against temperature relationship by using viscosity at two temperature 135 and 165 °C. Figure (2) and (3) represent the compaction and mixing temperature for modified bitumen at rate of shear equal to 6.8 and 500 s^{-1}.

Adjusted Viscosity Ranges for Compaction and Mixing

It is recommended to increase the viscosity value to (0.275±0.03 Pascal.sec) and (0.550±0.06 Pascal.sec) since it does not match the equiviscous assumption (Micaelo et al., 2012; Yildirim et al., 2006). As shown in figure (4), this techniques is called as "the High Shear Rate Viscosity (evolution), HSRV-E"

3-3 Asphalt mixture test

In order to analyze how bitumen consistency and temperature affected lubrication, aggregate covering, and the resistance of shear through compaction, asphalt mixture tests were conducted. As illustrated in table (7), 72 specimens in various conditions were used for each asphalt test, including the mix coating and compaction tests.

Mix coating test

The percentage of coated aggregate test findings for samples under various conditions examined using the ross count method are summarized in table (8).plate (3) shows an evaluation of the percentage of coated using the Ross count method ASTM D2489 depends on how effectively the aggregate coats by asphalt, the lowest temperature that is appropriate for mixing should be determined .the temperature at which they mix are 150,170 and 190. As shown in tables 8 and9, each case is dependent on a particular variable (filler type, asphalt content and SBS percentage). The function of sigmoid were employed to connect the coating percentages to mixing temperature for each case(West, Watson, Turner, & Casola, 2010).

$$C = \frac{1}{1+a*e^{-b*T}} \qquad \text{……………………………………………………….. (2)}$$

The value of a and b and the expected temperature of mixing processes for equivalent coating, which are the results of the analysis of regression are shown in table 9.

Compaction of hot mix asphalt test

As illustrated in plate (4), th72 sample are compacted by SGC at (140,160and 180 º C). At 25 gyration, the percentage Gmm was computed for every specimen. The result of compaction test demonstrates in table (10). The linear equation derived from linear regression was used to predict the temperature of compaction for each case and linear regression between % Gmm and compaction temperature were developed as illustrated in table (11).

4- ANALYSIS AND DISCUSSION OF EXPERIMENT OUTCOME

4-1 Variation of viscosity with shear rate

The viscosity variation with the rate of shear for the SBS percentages at 135 and 165 º C respectively as illustrated in figures (5),(6) and (7).because the modified asphalt exhibit pseud plastic characteristics ,where the viscosity varies with shear rate, the figures generally show that the viscosity dropped with rising the rate of shear.the relationship between shear rate and viscosity dropped while the value of temperature rised from 135 º C to 165 º C

4-2 Difference of mixing temperature and compaction temperature for modified asphalt with used determination processes

Figure (8) shows the association between the temperature of mixing and the techniques HSRV-E, Superpave, HSRV-O for the different SBS content, whereas figure (9) shows the association of compaction temperature and the techniques. Both graphs illustrate a decrease in the temperatures of asphalt when the HSRV-O method to the superpave. Because the rate of shear is taken in to account when computing the temperatures in HSRV-E and HSRV-O methods, more declining can been seen inHSRV-E. The results trend aligns with the outcome of (Micaelo et al., 2012) " discovered that the HSRV-E approach outcomes in lower average mixing and compaction temperatures than the superpave and HSRV-O procedures ".

4-3 Effect the content of asphalt:

The mixing temperatures with (3%, 4%, 5% and 0%) over the content of asphalt are compared in figure (10). The figure shows that the temperatures declined as the amount of bitumen grew and the variation magnitude raised as the amount of bitumen's polymer reduced. Figure (11), (12) and (13) show that increasing asphalt content causes particles to lubricant and rearrange under load, as a result, asphalt requires a lower temperature to provide cohesion to asphalt and facilities aggregate particle movement, resulting in a compact and durable structure. Higher mixing temperature and compaction temperature are needed because the increasing of the viscosity of asphalt.

4-4 SBS content's effect

Figure (14) to (17) demonstrate the relationship between the temperatures of mixing and compaction of the modified mixture and the styrene butadiene styrene percentages. Figures illustrate that raising the SBS content leads to higher mixing and compaction temperatures**.**

4-5 filler type effects:

The mixing temperatures for modified bitumen with limestone dust and cement are shown in bar chart (18).the mixing temperature for asphalt mixtures including limestone rose slightly from 165 º C at 0% styrene butadiene styrene concentration to 168 º C at 3% styrene butadiene styrene concentration and subsequently to 171 º C at 5% SBS concentration .the mixing temperature for asphalt mixture with cement is low ,beginning around 164 º C .it is evident that figure (19) exhibited the similar pattern .in general, increasing the proportion of SBS content resulted in higher mixing temperature and compaction temperature, especially in mixtures with lime stone dust compared to cement .this is because ,when combined with the binder lime stone dust exhibits the maximum viscosity for the asphalt mixture when compared to all other filler kinds (Cross & Brown, 1992).

5-CONCLUSION

The experimental results, within the restrictions of test methods and the materials used, lead to the following conclusion:

1. This study predict tow models:

a) The temperature of mixing model for asphalt mixture modified with styrene butadiene styrene (MT)is based on coating test results:

MT=183.586-4.88*(AC)+0.311*(F)+2.24*(SBSC)

b) The temperature of compaction model for the mixture modified with styrene butadiene styrene (CT) is based on the test results for asphalt mixture compaction :

CT=170.123-4.294*(AC)+1.818*(F)+2.094*(SBSC)

Where,

CT=compaction temperature, C^o

MT=mixing temperature, C^o

Ac=asphalt content, %

F=type of filler (limestone dust 2.9; Portland cement 3.1)

SBSC =SBS content, %

2. The limitations of the data used to develop the compaction and mixing models.
3. When the asphalt concentration is 0.5% higher than the optimum, mixing and compaction temperatures decrease. On the other hand, when the asphalt content is decrease by 0.5 %, they rise.
4. The compaction temperature and mixing temperature of modified asphalt mixes decrease as the percentage of SBS in the mixture decreases. In contrast, mixing temperature and compaction temperature rise as the percentage of SBS increases. The modified mixture with

lime stone dust has produced higher mixing and compaction temperatures than the mixture with Portland cement.

5. According to the results of asphalt tests using a Brookfield viscometer, the viscosity declining as the shear rate risen.
6. In comparison to the superpave approach, the HSRV-O method showed lower temperatures for mixing and compaction of modified asphalt with styrene butadiene styrene, whereas the HSRV-E method showed greater diminishment.

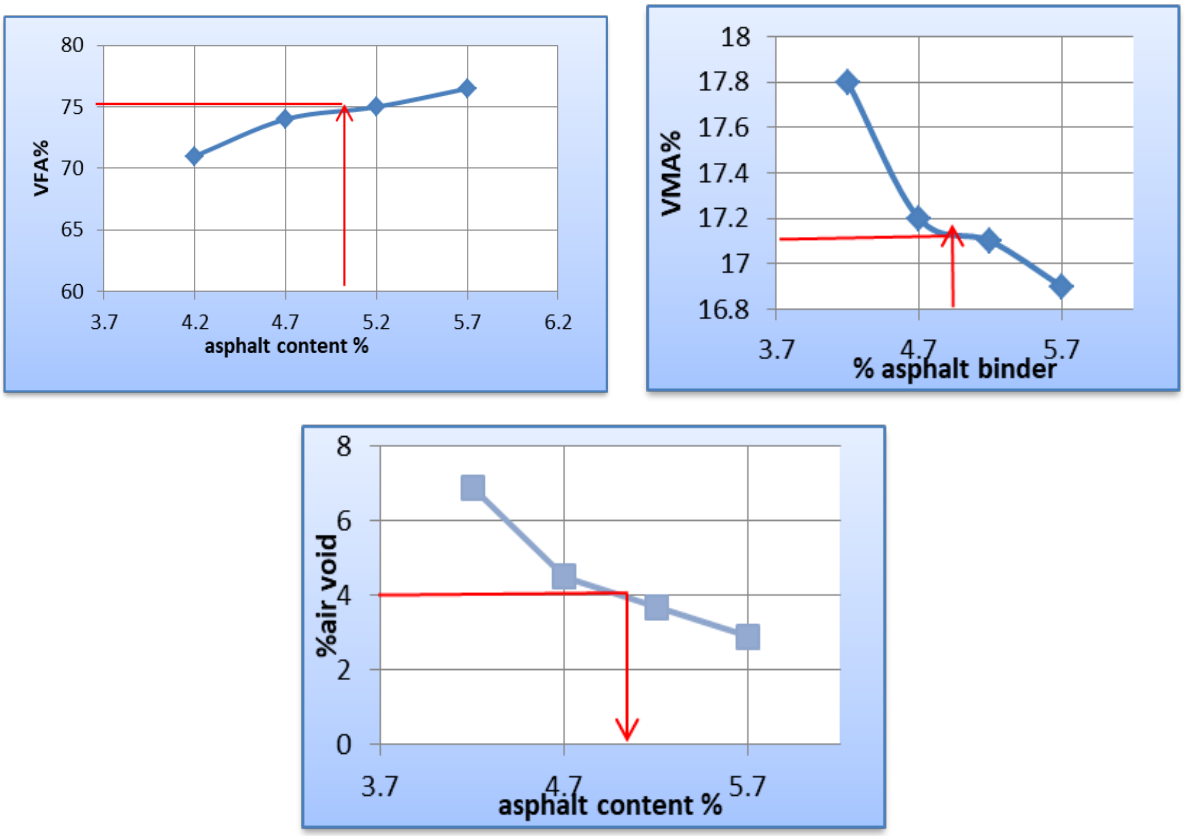


Figure (1): relationship between asphalt composition and air void percentage, VMA %and VMA%

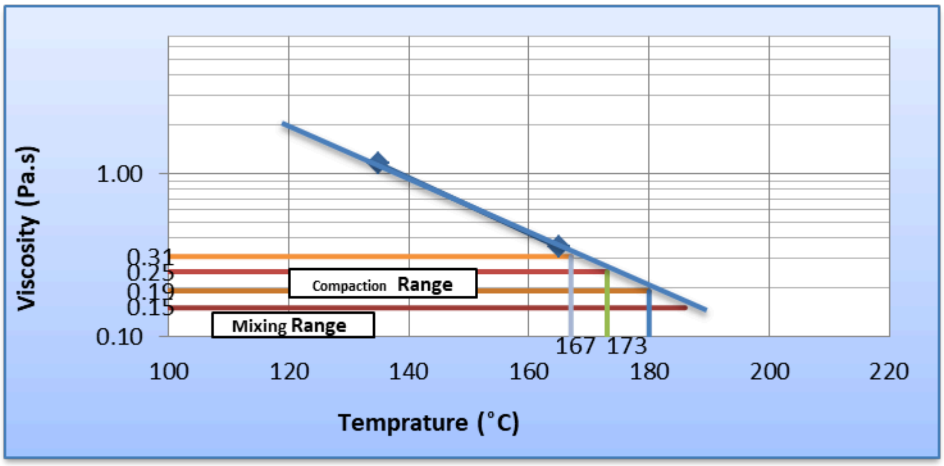


Figure (2): compaction and mixing temperatures at shear rate of 6.8 S^{-1} for asphalt modified by 3% SBS

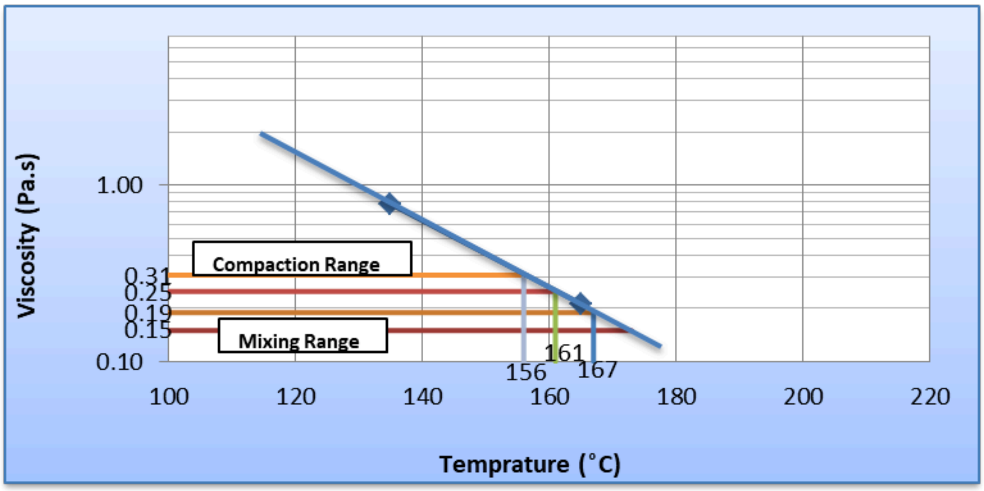


Figure (3): compaction and mixing temperatures at shear rate of 500 $s^{-1}$for asphalt modified by 3% styrene butadiene styrene

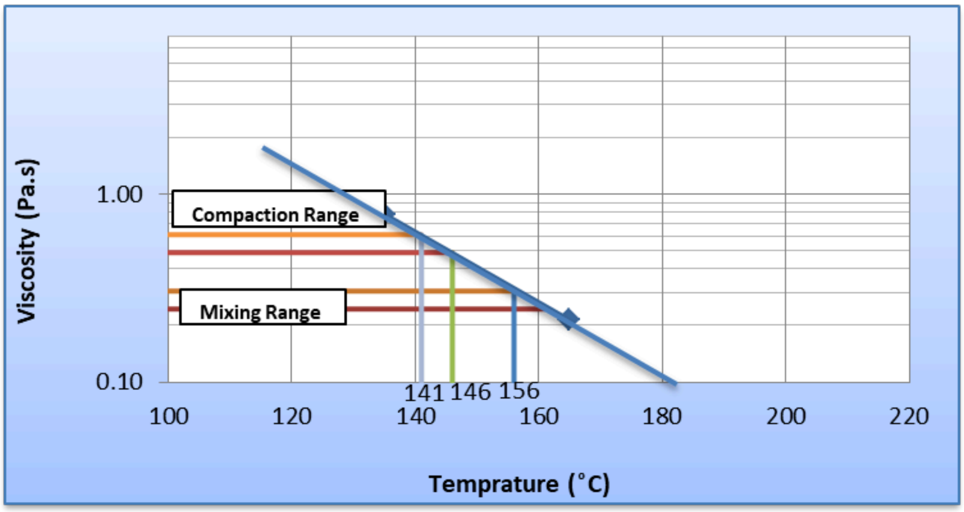


Figure (4) mixing and compaction temperature by utilizing HSRV-E process for asphalt modified by 3% SBS

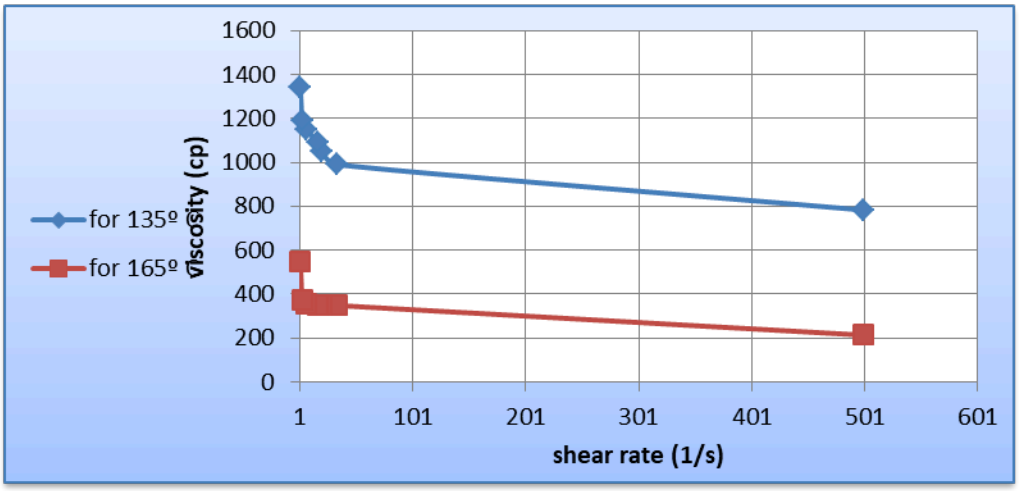


Figure (5): relationship between viscosity and rate of shear at temperature 135 º C and 165 º C for 3% SBS modified bitumen.

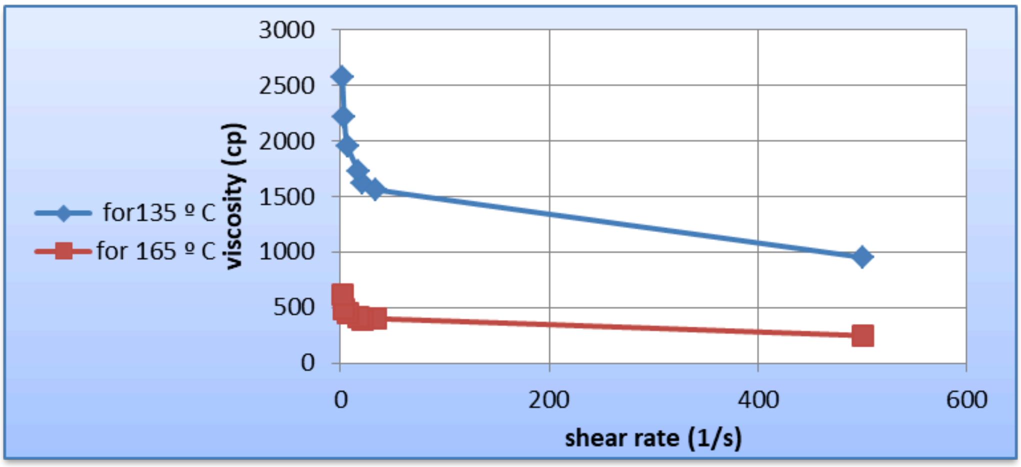


Figure (6): relationship between viscosity and rate of shear for 4% SBS modified bitumen.

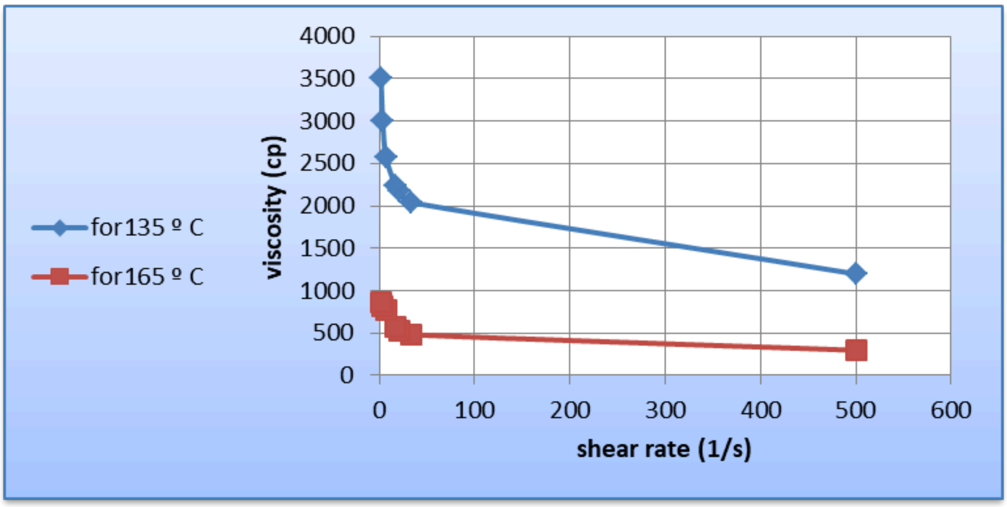


Figure (7): relationship between viscosity and Shear rate for 5% SBS modified bitumen.

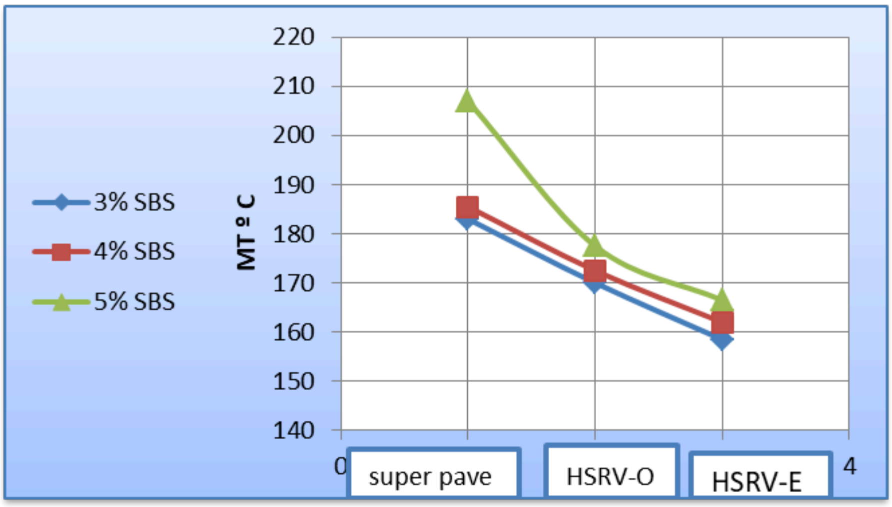


Figure (8): variation in the mixing temperature with HSRV-O, HSRV-E and super pave,).

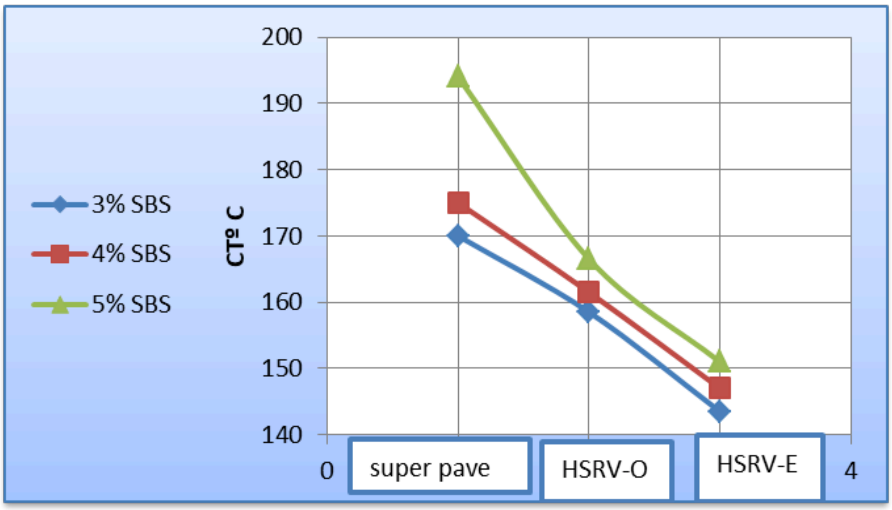


Figure (9): variation of compaction temperature with super pave, HSRV-O, and HSRV-E.

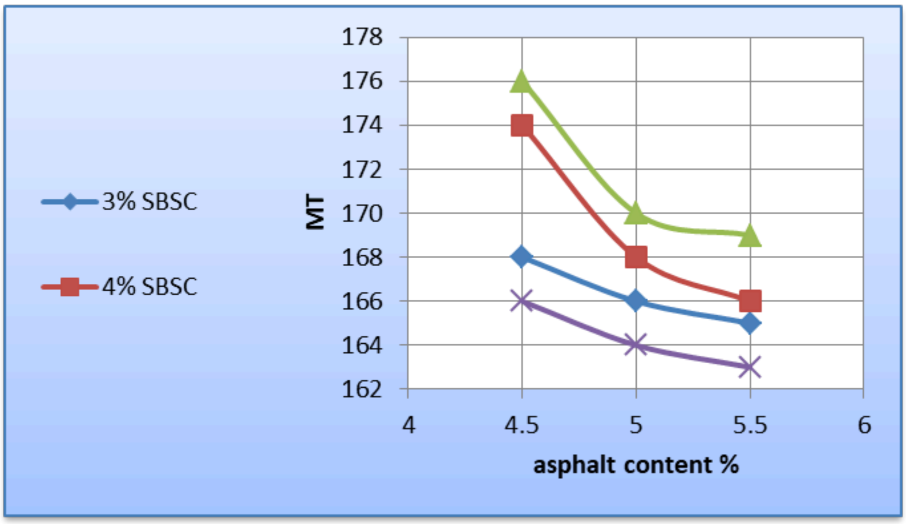


Figure (10): Relationship between AC % and mixing temperatures for Portland cement.

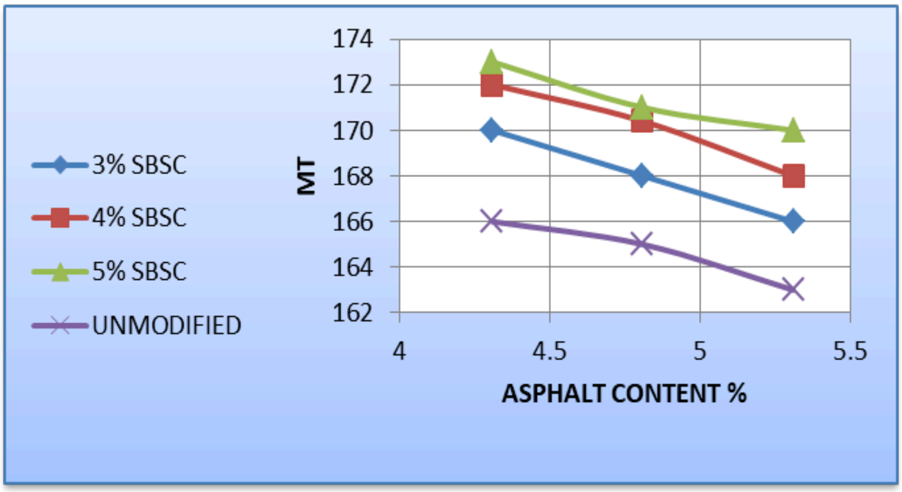


Figure (11): Relationship between AC % and mixing temperatures for lime stone dust.

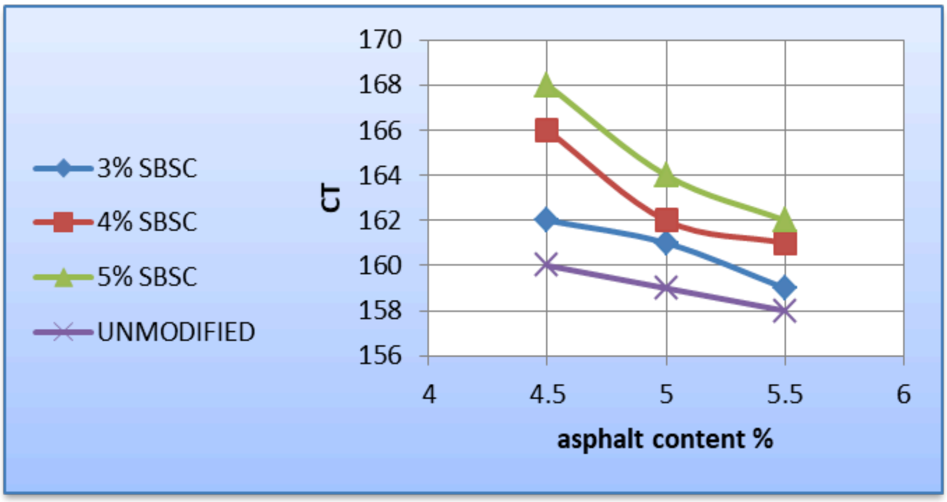


Figure (12): Relationship between AC % and compaction temperatures for Portland cement

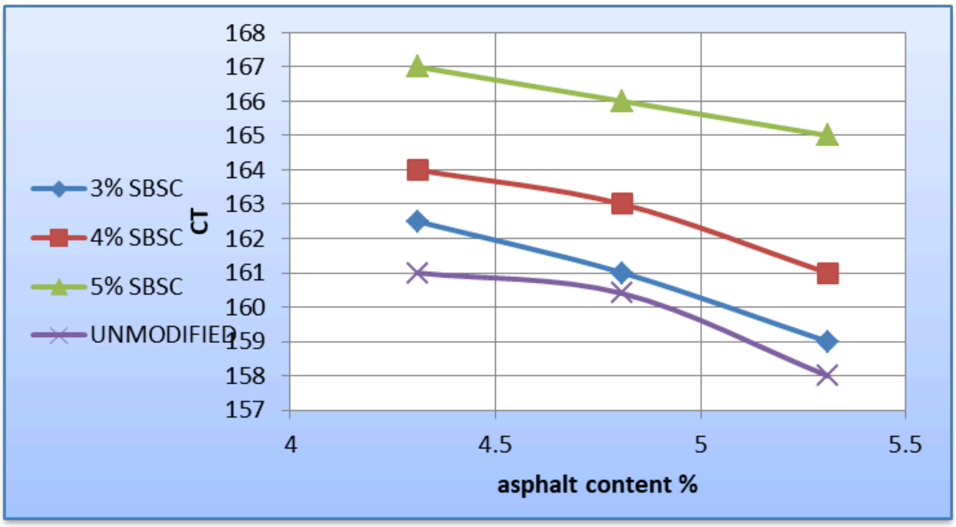


Figure (13) Relationship between AC % and CT for lime stone dust

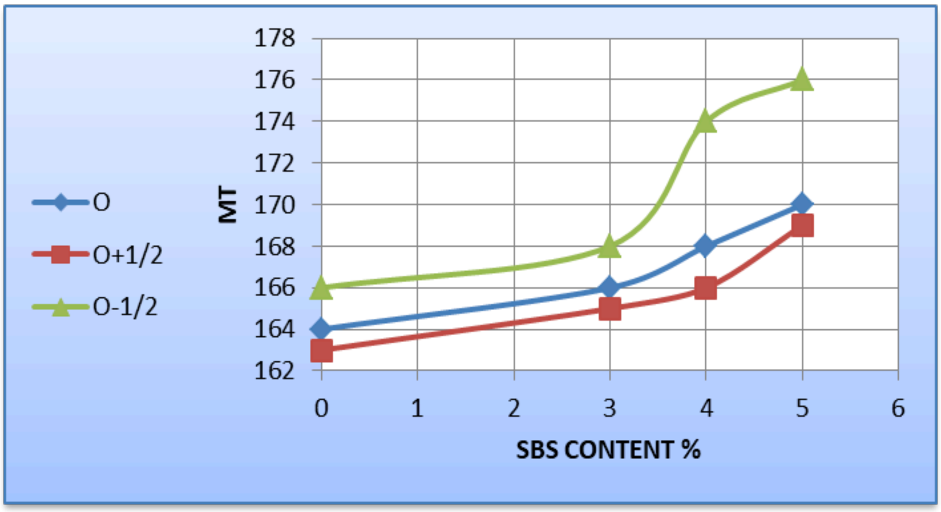


Figure (14): Relationship between SBS content and MT for cement.

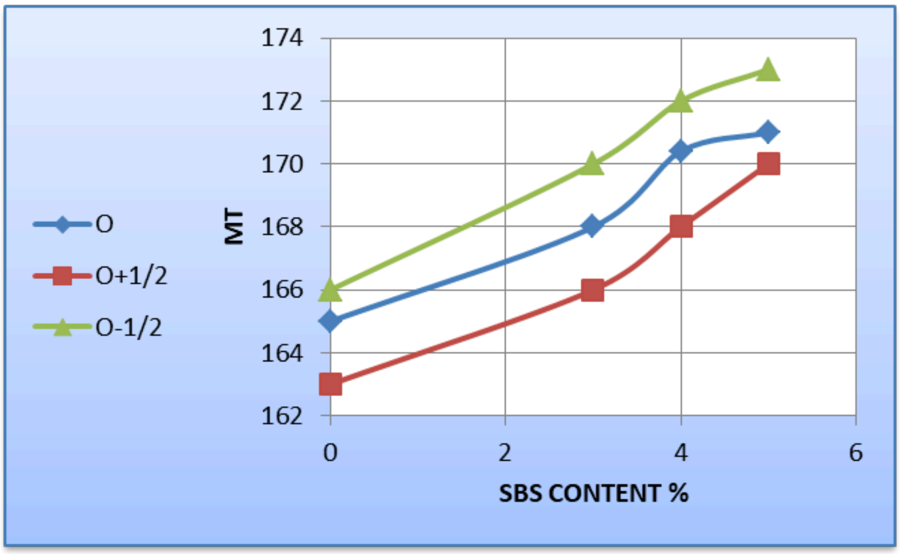


Figure (15): association between SBSC % and mixing temperatures for lime stone dust

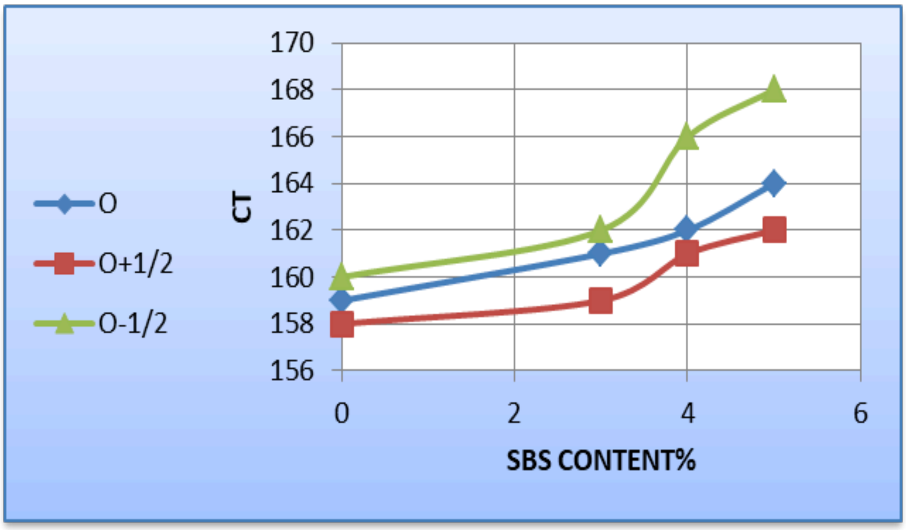


Figure (16): Relationship between SBSC % and CT for Portland cement.

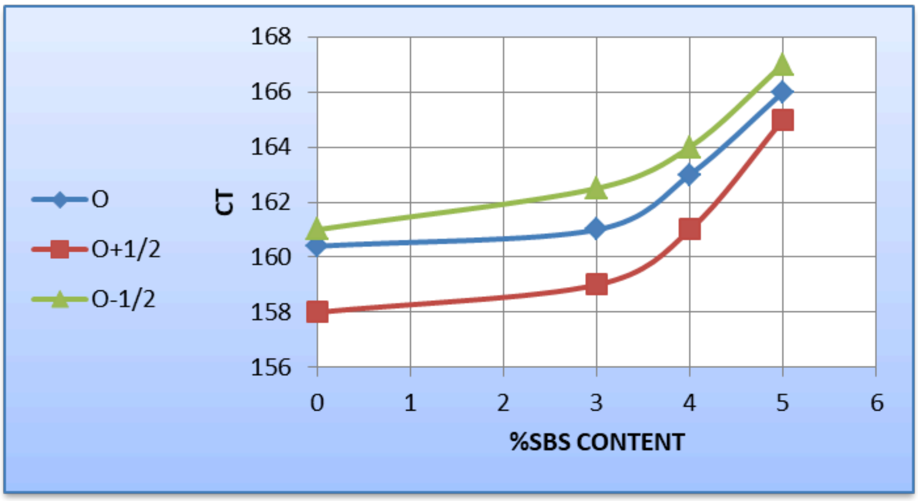


Figure (17): association between SBS content and compaction temperatures for lime stone dust.

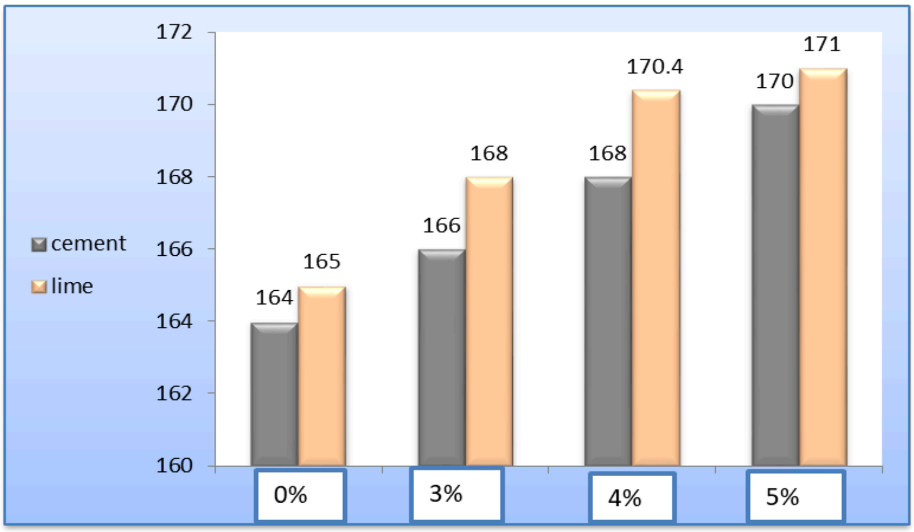


Figure (18): effect of SBS content on mixing temperatures for lime stone dust and cement

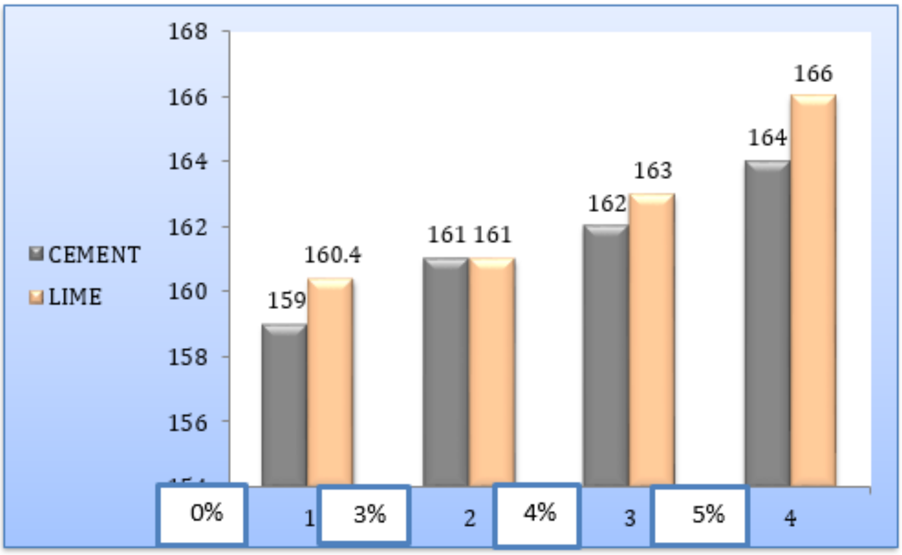


Figure (19): effect of SBS content on compaction temperatures for lime stone dust and cement

Table (1): Physical Properties of Selected Aggregate

Laboratory Test		**ASTM Designation and Specification**	**Results**			
Specific gravity	**Coarse aggregate**	ASTM C127	sieve size (mm)	Apparent Gs	Bulk Gs	Abs.%
			19-12.5	2.672	2.650	0.32%
			12.5-9.5	2.593	2.580	0.35%
			9.5-4.75	2.570	2.565	0.22%
	Fine agg.	ASTM C128	Crashed sand (<#4)	2.67	2.64	0.63%
Angularity for Coarse aggregate		ASTM D 5821 **Min 90%**	93%			
Soundness for Coarse aggregate		ASTM C88 **10-20% Max**	4.3%			
Equivalent sand (clay content)	Crashed(<#4)	ASTM D2419 **Min 45%**	96%			
Flat & Elongation aggregate	Flat	ASTM D4791 **Max 10%**	1%			
	Elongation		4%			
Toughness, by (Los Angeles Abrasion)	Aggregate Size < 25mm	ASTM C131 **35-45% Max**	21.7%			

Table (2): standard limitation and physical properties of asphalt

Test	Test Conditions	Standard	Test value (measured)		Standard Limit according to SCRB /R9, 2003
Penetration	100 gm., 25°C, 5sec., (0.1mm)	ASTM D5	43.6		40-50
Ductility	25°C, 5cm/min	ASTM D113	+115		+100
Specific gravity asphalt	25°C	ASTM D70	1.03		-----
Flash and fire points	.....	ASTM D92	Flash	335°C	> 232 °C
			Fire	339°C	-------
Loss on heating	163 °C, 50gm, 5 hr	ASTM D1754	Penetration	67	>55
			Ductility	45	>25
Rotational viscometer	Pa.sec	ASTM D 4402	0.6625 @ 135°C* 0.2375 @ 165°C**		

Table (3): SBS Properties, (Polimeri Europe SPA, 2012)

Items	Results	Items	results
Molecular Weight Avg.	353.164	Elongation at break (%)	660
Polydispersity	1.08	Permanent deformation	≤55
Diblock content (%)	14	Hardness shore (A) ASTM D 2240	82 Radial
Styrene (%)	30.1	Oil-Extended	10
Tensile strength (MPa)	16.5	Melt flow index (g/10min) ASTM D1238	0.1-0.5
Main application	Bitumen modification adhesive	Melting point temperature	180°C

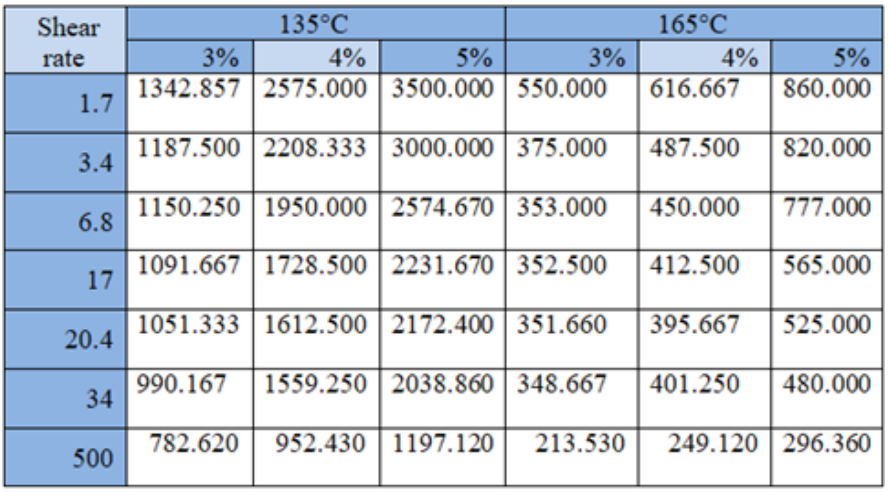
Table (4): Limestone Physical Properties

Property	Test Result
Specific gravity	2.92
%Passing Sieve No.200 (0.075 mm)	96%

Table (5): Portland cement Physical Properties

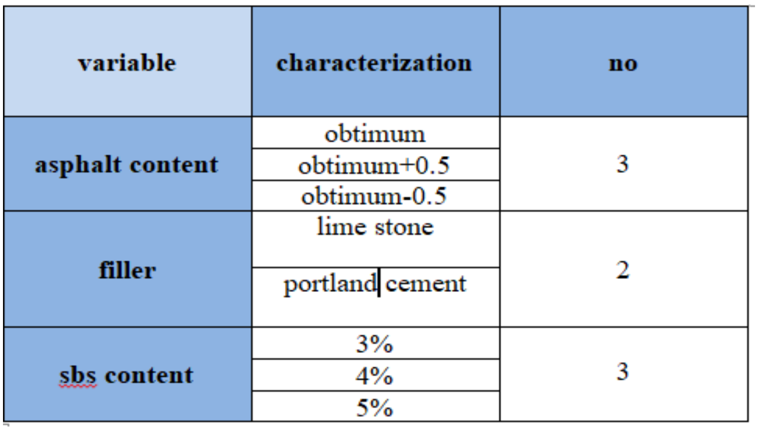
Property	Test Result
Bulk specific gravity	3.10
Specific surface area	312.5 m^2/kg
%Passing Sieve No.200 (0.075 mm)	97

Table (6): viscosity values for 3%, 4%, and 5%



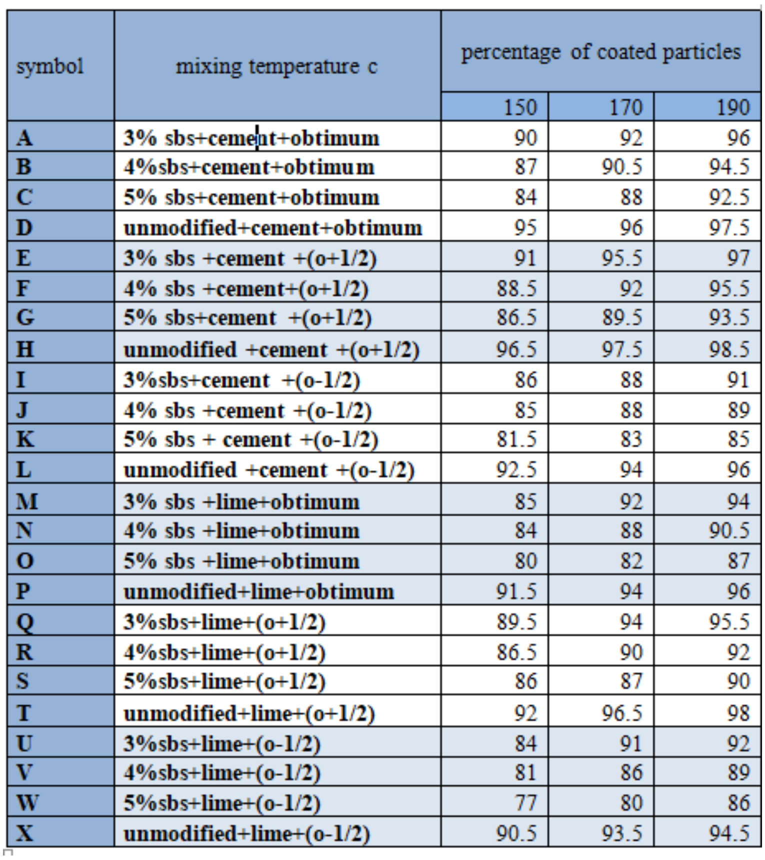
Shear rate	135°C			165°C		
	3%	4%	5%	3%	4%	5%
1.7	1342.857	2575.000	3500.000	550.000	616.667	860.000
3.4	1187.500	2208.333	3000.000	375.000	487.500	820.000
6.8	1150.250	1950.000	2574.670	353.000	450.000	777.000
17	1091.667	1728.500	2231.670	352.500	412.500	565.000
20.4	1051.333	1612.500	2172.400	351.660	395.667	525.000
34	990.167	1559.250	2038.860	348.667	401.250	480.000
500	782.620	952.430	1197.120	213.530	249.120	296.360

Table (7): factors included in the research



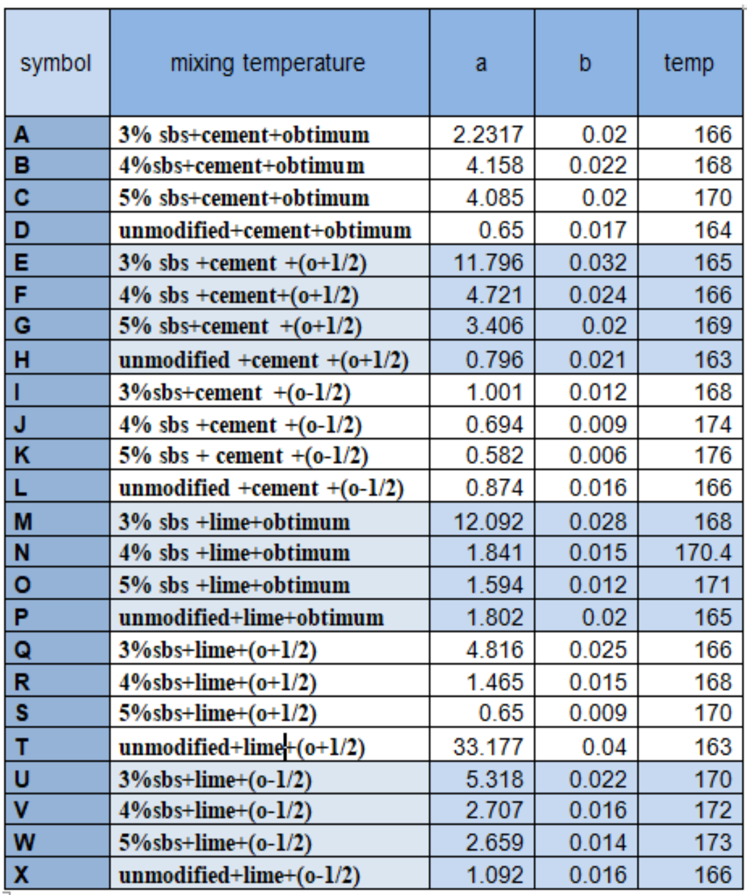
variable	**characterization**	**no**
asphalt content	obtimum	3
	obtimum+0.5	
	obtimum-0.5	
filler	lime stone	2
	portland cement	
sbs content	3%	3
	4%	
	5%	

Table (8): results of the percent coating tests



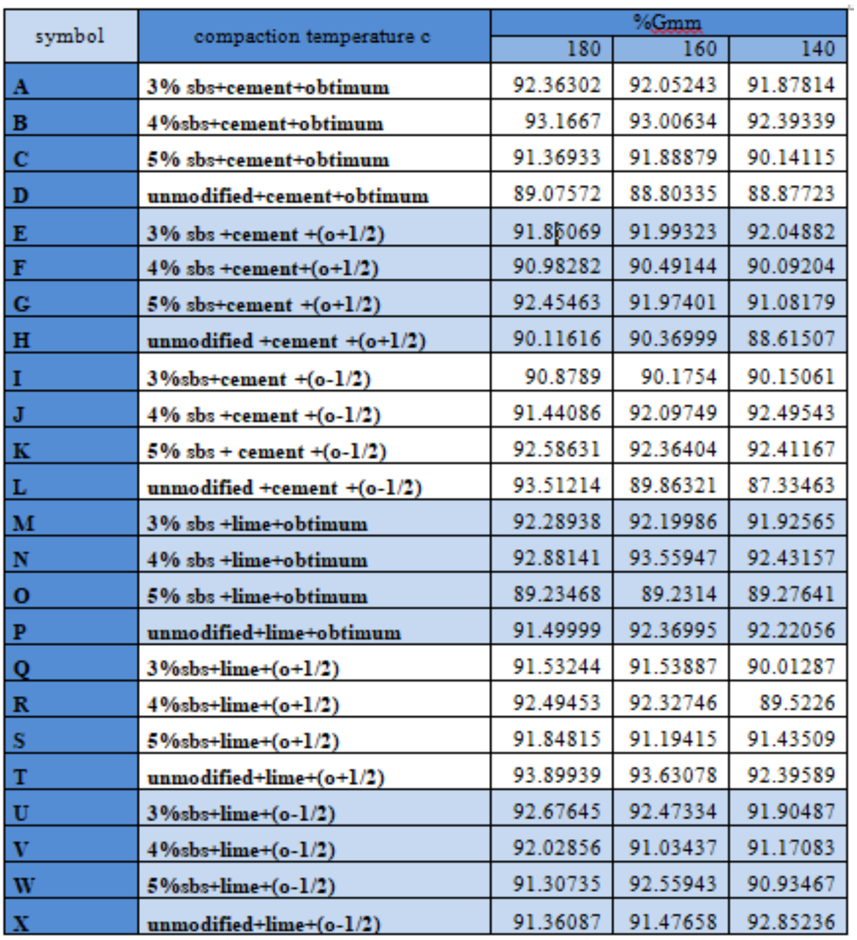
symbol	mixing temperature c	percentage of coated particles		
		150	170	190
A	**3% sbs+cement+obtimum**	90	92	96
B	**4%sbs+cement+obtimum**	87	90.5	94.5
C	**5% sbs+cement+obtimum**	84	88	92.5
D	**unmodified+cement+obtimum**	95	96	97.5
E	**3% sbs +cement +(o+1/2)**	91	95.5	97
F	**4% sbs +cement+(o+1/2)**	88.5	92	95.5
G	**5% sbs+cement +(o+1/2)**	86.5	89.5	93.5
H	**unmodified +cement +(o+1/2)**	96.5	97.5	98.5
I	**3%sbs+cement +(o-1/2)**	86	88	91
J	**4% sbs +cement +(o-1/2)**	85	88	89
K	**5% sbs + cement +(o-1/2)**	81.5	83	85
L	**unmodified +cement +(o-1/2)**	92.5	94	96
M	**3% sbs +lime+obtimum**	85	92	94
N	**4% sbs +lime+obtimum**	84	88	90.5
O	**5% sbs +lime+obtimum**	80	82	87
P	**unmodified+lime+obtimum**	91.5	94	96
Q	**3%sbs+lime+(o+1/2)**	89.5	94	95.5
R	**4%sbs+lime+(o+1/2)**	86.5	90	92
S	**5%sbs+lime+(o+1/2)**	86	87	90
T	**unmodified+lime+(o+1/2)**	92	96.5	98
U	**3%sbs+lime+(o-1/2)**	84	91	92
V	**4%sbs+lime+(o-1/2)**	81	86	89
W	**5%sbs+lime+(o-1/2)**	77	80	86
X	**unmodified+lime+(o-1/2)**	90.5	93.5	94.5

Table (9): the expected mixing temperature and the regression result



symbol	mixing temperature	a	b	temp
A	3% sbs+cement+obtimum	2.2317	0.02	166
B	4%sbs+cement+obtimum	4.158	0.022	168
C	5% sbs+cement+obtimum	4.085	0.02	170
D	unmodified+cement+obtimum	0.65	0.017	164
E	3% sbs +cement +(o+1/2)	11.796	0.032	165
F	4% sbs +cement+(o+1/2)	4.721	0.024	166
G	5% sbs+cement +(o+1/2)	3.406	0.02	169
H	unmodified +cement +(o+1/2)	0.796	0.021	163
I	3%sbs+cement +(o-1/2)	1.001	0.012	168
J	4% sbs +cement +(o-1/2)	0.694	0.009	174
K	5% sbs + cement +(o-1/2)	0.582	0.006	176
L	unmodified +cement +(o-1/2)	0.874	0.016	166
M	3% sbs +lime+obtimum	12.092	0.028	168
N	4% sbs +lime+obtimum	1.841	0.015	170.4
O	5% sbs +lime+obtimum	1.594	0.012	171
P	unmodified+lime+obtimum	1.802	0.02	165
Q	3%sbs+lime+(o+1/2)	4.816	0.025	166
R	4%sbs+lime+(o+1/2)	1.465	0.015	168
S	5%sbs+lime+(o+1/2)	0.65	0.009	170
T	unmodified+lime+(o+1/2)	33.177	0.04	163
U	3%sbs+lime+(o-1/2)	5.318	0.022	170
V	4%sbs+lime+(o-1/2)	2.707	0.016	172
W	5%sbs+lime+(o-1/2)	2.659	0.014	173
X	unmodified+lime+(o-1/2)	1.092	0.016	166

Table (10): the compaction test result summary



symbol	compaction temperature c	%Gmm		
		180	160	140
A	3% sbs+cement+obtimum	92.36302	92.05243	91.87814
B	4%sbs+cement+obtimum	93.1667	93.00634	92.39339
C	5% sbs+cement+obtimum	91.36933	91.88879	90.14115
D	unmodified+cement+obtimum	89.07572	88.80335	88.87723
E	3% sbs +cement +(o+1/2)	91.86069	91.99323	92.04882
F	4% sbs +cement+(o+1/2)	90.98282	90.49144	90.09204
G	5% sbs+cement +(o+1/2)	92.45463	91.97401	91.08179
H	unmodified +cement +(o+1/2)	90.11616	90.36999	88.61507
I	3%sbs+cement +(o-1/2)	90.8789	90.1754	90.15061
J	4% sbs +cement +(o-1/2)	91.44086	92.09749	92.49543
K	5% sbs + cement +(o-1/2)	92.58631	92.36404	92.41167
L	unmodified +cement +(o-1/2)	93.51214	89.86321	87.33463
M	3% sbs +lime+obtimum	92.28938	92.19986	91.92565
N	4% sbs +lime+obtimum	92.88141	93.55947	92.43157
O	5% sbs +lime+obtimum	89.23468	89.2314	89.27641
P	unmodified+lime+obtimum	91.49999	92.36995	92.22056
Q	3%sbs+lime+(o+1/2)	91.53244	91.53887	90.01287
R	4%sbs+lime+(o+1/2)	92.49453	92.32746	89.5226
S	5%sbs+lime+(o+1/2)	91.84815	91.19415	91.43509
T	unmodified+lime+(o+1/2)	93.89939	93.63078	92.39589
U	3%sbs+lime+(o-1/2)	92.67645	92.47334	91.90487
V	4%sbs+lime+(o-1/2)	92.02856	91.03437	91.17083
W	5%sbs+lime+(o-1/2)	91.30735	92.55943	90.93467
X	unmodified+lime+(o-1/2)	91.36087	91.47658	92.85236

Table (11): the result of compaction test regression

symbol	Regression Equation	R^2	C
A	%Gmm=90.158+0.012T	0.949	161
B	%Gmm=89.762+0.019T	0.795	162
C	%Gmm=86.22+0.031T	0.468	164
D	%Gmm=88.125+0.005T	0.496	159
E	%Gmm=92.757-0.005T	0.94	158
F	%Gmm=86.959+0.022T	0.996	161
G	%Gmm=86.345+0.034T	0.971	162
H	%Gmm=83.696+0.038T	0.626	158
I	%Gmm=87.488+0.018T	0.776	162
J	%Gmm=96.230-0.026T	0.961	166
K	%Gmm=91.755+0.004T	0.557	168
L	%Gmm=65.527+0.154T	0.989	160
M	%Gmm=90.683+0.009T	0.921	161
N	%Gmm=91.158+0.011T	0.157	163
O	%Gmm=89.414-0.001T	0.691	166
P	%Gmm=94.912-0.018T	0.6	160.4
Q	%Gmm=84.950+0.038T	0.747	159
R	%Gmm=79.56+0.074T	0.792	161
S	%Gmm=89.840+0.01T	0.39	165
T	%Gmm=87.295+0.038T	0.879	158
U	%Gmm=89.265+0.019T	0.93	162.5
V	%Gmm=87.98+0.021T	0.633	164
W	%Gmm=90.11+0.009T	0.048	167
X	%Gmm=97.863-0.037t	0.808	161

Table (12): data limitations for the compaction and mixing models

	AC%	filler	SBSC %
max	5.5	3.1	5
min	4.31	2.72	3
mean	4.905	2.91	4

Plate (1): SBS polymer

Plate (2): Preparation the specimens by use Gyratory Compactor

Plate (3): test of mix coating

Plate (4): compacted specimen

REFRENCES

1. ASTM D 4402-03, (2010), "Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer", West Conshohocken, USA.
2. ASTM D 2493, "Standard Viscosity-Temperature Chart for Asphalts", West Conshohocken, USA.
3. ASTM D 6925, "Standard Test Method for Preparation and Determination of the Relative Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor ", West Conshohocken, USA.
4. ASTM D2489, "Standard Test Method for Estimating Degree of Particle Coating of Asphalt Mixtures", West Conshohocken, USA.
5. Bahia, H. U., Hanson, D. I., Zeng, M., Zhai, H., Khatri, M. A., & Anderson, R. M. (2001). Characterization of modified asphalt binders in superpave mix design.
6. Cross, S. A., & Brown, E. R. (1992). Selection of aggregate properties to minimize rutting of heavy duty pavements. In Effects of aggregates and mineral fillers on asphalt mixture performance. ASTM International.
7. DeSombre, R., Newcomb, D. E., Chadbourn, B., & Voller, V. (1998). Parameters to define the laboratory compaction temperature range of hot-mix asphalt. Journal of the Association of Asphalt Paving Technologists, 67.

8. Khatri, A., Bahia, H. U., & Hanson, D. (2001). MIXING AND COMPACTION TEMPERATURES FOR MODIFIED BINDERS USING THE SUPERPAVE GYRATORY COMPACTOR (WITH DISCUSSION). Journal of the Association of Asphalt Paving Technologists, 70.
9. Micaelo, R., Santos, A., & Duarte, C. (2012). Mixing and compaction temperatures of asphalt mixtures with modified bitumen. In 5th Congress Eurasphalt & Eurobitume. Istanbul, Turkey.
10. Read, J., & Whiteoak, D. (2003). The shell bitumen handbook. Thomas Telford.
11. Reinke, G. (2003). Determination of Mixing and Compaction Temperature of PG Binders Using a Steady Shear Flow Test. Presentation Made to the Superpave Binder Expert Task Group.
12. West, R. C., Watson, D. E., Turner, P. A., & Casola, J. R. (2010). Mixing and compaction temperatures of asphalt binders in hot-mix asphalt.
13. Yildirim, Y. (2000). Mixing and compaction temperatures for superpave mixes.
14. Yildirim, Y., Ideker, J., & Hazlett, D. (2006). Evaluation of Viscosity Values for Mixing and Compaction Temperatures. Journal of Materials in Civil Engineering, 18(4), 545–553. https://doi.org/10.1061/(ASCE)0899-1561(2006)18:4(545)
15. Yildirim, Y., Solaimanian, M., & Kennedy, T. W. (2000). Mixing and Compaction Temperatures for Hot Mix Asphalt Concrete (1250-5), 7(1250).