Analysis of Laboratory Techniques for Simulating the Effect of Segregation on Rutting Performance of Asphalt Concrete Mixture

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Abstract - Segregation occurs on the part of the pavement when the rough material is concentrated on this part and fine materials in others because bad performance on pavements. The purpose of this paper is to discuss the effect of segregation on the rut performance of asphalt pavement mixtures. The materials applied included aggregate and 60/70 asphalt cover. In addition to the control asphalt mixture, 4 artificially segregated mixtures were intended to represent coarse and fine segregation of different grades. Samples to mix design purposes were compacted then the 5 mixes were evaluated in the laboratory with different degree of segregation. An optimal asphalt content (OAC) for all mixtures is determined. The rutting test is performed for various level of temperatures (20^{o}C, 25^{o}C, and 30^{o}C) by using static uniaxial loading strain test. Results of the investigation indicated that the segregation was significantly affected on the rutting performance of the asphalt concrete mix with multiple determinations R^{2} about 0.9 at different temperatures. As temperature increases, the mixture will more susceptible to rutting and the more finely segregated asphalt mixture (SAM) will exhibit with longer tiredness lifetime.

Keywords: Segregation, Rutting, Static uniaxial loading strain test.

1. INTRODUCTION/LITERATURE REVEIW

Segregation of asphalt mixtures, which indicates the non-regular division of coarse and accurate aggregate parts, happens due to the improper processing of the material during the various stages of construction including asphalt production in the plant, carting, operation, and compaction. Generally, segregation denotes an altered aggregate gradation with immoderate coarse aggregates and incomplete accurate aggregates in the final asphalt mat. A segregated mixture displays increased air voids and decreased asphalt content if compared to a mixture free of segregation. This is due to its coarse aggregate-rich nature. Former literature reviews have informed that such inconsistency caused by segregation either outcomes in short term early failures or minimizes the long term pavement service life. (Williams et al. 1996; Gardiner and Brown, 2000; Khedaywi and White, 1996).

Gradation as well as content of asphalt have a significant effect on segregation opportunities. For example, gap-graded mixtures with low asphalt content are prone to segregation. Bryant (1967) is intended to mean that differences in asphalt content may be considered as local effects of segregation, which means that the mixture is not properly designed. Brock (1986) proposed a gap-graded mixing as having a gradation that produces S across the maximum density line. This study resulted that there was a correlation between the percentage of extracted asphalt and the degree of segregation, and recommended a significant amount of work to reduce segregation due to possible effects on the properties of the asphalt mixture. Segregated areas are generally eight to five percent thicker than areas in sieve No. 8; the gaps are typically three to five percent higher; and the content is often one to two percent lower. (Brown et al. 1989). Lacky (1986) decided that segregation is usually not easily observed when built the pavement. However, within a year, this area shows as the mastic is taken away by traffic. Khedaywi and White (1995) have advanced laboratory techniques to simulate the segregation, suitability, and physical properties of concrete mixtures. This paper stated that segregation has remarkable effect on rut depth (RD), indirect tensile strength, moisture, asphalt content, air voids, gradation, compatibility index, unit weight, and stability index. Because segregation may produce in a considerable variation in the aggregate build of a mixture as shown in Figure 1, segregated mixtures may display an increased possibility for rutting or regular deformation, through all other distresses. Rutting, a main distress accomplished in asphalt pavements, is highly associated to the mixture's durability to shear distortion. (Young-Chan et al. 2011).

In general, rutting is defined as a deformation that can occur in the different pavement layers and it does not always procedures a shift of the material to the sides of the wheel paths. But, the most famous mode of rutting is the surface rutting. This mode of rutting is defined as a perpetual deformation (surface depression) under the wheel paths in the pavement surface. This mode of rutting is remarkable only after a rainfall when the paths are filled with water as shown in Figure

2. Considerable rutting can lead to main structural failure of the pavement.

Surface rutting commonly occurs under the wheel paths in the pavement. The causes of rutting are as follows: wrong mixture design that may be detected by analyzing different mixture parameters such as density, weak subgrade, high temperature (heat), lack of or improper compaction and traffic loading (Young-Chan et al. 2011). Figure 3 shows how to calculated mean RD. Rutting is described mostly as mean RD in millimeters. The mean is calculated by laying a straightedge across the rut, measuring its depth, then using measurements taken along the extension of the rut to compute its mean depth in inches (Young-Chan et al. 2011).

Figure 1: Example for Level of Segregation of Asphalt Concrete Mixture (Young-Chan et al. 2011).

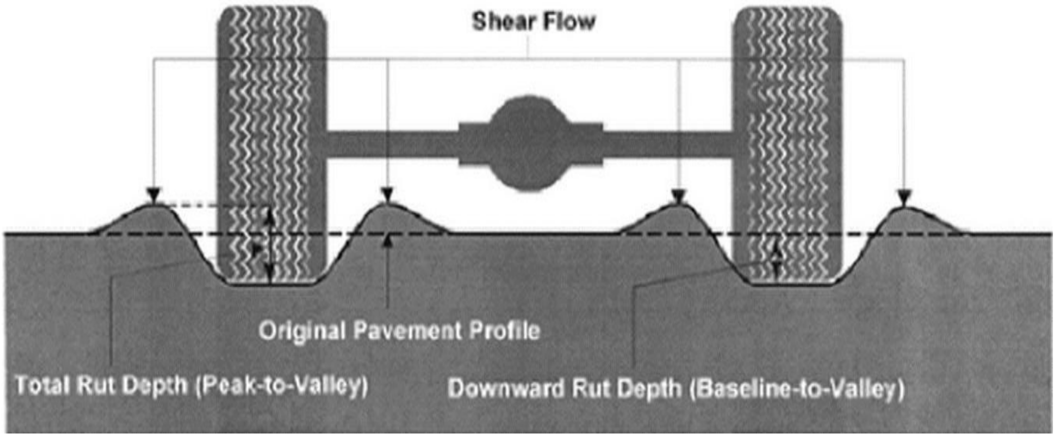


Figure 2: Example of One Mode of Rutting (Surface Rutting) under the Wheel Paths (Young-Chan et al. 2011).

Figure 3: Example to Compute Mean RD (Young-Chan et al. 2011).

The values of RD were cracked down to groups of fifty Inch/mile as well as 0.5 Inch respectively. For each category, crash rates (accidents) are calculated using method, which is the average number of accidents per vehicle per year multiplied by 100,000,000 this method was applied in the US Department of Transportation. The variations of crash rate with average RD were inspected. Linear regression analysis is utilized to study the correlation. Crash rate has good correlation with RD in all cases. Increasing RD increases crash rate, if the RD increases more than 6.5 mm, the number of accidents and risk will increase immediately (Vinayakamurthy 2017). This orientation passed for different crash severity levels with various degrees of correlation (Vinayakamurthy 2017). Figure 4 explains the connection between crash rate and RD for year of 2014 in the Arizona city. It can be observed that there is a positive correlation between the two operators with a high □□2value of 0.6988 (Vinayakamurthy 2017)

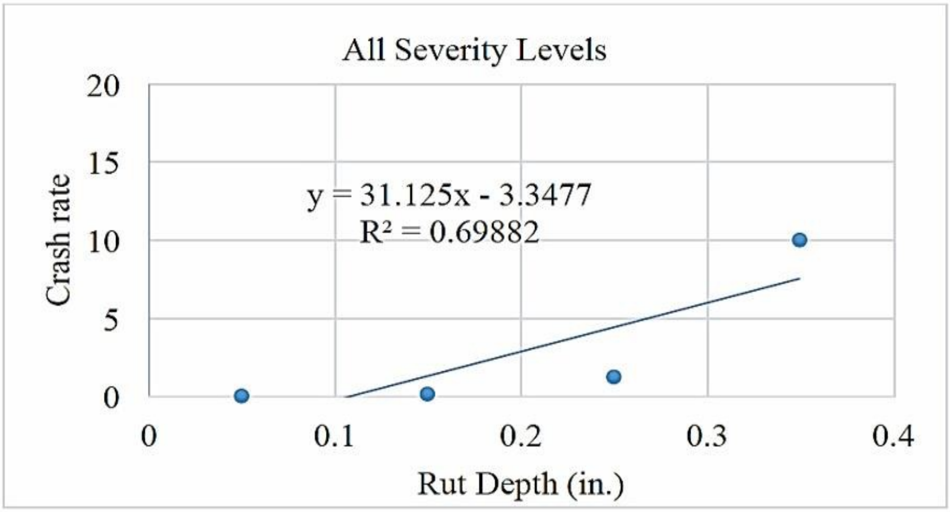


Figure 4: Shows all severity levels.

Past research have shown that the shear toughness of asphalt mixtures is related to the overlap of coarse aggregate particles (Roque et al. 1997; Birgisson and Ruth, 2001Other studies conducted by Kim et al. (2006) presented the concept and porosity of dominant aggregate size range (DASR) to recognize the coarse aggregate structure of asphalt mixtures (Kim et al 2009; Kim et al 2006). An accelerated pavement testing (APT) supported that DASR porosity has a fully mutual relationship with the rutting representation of asphalt mixtures, displaying that the characteristics of a coarse aggregate structure may supply a large possibility for determining the rutting representation of hot-mix asphalt this study applied by the Florida Department of Transportation (FDOT) (Greene et al. 2011). In this paper, tests were conducted to estimate the impact of segregation on the shift in the structure of coarse aggregate that may impact the rutting potential of asphalt pavements.

3. The Materials

3.1. Aggregate

Gradation was following specifications by Jordanian ministry of public works and housing in 2008 and was imparted from Al-Halabat Quarries in Jordan. The aggregate properties and lists the aggregate gradation for the control mix shown in Table 1 and 2. Gradations of the aggregate were defined for each segregated mixture according to ASTM C136. Aggregate gradations for five mixtures, mixture 1 represents very fine, mixture 2 represents fine, mixture 3 represents mix design, mixture 4 represents coarse while mix five represents very coarse.

Table 1: Shows aggregate properties

Aggregate Type (Limestone)	ASTM Test Designation	Bulk Specific Gravity	Apparent Specific Gravity	Absorption (%)
Coarse Agg.	C127	2.426	2.618	3.0
Fine Agg.	C128	2.460	2.628	3.6
Mineral Filler	C128	2.485	2.485	5.0

Table 2: Shows aggregate gradation

Sieve Size	Specification Limits* (% Passing)	%Passing (Midpoint)
1» (25 mm)	011	011
¾» (19 mm)	90-100	95
½» (12.5 mm)	71-90	80.5
3/8» (9.5 mm)	56-80	68
No. 4 (4.75 mm)	35-56	45.5
No. 8 (2.35 mm)	23-38	30.5
No. 20 (850 µm)	13-27	20
No. 50 (300 µm)	5-17	11
No. 80 (180 µm)	4-14	9
No. 200 (75 µm)	2-8	5

3.2. Asphalt cover

In this research, 60/70 penetration grade of asphalt from Jordan Petroleum Refinery. Table 3 shows the test and with ASTM D with results.

Table 3: Shows the test and results of asphalt

Test	ASTM D	Results
Ductility, 25°C, Cm	113	110
Penetration, 25 ^{0}C, 100 g, 5 s, 0.1 mm	5	65
Softening Point, ^{0}C	36	50
Flash Point (Cleveland Open Cup), ^{0}C	92	330
Fire Point, ^{0}C	92	335
Specific Gravity, 25 ^{0}C	70	1.01 4

4. Laboratory performance

Laboratory research was performed to show the effect of different grades of segregation. In this paper a description of tests utilized is explained.

4.1. Mixture Preparation

To define the OAC by weight of total mixture, the method indicated by the standard Asphalt Institute MS-2 Manual (2008) and ASTM D1559 (2000) was determined using Marshal Mix design. Samples for the purpose of mix design were compressed using 75 strokes on both sides with a Marshall hammer. An OAC of 5.4% was chosen for a 6% void space. Five mixtures with different degrees of segregation were evaluated in the laboratory. A mixture with median gradation based on the specification of MPWH cover gradation and an asphalt content of 5.4% was used as one degree of segregation (mixing design). This heated mixture was sieved over a 10-mm (3/8.in) sieve creating course (retained) and fine (passing) mixtures performing the extremes of segregation. Two other mixtures with intermediate degrees of segregation were generated by joining percentages of the very coarse (+10 mm) and very fine material (-10 mm) as shown in Table 4 (1 mm=0.04 in). Mixture 1 and 5 have visible segregation; There is no visible segregation between 2, 3 and 4.

Table 4: Segregation Classification for five mixtures.

Segregation Classification with Mix No.	Percentage of material	
	+ 10 mm	-10 mm
Mix. 1=Very Fine	0.0	100.0
Mix. 2=Fine	24.0	76.0
Mix. 3=Mix Design	48.3	51.7
Mix. 4=Coarse	74.0	26.0
Mix. 5=Very coarse	100.0	0.0

4.2. Extracted Content

Three extraction tests (ASTM D2171, Method B) were shown for each of the all mixtures. the content of asphalt is expressed as a percentage by weight relative to the total weight of the moisture free mixture. The average was (9.4, 7.1, 5.4, 3.5 and 2.3) percent for Mixes, respectively. The asphalt content for each mixture was determined using extraction tests.

4.3. Sample Gradation

The gradation of the extracted aggregate was presented based on ASTM C136. The gradation is shown in Figure 5.

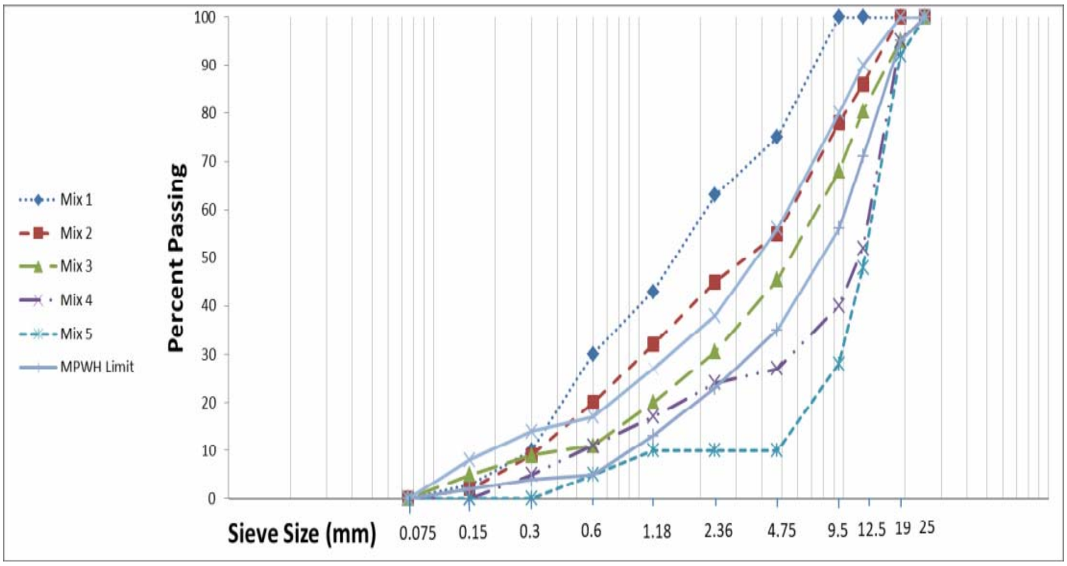


Figure 5: Aggregate Gradations for Five Mixtures.

4.4. Rutting Test

The permanent deformation (rutting) test was performed by using static uniaxial loading strain test. Three specimens were tested. The procedure for the identification of resistance to permanent deformation (rutting) of bituminous mixtures subject to unconfined uniaxial loading comprises the application of a static load to a sample for 3600 second loading at various temperatures ($20^{O}C$, $25^{O}C$, and $30^{O}C$). It is utilized by Universal Testing Machine (UTM). This test was done in accordance with UTM Reference Manual (1996) also BSI standards. Samples were put in a cabinet with an appropriate force air circulation, in which the sample obtains the test temperature for 24 hours, after that the test was utilized for various level of temperatures ($20^{O}C$, $25^{O}C$, and $30^{O}C$). A software program in a stress of 10 KPa for 20 second was used for making conditioning. Sample was succumbed to static loading for 3600 second with a stress of 100 KPa. Then sample was levelled by using Linear Variable Displacement Transformers (LVDTs). Finally, accumulated strain, creep stiffness, accumulated strain slope and temperature data were measured using a computer. Figure 6 shows the testing setup.

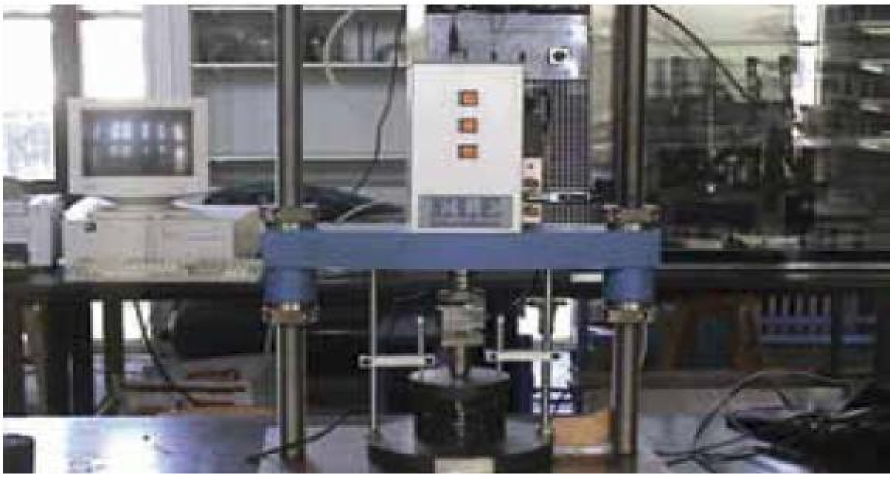
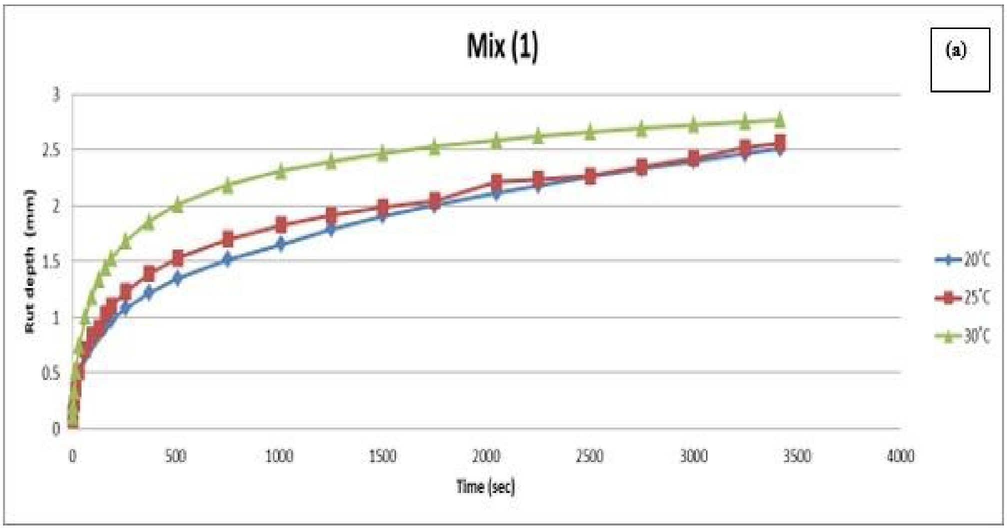
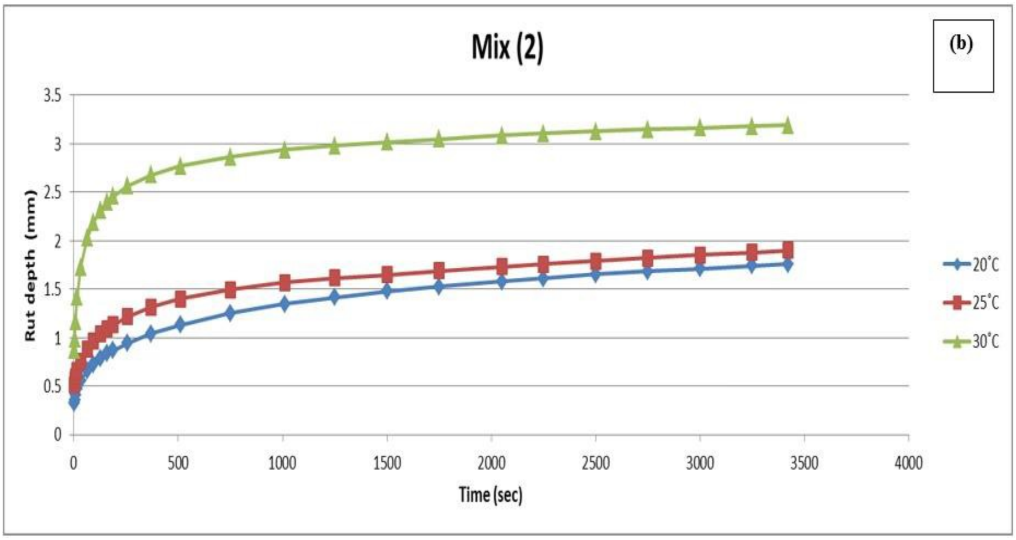


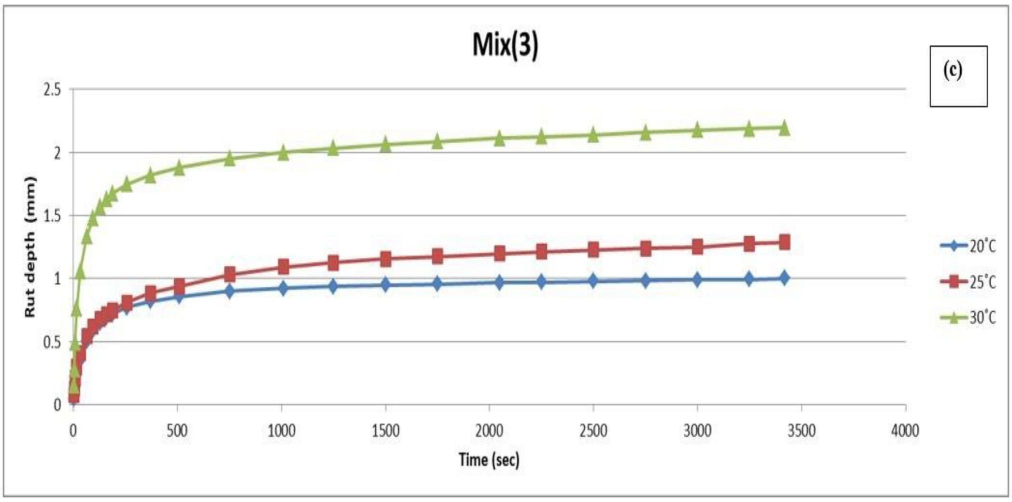
Figure 6: Specimen in the Static Creep Frame of a UTM.

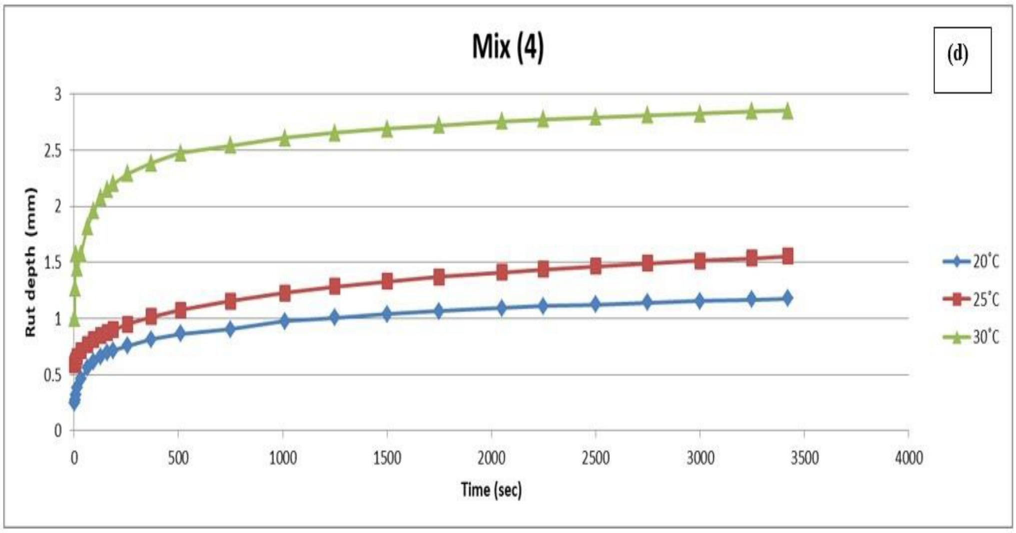
5. RESULTS AND DISCUSSION

In this study many different techniques and test procedures have been utilized. The results of applying these techniques and tests are discussed. segregation for all mixtures was measured by simulation. Figure 7 shows the relationship between rutting (mm) and time (seconds) for mixes, respectively. The influence of degree of segregation on the rutting values at different temperatures ($20^{O}C$, $25^{O}C$, and $30^{O}C$) for different mixtures is shown in Figure 8.




Mix (2)
(b)
Rut depth (mm)
3.5
3
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000
3500
4000
Time (sec)
20°C
25°C
30°C


Mix(3)
(c)
Rut depth (mm)
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000
3500
4000
Time (sec)
20°C
25°C
30°C


Mix (4)
(d)
Rut depth (mm)
3
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000
3500
4000
Time (sec)
20°C
25°C
30°C

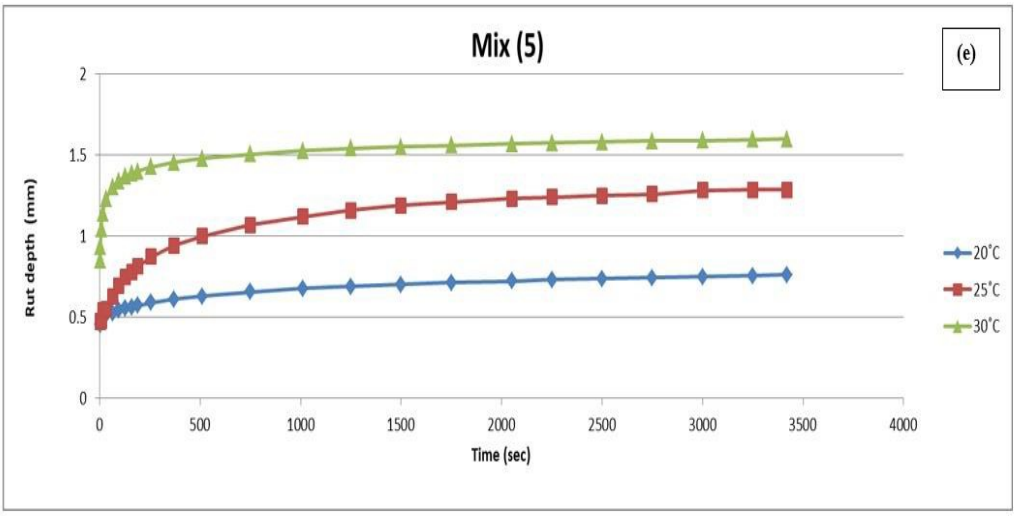


Figure 7: The relationship between RD (mm) and time (seconds) for all mixes.

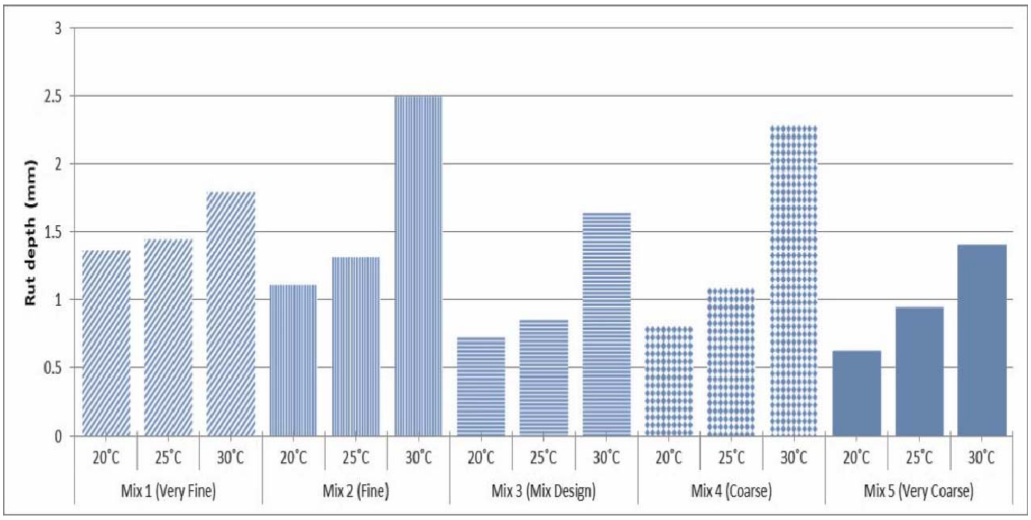


Figure 8: The influence of degree of segregation at different temperatures.

The following are observations made during the rutting test as follows:

1. In Figure 8, the rutting values (mm) rises to a maximum value with increasing the temperature; where all mixtures have a greatest value for rutting at 30^{O}C, compared with the rutting values at 20^{O}C and 25^{O}C; respectively. This result agrees with the causes of rutting where the high temperature is the most important reason for rutting occurrence.
2. In general, Mixes 1,2 and 4 are more sensitive to rutting at different temperatures than Mixes 5 and 3; whereas Mixes 5 and 3 creates a potential for fatigue, fretting, thermal cracking and raveling. These results correspond with the rutting potential using the Purwheel tracking devices investigated by Khedaywi and White (1996).
3. Mixture 1 is the worst and having a higher amount of rutting, whereas Mixture 5 is the better and having the lower values of rutting. Mixture 3 is considered as a control.
4. Results for the all mixtures indicate a log relation between rutting values (mm) as well as time (seconds). Table 3 shows the developments of models for rutting values (mm) with corresponding R^2.
5. The segregation has a major effect on the rutting performance of concrete mixtures.
6. The more finely segregated asphalt mixture (lack of coarse aggregate) will exhibit longer fatigue life and will make the mixture more sensitive to rutting.

Table 3: Developments of models for Rutting Values.

Mixture Number	Temperature (C°)	Equations*	R^2
Mix 1 (Very Fine)	$20^{o}C$	Y=0.3551ln(x)-0.5844	0.9564
	$25^{o}C$	Y=0.3551ln(x)-0.5844	0.9564
	$30^{o}C$	Y=0.3965ln(x)-0.4754	0.9877
Mix 2 (Fine)	$20^{o}C$	Y=0.2128ln(x)-0.1021	0.9433
	$25^{o}C$	Y=0.2041ln(x)+0.1489	0.9682
	$30^{o}C$	Y=0.3266ln(x)+0.6308	0.9867
Mix 3 (Mix Design)	$20^{o}C$	Y=0.1391ln(x)-0.0749	0.9755
	$25^{o}C$	Y=0.1746ln(x)-0.1448	0.9939
	$30^{o}C$	Y=0.2747ln(x)+0.0743	0.9681
Mix 4 (Coarse)	$20^{o}C$	Y=0.1365ln(x)+0.0324	0.9848
	$25^{o}C$	Y=0.1437ln(x)+0.2668	0.9151
	$30^{o}C$	Y=0.2472ln(x)+0.8724	0.9864
Mix 5 (Very Coarse)	$20^{o}C$	Y=0.0455ln(x)+0.366	0.9479
	$25^{o}C$	Y=0.1308ln(x)+0.197	0.9502
	$30^{o}C$	Y=0.0944ln(x)+0.8674	0.9719
*Y=RD (mm) and x=Time (sec)			

6. CONCULSIONS

The following conclusions can be made based on the rut test conducted in this study:

1. In general, segregation has a significant influence on the rutting performance of the asphalt concrete mixture.
2. The predictive model is statistically significant with a multiple determination coefficient R^2 about 0.9 for all mixtures at different temperatures; also, the model and the included variables had a high level of significance; there is an increase in the rutting potential of the asphaltic mixtures as the degree of segregation increases.
3. Temperature has a significant effect on rutting potential; so as temperature increases, the mixture will more susceptible to rutting.
4. Rutting values increases with time for different level of segregation at different levels of temperatures.
5. Maximum rutting value was found at 30 C^{o} and was (2.8 mm) for mix 1 (very fine).
6. Minimum rutting value was found at 20 C^{o} and was (0.04 mm) for mix 3 (mix design) then for mix 5 (very coarse) it was (0.4mm) at same temperature.
7. The more coarsely SAM decreases the potential for rutting; otherwise the more finely SAM increase the performance of rutting.
8. Ultimately, a correlation with the field performance of the mixture will be required.
9. Additional testing of the mixture with other aggregates should be conducted and planned.

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