STATE OF FLORIDA

Analysis of APA Rut Data for Production Laboratory Mix Design Pills With and Without Polymer Modified Binder

Research Report

FL/DOT/SMO/07-501

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1 Executive Summary

The main objective of this study was to compare the Asphalt Pavement Analyzer (APA) test results obtained from fine graded Superpave mixtures made with two different asphalt binders; a PG 67-22 and a PG 76-22 binder. A total of 54 asphalt mixtures, each made with the above mentioned binders were included in this study. For each binder type, two replicate specimens each were prepared and tested in the APA. A total of 216 specimens were thus tested. Additional information including air void content of each specimen, and all available volumetric mixture design data was also obtained and compiled into a database for analysis. The results of the subsequent analysis are presented in this report.

2 Experiment Design and Objective

2.1 BACKGROUND

The Florida Department of Transportation (FDOT) specifies several different asphalt binders for use in asphalt mixtures in the state's transportation system. The most commonly used binder is a PG 67-22 (where PG stands for 'Performance Graded' and the two numbers are the temperature ranges in degrees Celsius for which the binder meets specifications.) Most other binders used in the state are derivatives of this binder. A newer binder, designated as PG 76-22 has also been specified for heavily trafficked roadways. This binder is a combination of PG 67-22 and one or more polymers blended together. A commonly used polymer is Styrene-Butadiene-Styrene or SBS. The polymer modified binder increases the rutting resistance of asphalt mixtures by remaining stiffer at higher temperatures.

The Department also specifies several different asphalt mixture types. All asphalt mixtures in the state, with the exception of open-graded friction courses, are designed with the Superpave criteria. In Florida, Superpave mixtures consist of three nominal maximum aggregate sizes (9.5, 12.5, and 19.0 mm) and can be either coarse or fine graded. Mixture size is determined by the lift, thickness, and location. The traffic level of the pavement governs the type of gradation. Pavements with a design life of less than 10 million equivalent single axle loads (ESALs) are designated as traffic level A, B, or C and have fine gradations. Pavements with a design life of more than 10 million ESALs are designated as either traffic level D or E and have coarse or fine gradations. Research at the Department's accelerated pavement testing facility and at the National Center for Asphalt Technology indicates that fine graded mixtures can perform equally as well or better than coarse graded mixtures. Therefore, in 2005, the Department's policy was changed to allow fine graded mixtures for traffic level D or E projects. This study focuses on APA rut depths for fine graded mixtures only since most contractors will or already have switched to this mixture type due to improved constructability and economic factors.

2.2 PREVIOUS RESEARCH

FDOT has conducted several studies including laboratory and Accelerated Pavement Tests (APT) to evaluate the rutting performance of asphalt mixtures with SBS modified asphalt binder[1,2]. In addition, FDOT also conducted a full-scale study at the National Center for Asphalt Technology (NCAT) to evaluate the performance of SBS modified and unmodified binders. These studies concluded that the SBS polymer modified binder clearly outperformed the unmodified binder in terms of rutting resistance. To extend previous research, this study was initiated with the objective of investigating the effect of polymer modified binder for a wide range of fine graded mixtures.

2.3 ASPHALT PAVEMENT ANALYZER (APA)

The Asphalt Pavement Analyzer (APA) is the new generation of the Georgia Loaded Wheel Tester. The APA has additional features that include a water storage tank and is capable of testing both gyratory and beam specimens. Three beam or six gyratory samples can be tested simultaneously. Wheel loads are applied on test samples by means of three pneumatic cylinders, each equipped with an aluminum wheel. The magnitude of the load applied on each sample is regulated by air pressure supplied to each pneumatic cylinder. The load from each moving wheel is transferred to a test sample through a stiff pressurized rubber hose mounted along the top of the specimen. The purpose of the pressurized hose is to simulate a tire. The pressure in the three hoses is regulated by a common pressure regulator so that the pressure in the three hoses should always be the same. The equipment is designed to evaluate not only the rutting potential of an HMA mixture, but also its moisture susceptibility and fatigue cracking under service conditions[3].

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[1] Laboratory Mixture and Binder Rutting Study, Research Report FL/DOT/SMO/03-465

[2] Evaluation of Rutting Resistance of Superpave Mixtures With and Without SBS polymer Modification by Means of Accelerated Pavement Testing, TRB/NAS 03-1226

[3] Investigation of the Suitability of the Asphalt Pavement Analyzer for Predicting Pavement Rutting, Research Report FL/DOT/SMO/98-427

In this study, a total of 54 asphalt mixtures (41 TL-D and 13 TL-E mixtures) were evaluated using the APA. These mixtures were prepared using both the modified and unmodified asphalt binders. Two gyratory specimens conforming to the test specifications were prepared for each mixture for both binder types, resulting in a total of 216 gyratory specimens. The air void content of each specimen was determined prior to testing. The specimens were then conditioned according to test specifications and subsequently tested in the APA. In addition, complete mixture design data was also obtained for each of the mixtures considered in this study. The raw APA data is provided in Appendix A.

2.4 OBJECTIVE

The main objective of this research was to evaluate the rutting performance of mixtures made with SBS polymer modified binder as compared to the same mixture made with unmodified binder. The effects of various mixture design components such as air void content, percentage of sand in the mix, VMA, FAA, optimum asphalt content and the percent of maximum density at initial number of gyrations (% Gmm @ N_{ini}) was also evaluated. In addition, effects of the percent of coarse aggregates (%CA) as a function of the total aggregate structure and the porosity of the mixture were also evaluated.

3 Summary of All Mixture Data

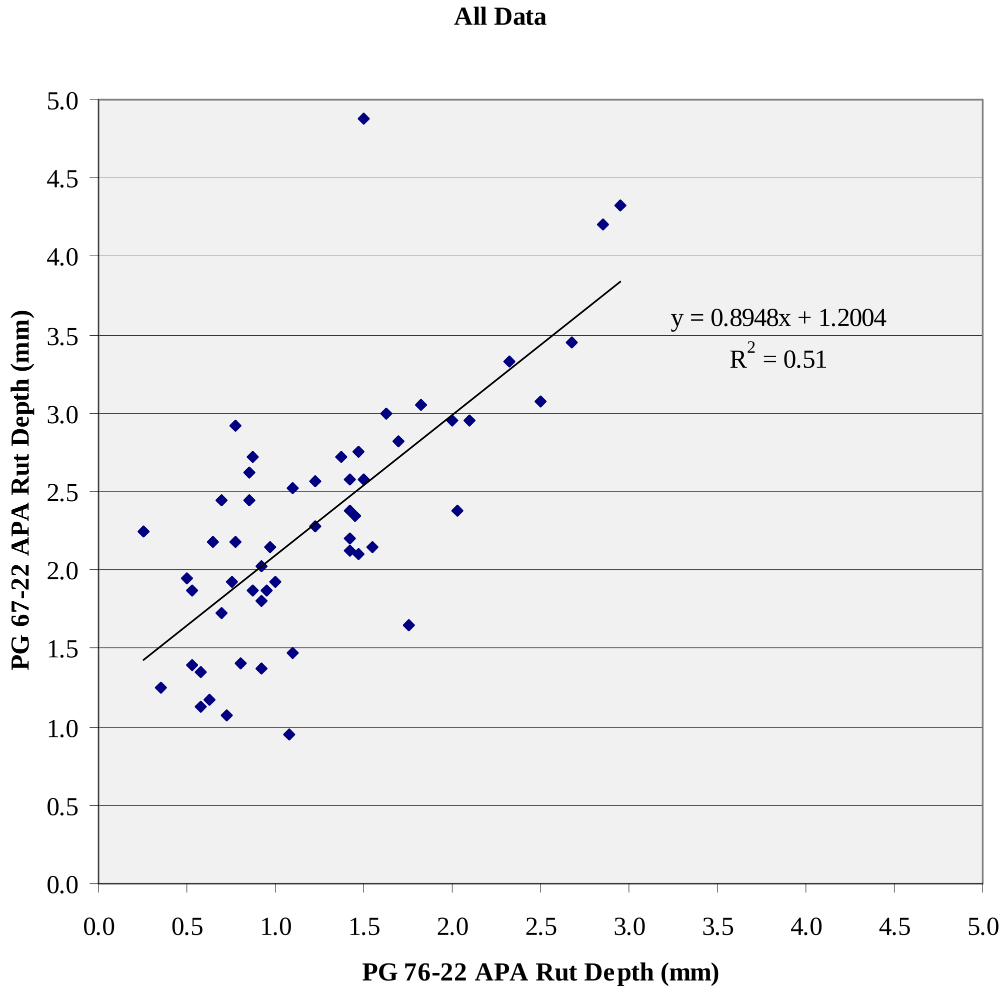


Figure 1 PG 67-22 Versus PG 76-22 APA Rut Data (All Data).

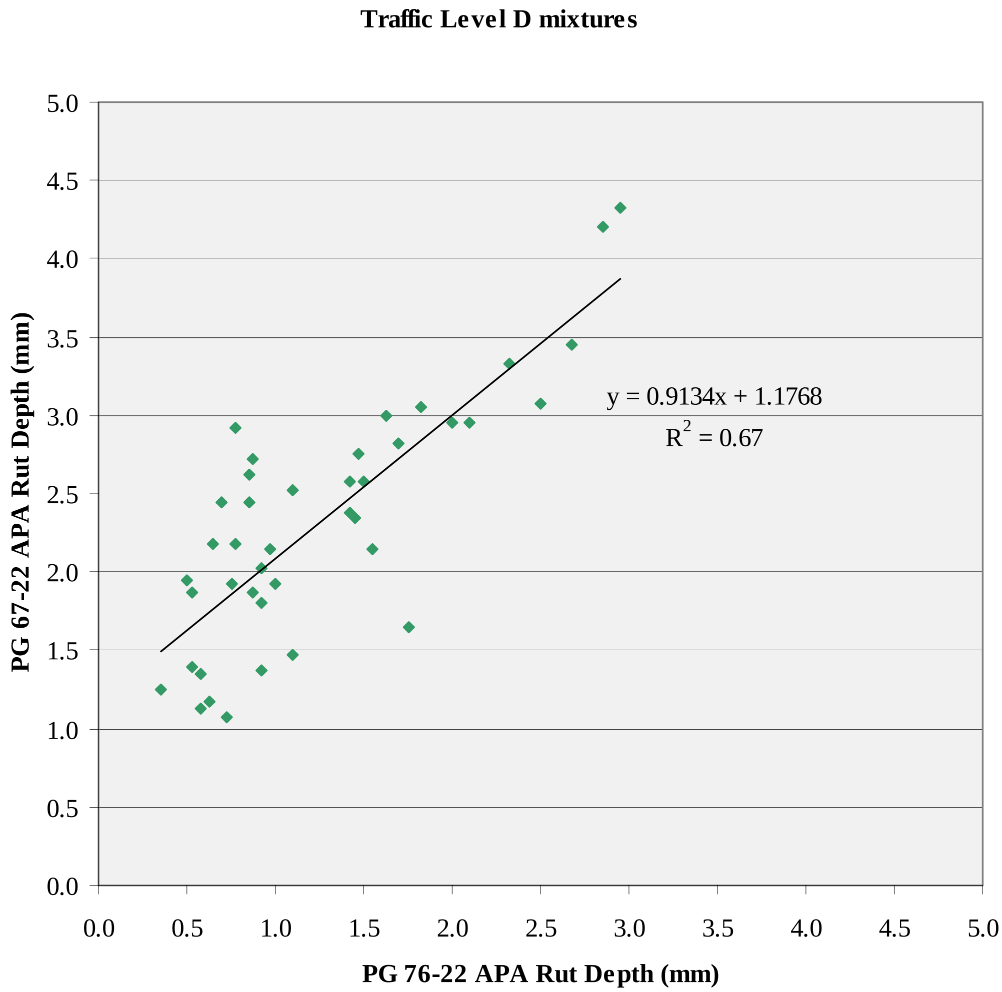


Figure 2 PG 67-22 Versus PG 76-22 APA Rut Data (Traffic Level D Mixtures).

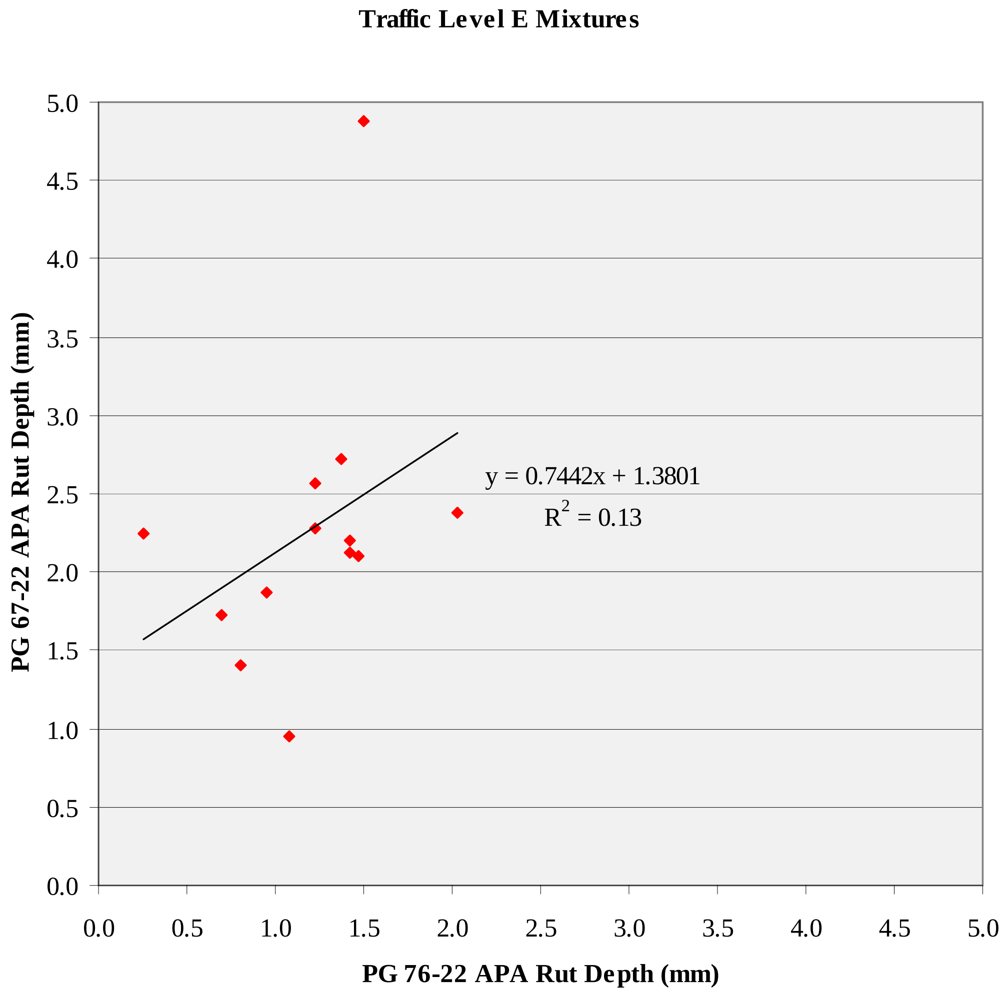


Figure 3 PG 67-22 Versus PG 76-22 APA Rut Data (Traffic Level E Mixtures.)

Table 1 Descriptive Statistics for APA Rut Data

Binder Type		N	Mean (mm)	Median (mm)	St. Dev (mm)	Min. (mm)	Max. (mm)
PG 67-22	All Data	54	2.33	2.25	0.80	1.00	4.90
	TL – D	41	2.34	2.40	0.77	1.10	4.30
	TL – E	13	2.28	2.20	0.92	1.00	4.90
PG 76-22	All Data	54	1.25	1.10	0.64	0.30	3.00
	TL – D	41	1.27	1.00	0.70	0.40	3.00
	TL – E	13	1.20	1.20	0.43	0.30	2.00

A careful examination of the data revealed that a majority of the mix designs (46 out of 54) had a 15% RAP content, as shown in Figure 4. 6 mixes had 0% RAP, while 1 mix each had 10% and 27% RAP respectively. In order to eliminate any compounding effects from varying percentages of RAP in the mix, it was decided to consider only those mixes containing 15% RAP. All further statistics were therefore performed on a slightly reduced data set comprising of 46 mix designs.

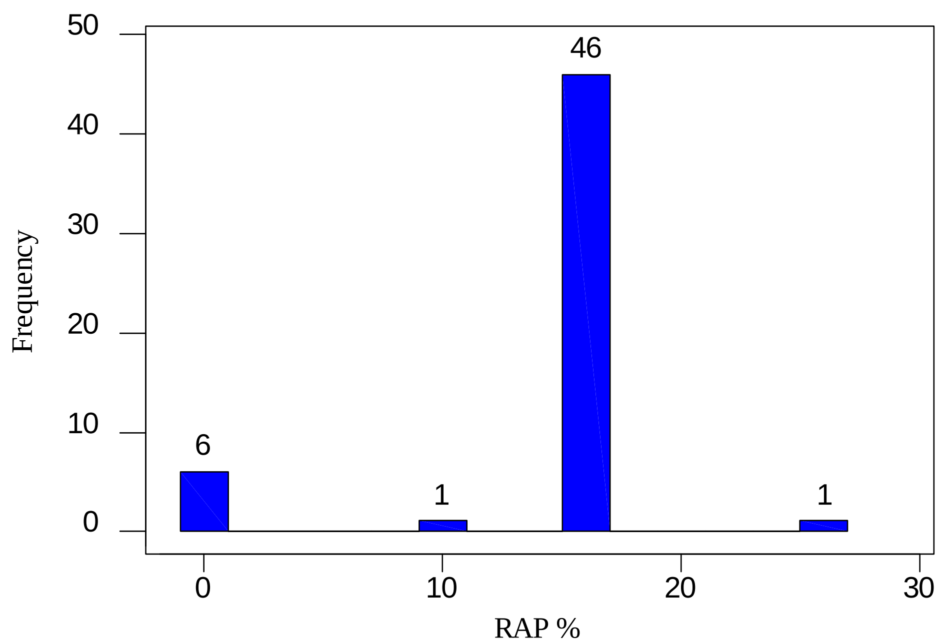


Figure 4 Histogram of RAP Content in the Mixtures Considered

The revised descriptive statistics for the new set of data are exhibited in Table 2.

Table 2 Descriptive Statistics for Revised APA Rut Data

Binder Type		N	Mean (mm)	Median (mm)	St. Dev (mm)	Min. (mm)	Max. (mm)
PG 67-22	All Data	46	2.33	2.20	0.82	1.00	4.90
	TL – D	35	2.34	2.20	0.77	1.10	4.30
	TL – E	11	2.82	2.20	1.00	1.00	4.90
PG 76-22	All Data	46	1.21	1.00	0.63	0.30	3.00
	TL – D	35	1.24	0.90	0.70	0.40	3.00
	TL – E	11	1.10	1.20	0.38	0.30	1.50

4 Effect of Specimen Air Void Content on APA Rut Data

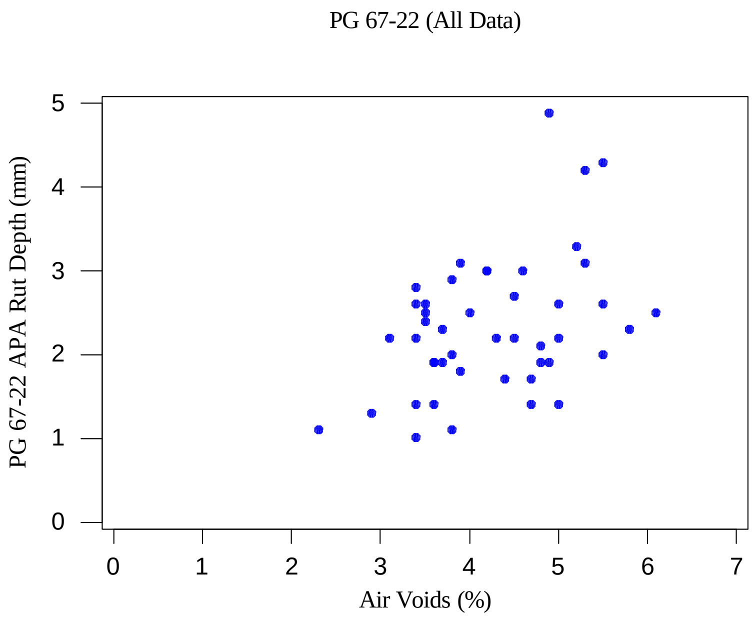


Figure 5 APA Rut Depth Versus Air Void Content (PG 67-22 All Mixture Data)

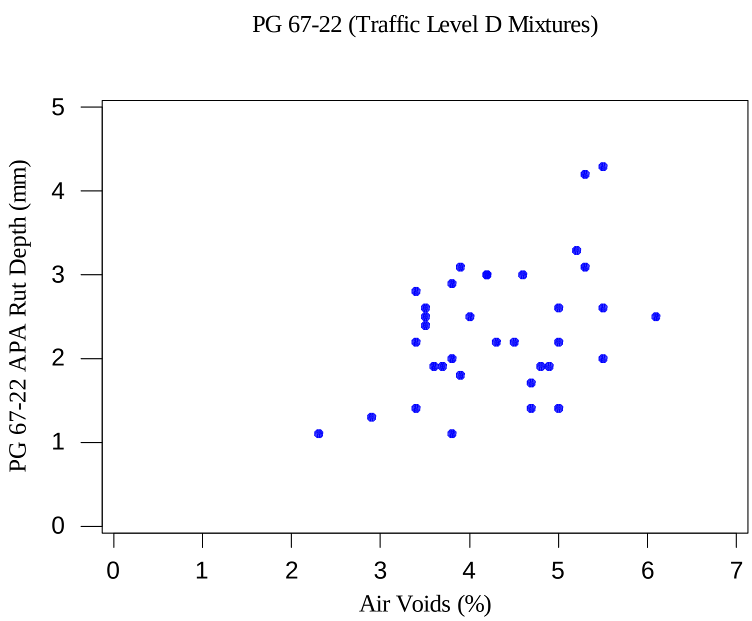


Figure 6 APA Rut Depth Versus Air Void Content (PG 67-22 Traffic Level D Mixtures)

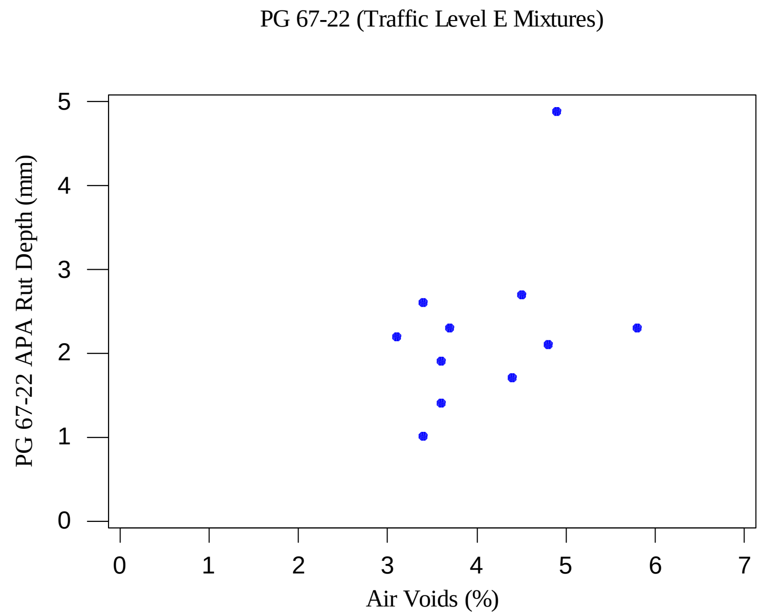


Figure 7 APA Rut Depth Versus Air Void Content (PG 67-22 Traffic Level E Mixtures)

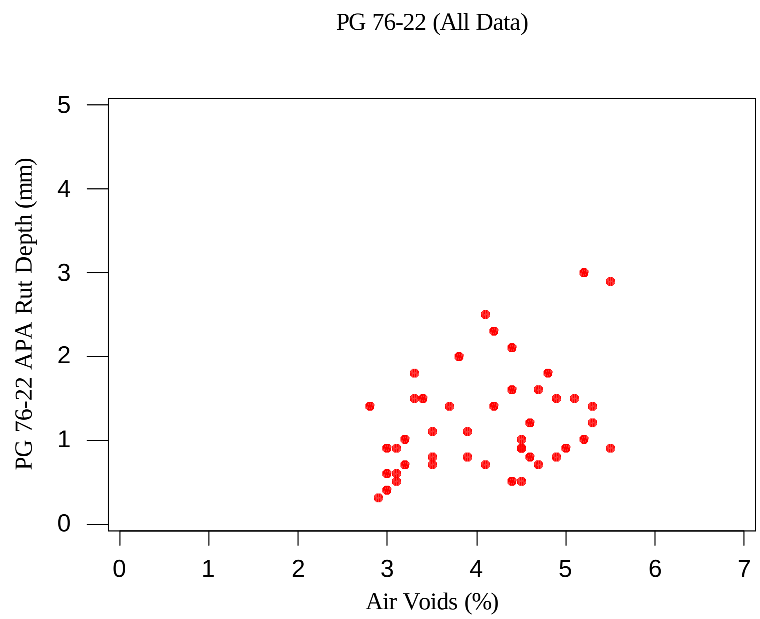


Figure 8 APA Rut Depth Versus Air Void Content (PG76-22 All Mixture Data)

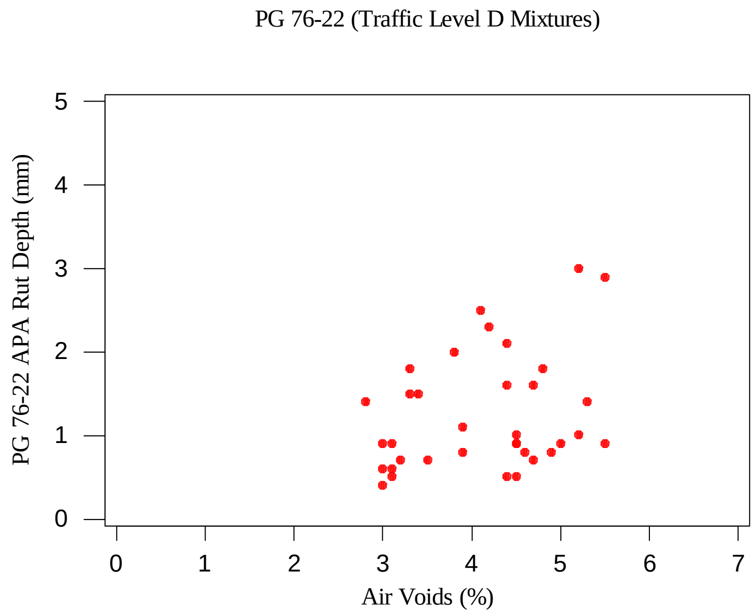


Figure 9 APA Rut Depth Versus Air Void Content (PG 76-22 Traffic Level D Mixtures)

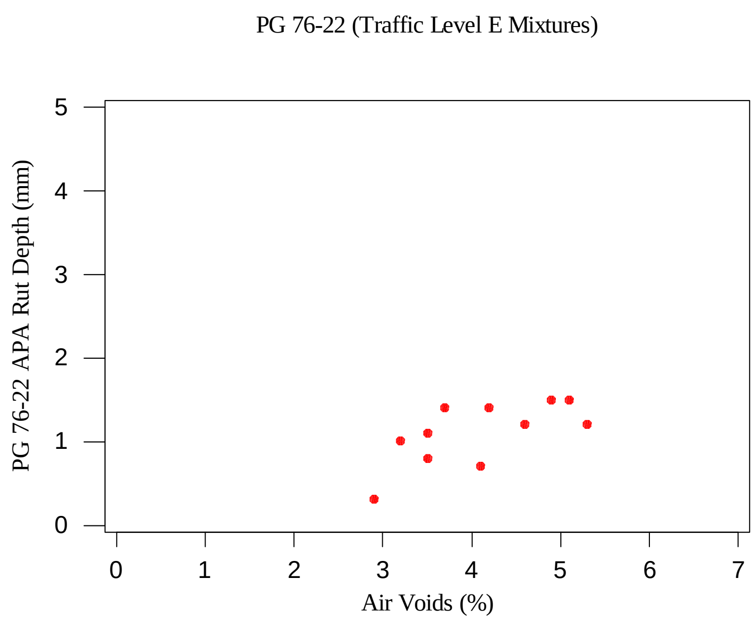


Figure 10 APA Rut Depth Versus Air Void Content (PG 76-22 Traffic Level E Mixtures)

5 Descriptive Statistics for PG 67-22

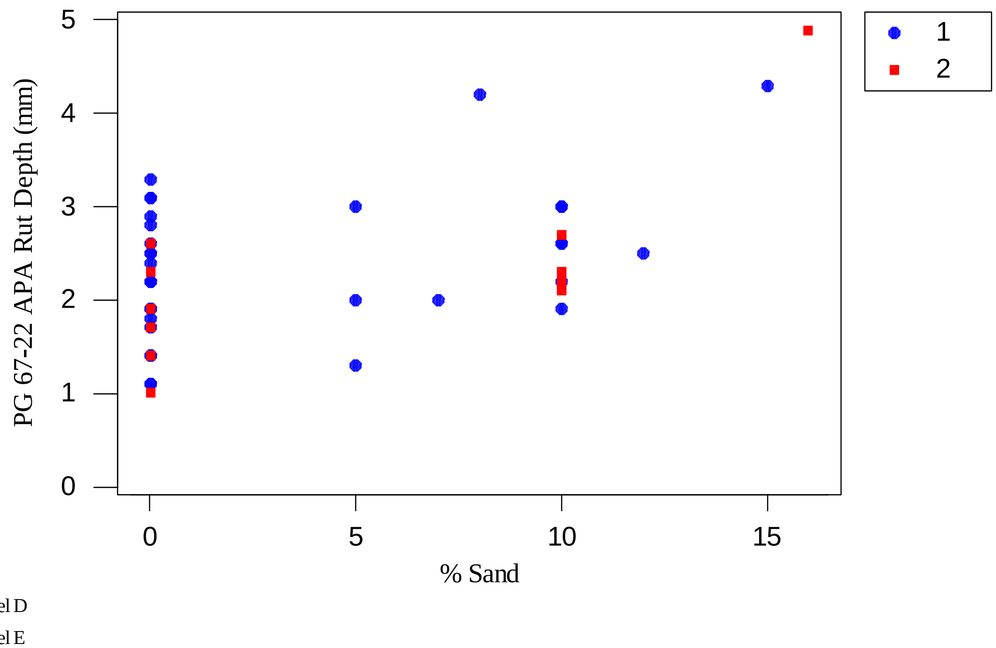


Figure 11 APA Rut Depth Versus % Sand (PG 67-22)

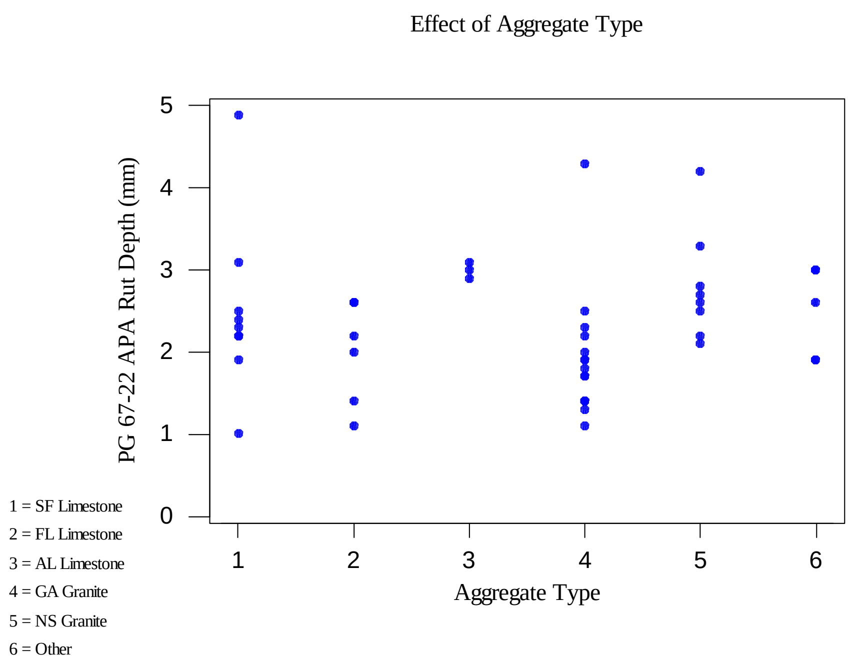
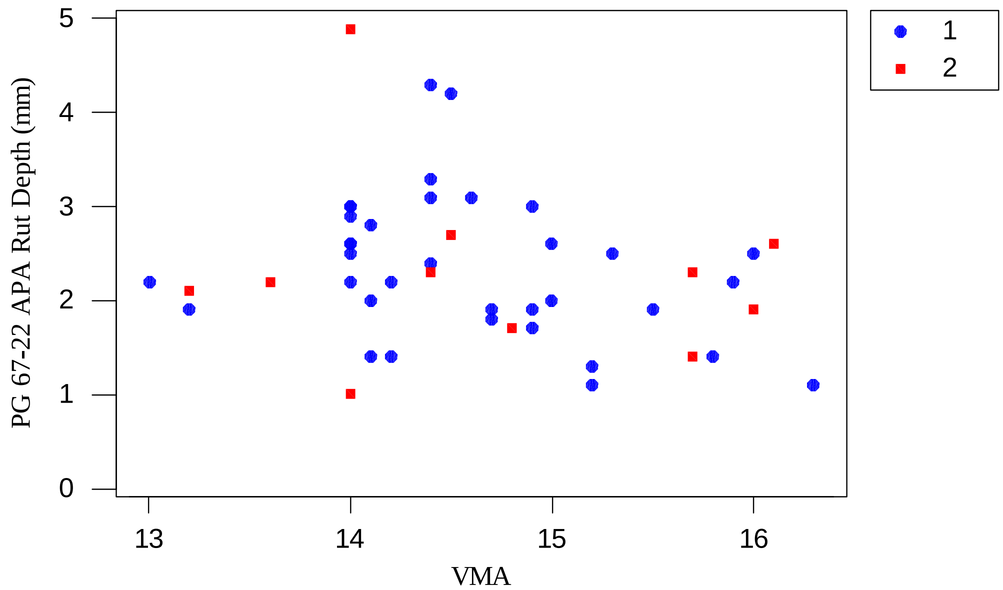
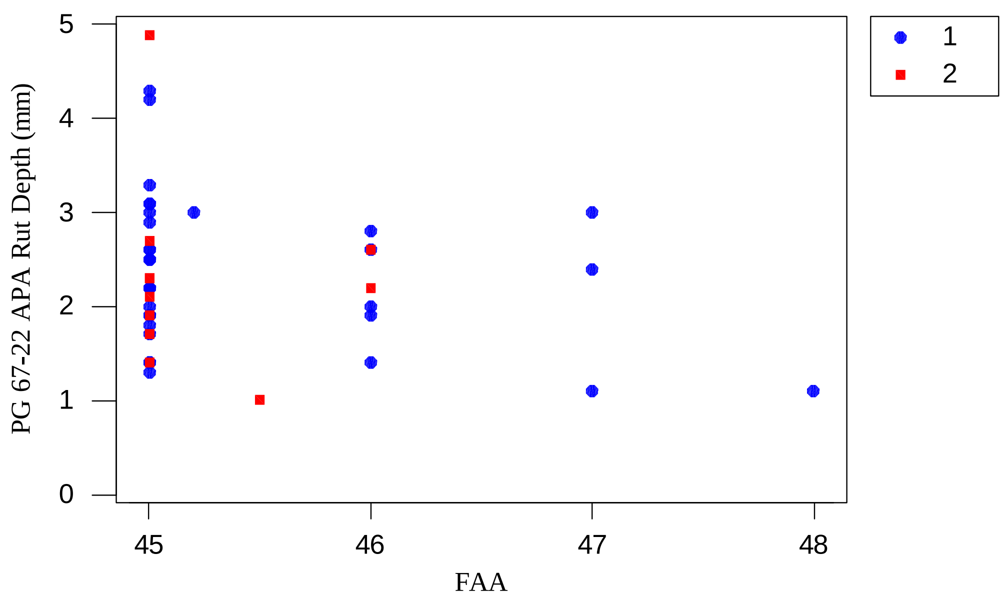


Figure 12 APA Rut Depth Versus Aggregate Type (PG 67-22)



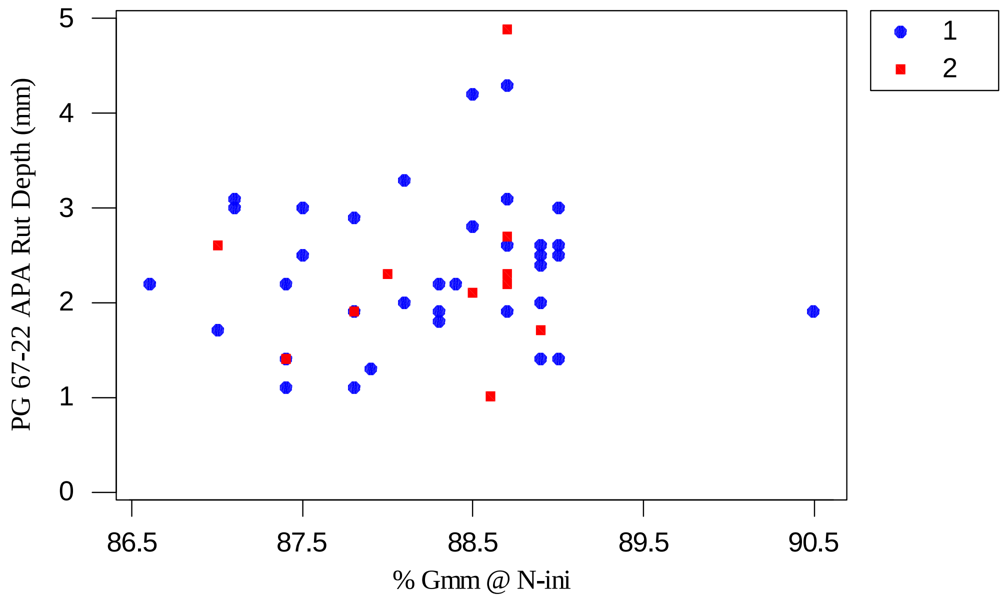
1 = Traffic Level D
2 = Traffic Level E

Figure 13 APA Rut Depth Versus VMA (PG 67-22)



1 = Traffic Level D
2 = Traffic Level E

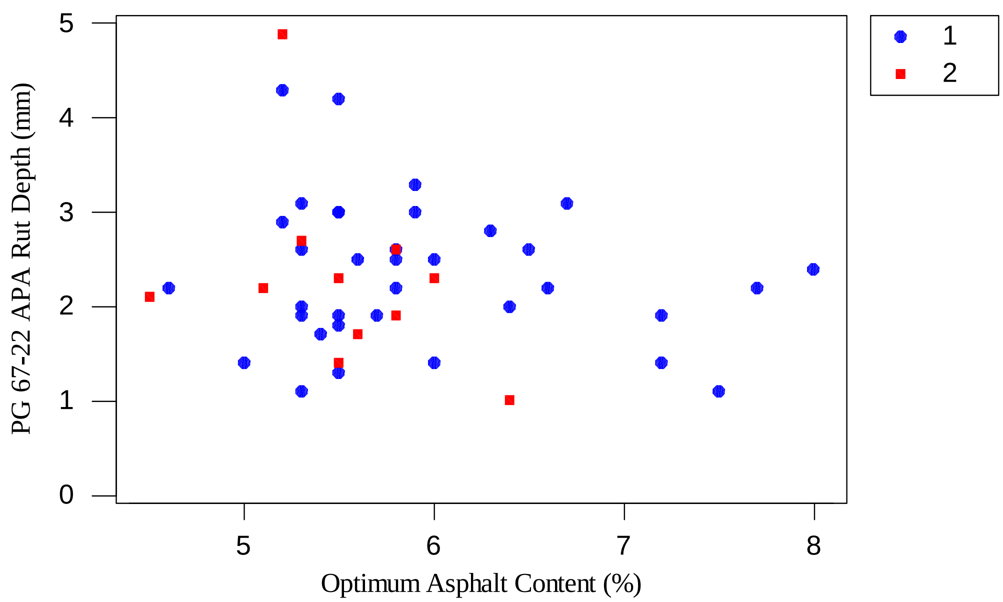
Figure 14 APA Rut Depth Versus FAA (PG 67-22)



1 = Traffic Level D

2 = Traffic Level E

Figure 15 APA Rut Depth Versus % G_{mm} @ N_{ini} (PG 67-22)

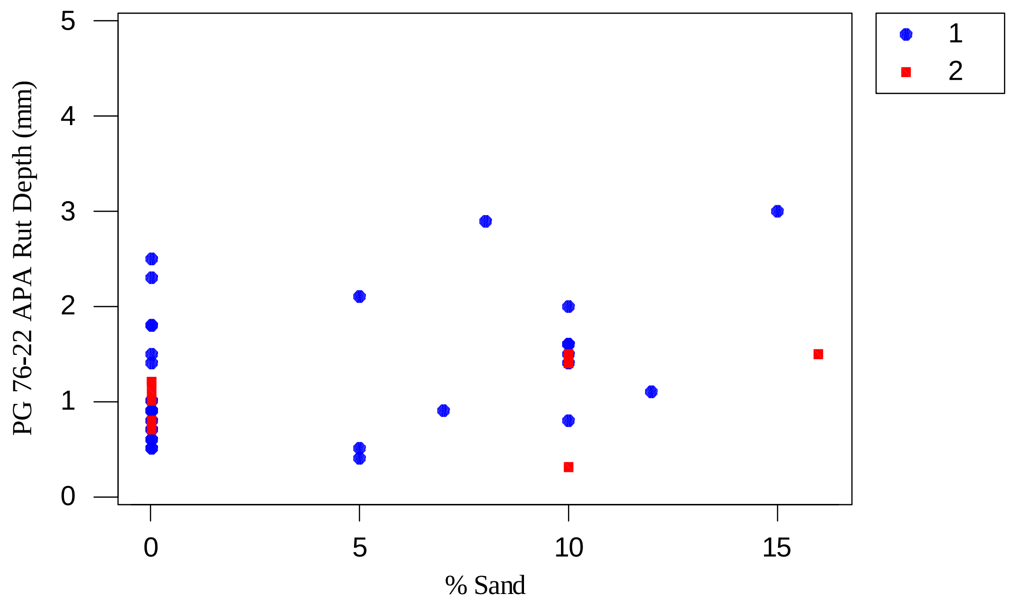


1 = Traffic Level D

2 = Traffic Level E

Figure 16 APA Rut Depth Versus Optimum Asphalt Content (PG-67-22)

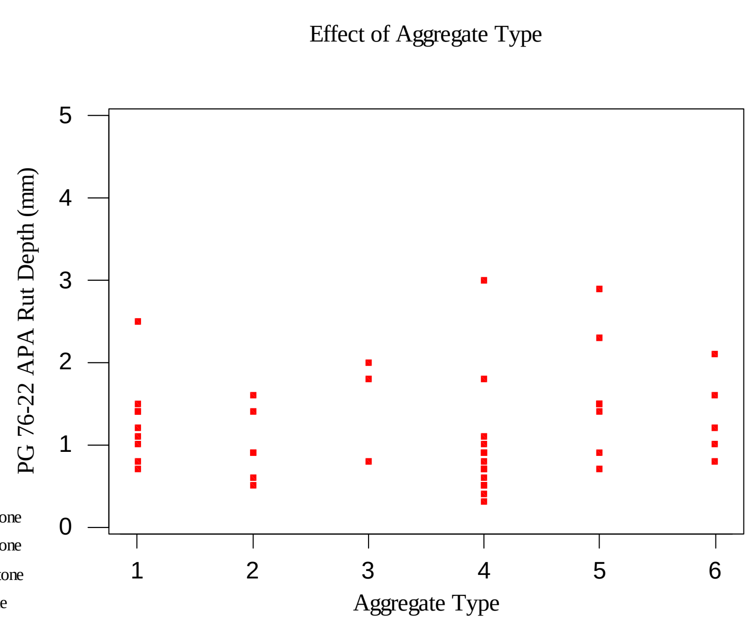
6 Descriptive Statistics for PG 76-22



1 = Traffic Level D

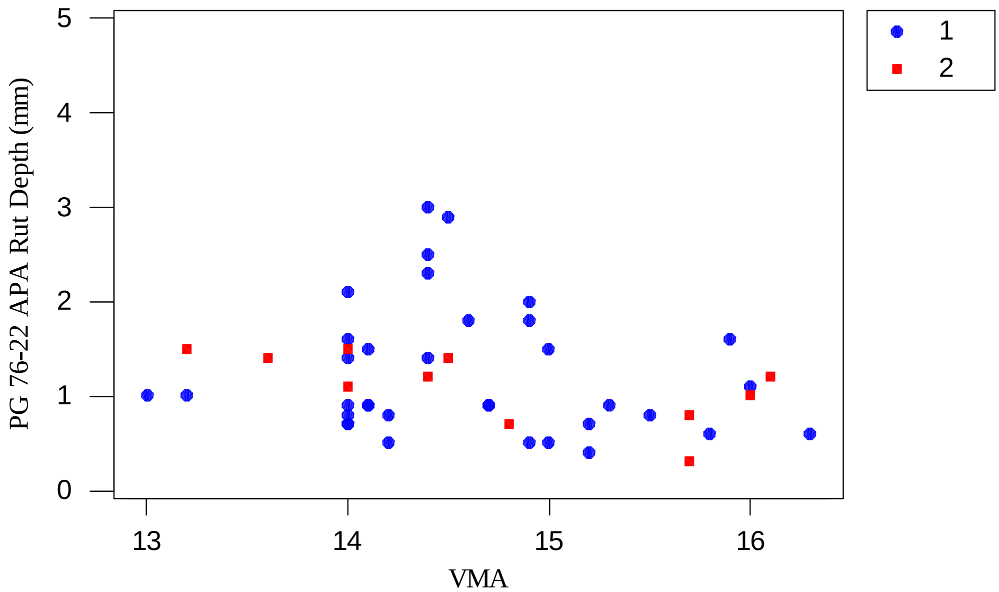
2 = Traffic Level E

Figure 17 APA Rut Depth Versus % Sand (PG 76-22)



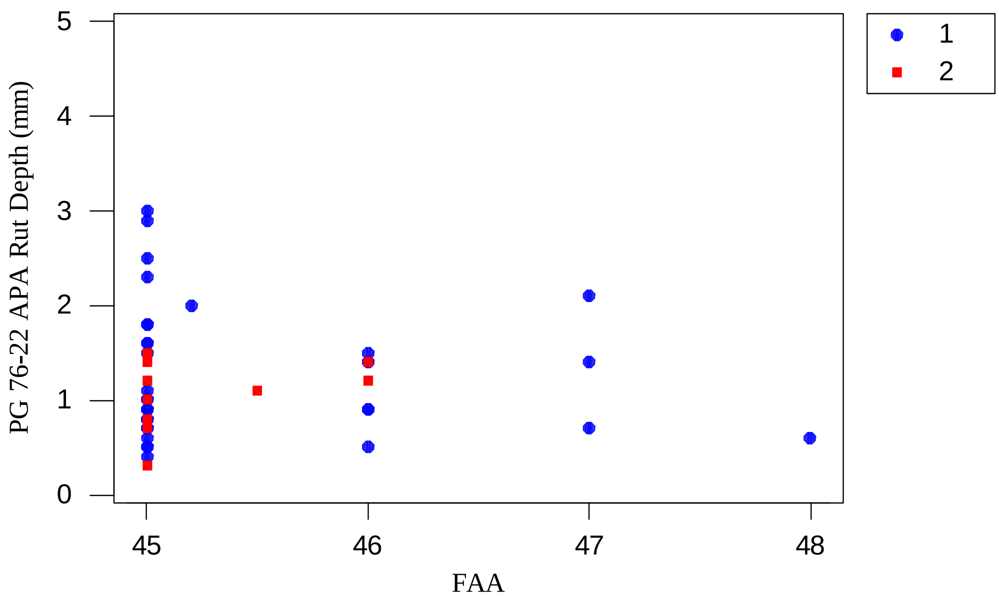
1 = SF Limestone
2 = FL Limestone
3 = AL Limestone
4 = GA Granite
5 = NS Granite
6 = Other

Figure 18 APA Rut Depth Versus Aggregate Type (PG 76-22)



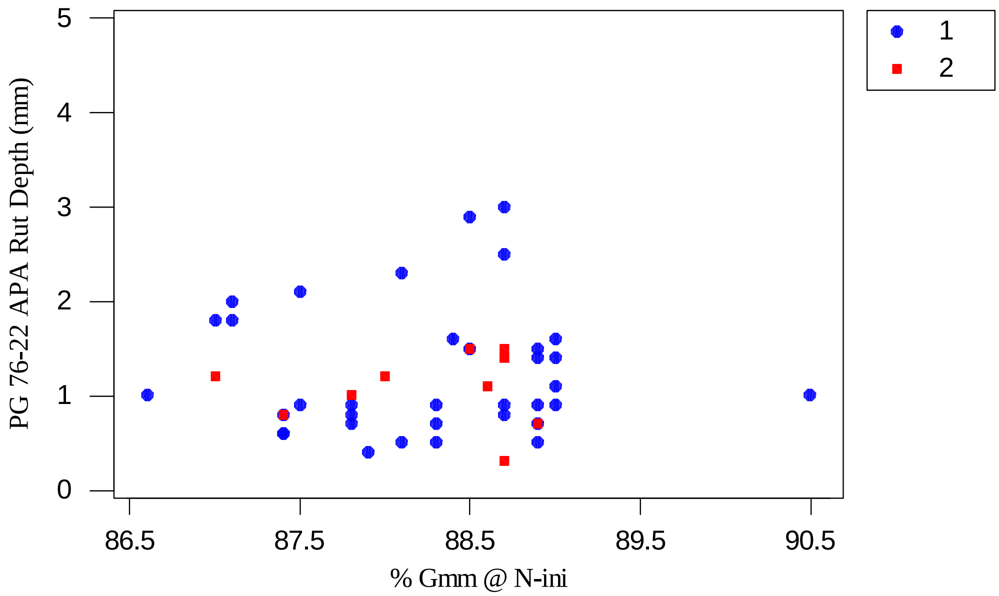
1 = Traffic Level D
2 = Traffic Level E

Figure 19 APA Rut Depth Versus VMA (PG 76-22)



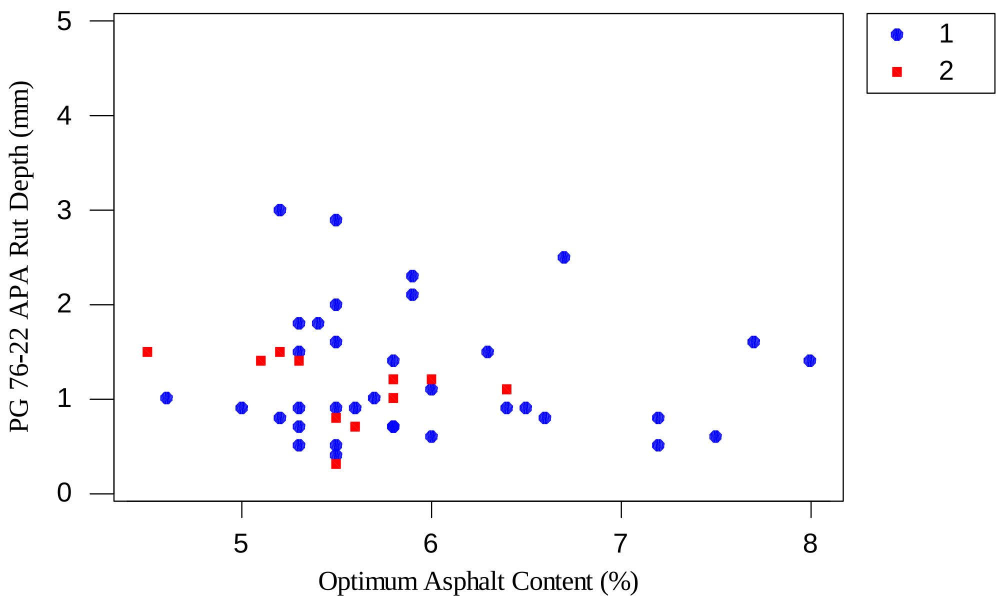
1 = Traffic Level D
2 = Traffic Level E

Figure 20 APA Rut Depth Versus FAA (PG 76-22)



1 = Traffic Level D
2 = Traffic Level E

Figure 21 APA Rut Depth versus % G_{mm} @ N_{ini} (PG 76-22)



1 = Traffic Level D
2 = Traffic Level E

Figure 22 APA Rut Depth versus Optimum Asphalt Content (PG 76-22)

7 Analysis of Variance

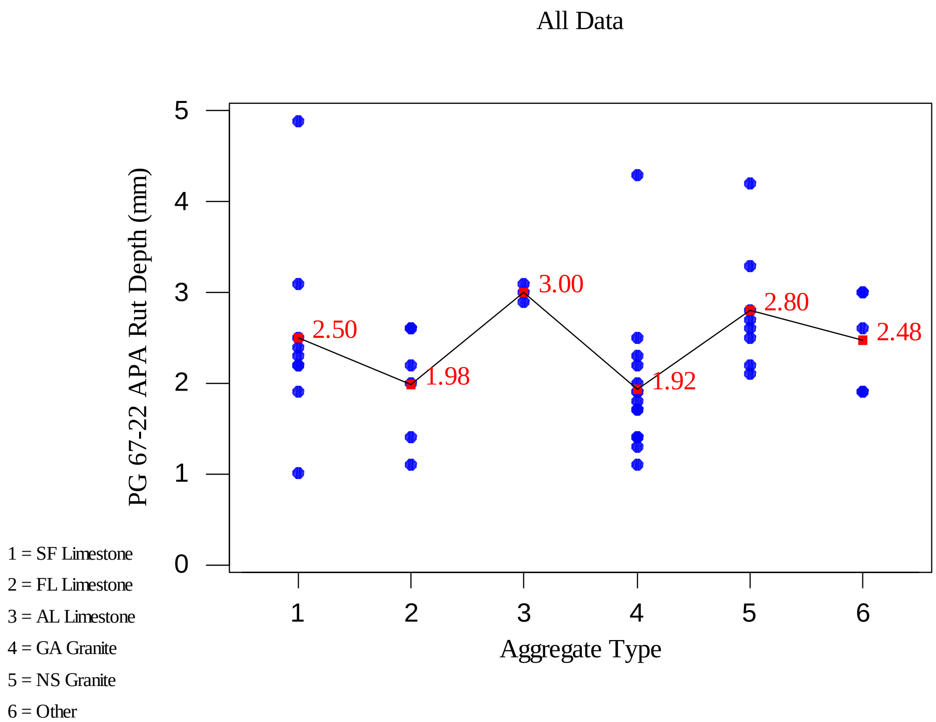
7.1 EFFECT OF AGGREGATE TYPE

An Analysis of Variance (ANOVA) was performed to determine the effect of type of aggregate on the measured APA rut depth. The mixture design data revealed that 6 types of aggregates were used in these mixtures (total of 46 mixtures). For analysis purposes, the aggregate types were coded as detailed below:

Code	Aggregate Source
1	SF Limestone
2	FL Limestone
3	AL Limestone
4	GA Granite
5	NS Granite
6	Other / Combination

Table 3 One Way ANOVA: APA Rut Depth Versus Aggregate Type (PG 67-22 All Data)

```
Analysis of Variance for 67-APA
Source      DF        SS         MS         F         P
AGG Type     5     6.648      1.330      2.26     0.067
Error       40    23.546      0.589
Total       45    30.193
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  -+---------+---------+---------+-----
1            9    2.5000    1.0583           (-------*------)
2            6    1.9833    0.6210  (--------*--------)
3            3    3.0000    0.1000             (------------*------------)
4           15    1.9267    0.7658     (-----*----)
5            8    2.8000    0.6761               (-------*-------)
6            5    2.4800    0.5541         (--------*---------)
                                    -+---------+---------+---------+-----
Pooled StDev =    0.7672           1.40      2.10      2.80      3.50
```



*Note: There were only 3 data points for Aggregate Type-3 (AL Limestone)

*Note: The blue circles depict individual data points and the red squares depict mean values.

Figure 23 Effect of Aggregate Type on APA Rut Depth (PG 67-22 All Data)

Table 4 Descriptive Statistics for Effect of Aggregate Type on APA Rut Depth (PG 67-22 All Data)

Binder Type	Aggregate Source	N	Mean (mm)	Median (mm)	St. Dev (mm)	Min. (mm)	Max. (mm)
PG 67-22	SF Limestone	9	2.50	2.30	1.06	1.00	4.90
	FL Limestone	6	1.99	2.10	0.62	1.10	2.60
	AL Limestone	3	3.00	3.00	0.10	2.90	3.10
	GA Granite	15	1.93	1.80	0.77	1.10	4.30
	NS Granite	8	2.80	2.65	0.68	2.10	4.20
	Other	5	2.48	2.60	0.55	1.90	3.00

This data has also been plotted individually for both traffic levels as shown in Figures 24 and 25.

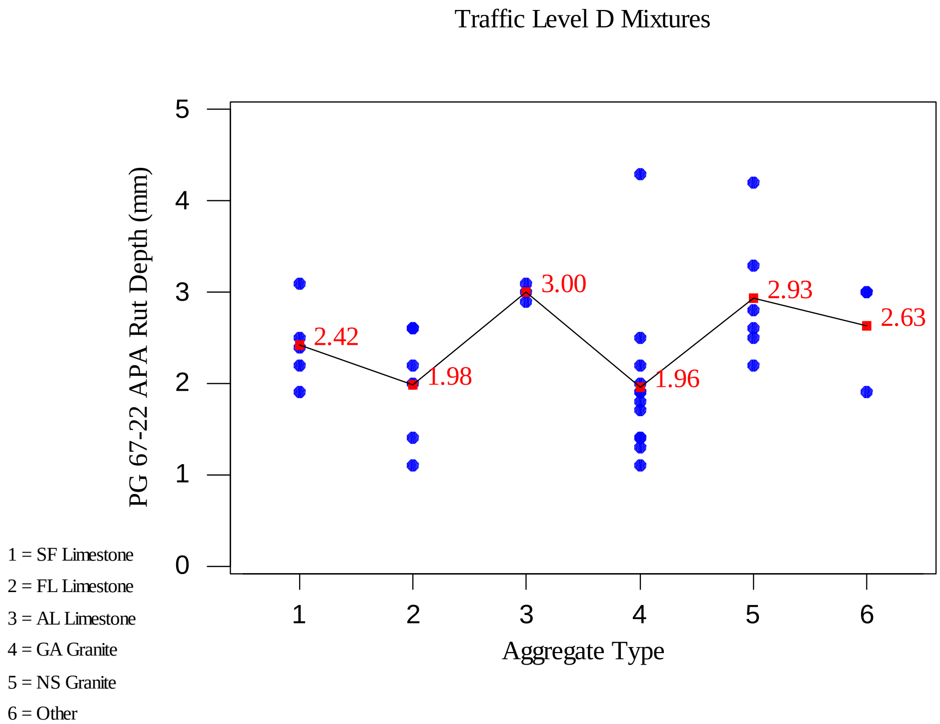


Figure 24 Effect of Aggregate Type on APA Rut Depth (PG 67-22 Traffic Level D Mixtures)

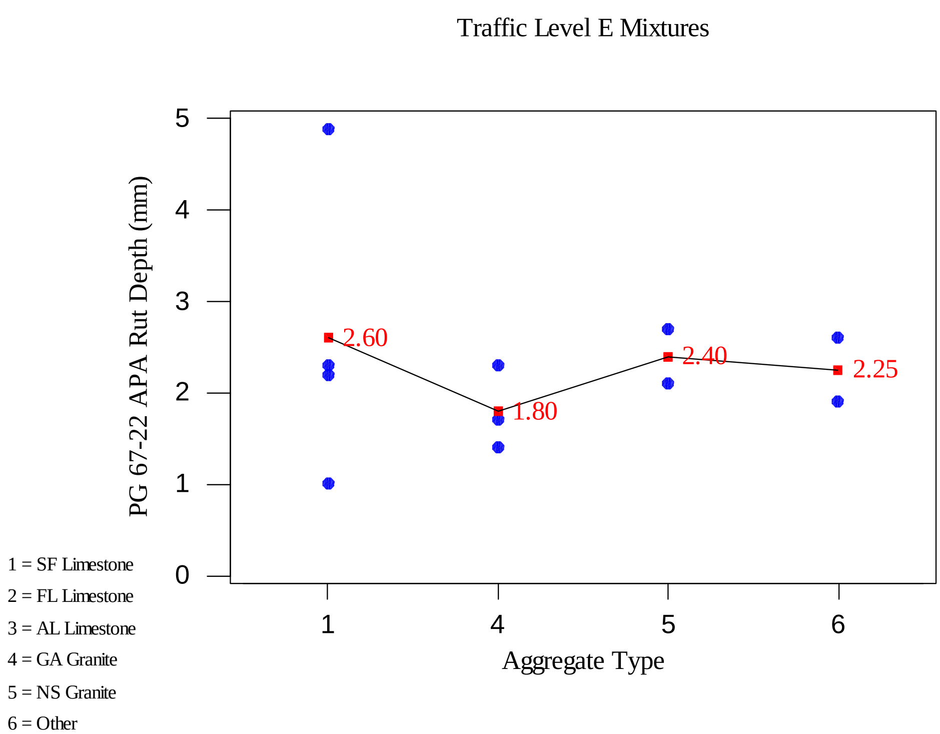
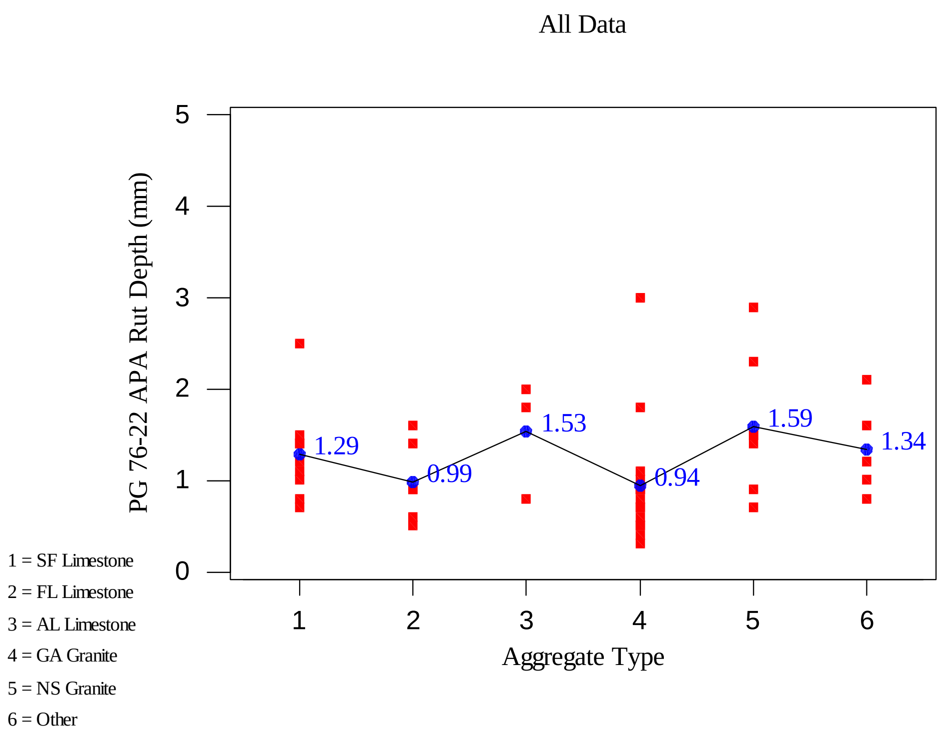


Figure 25 Effect of Aggregate Type on APA Rut Depth (PG 67-22 Traffic Level E Mixtures)

Table 5 One Way ANOVA: APA Rut Depth Versus Aggregate Type (PG 76-22 All Data)

```
Analysis of Variance for 76-APA
Source      DF        SS        MS        F        P
AGG Type     5     2.996     0.599     1.60    0.183
Error       40    15.001     0.375
Total       45    17.997
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  -+---------+---------+---------+-----
1            9    1.2889    0.5302           (-------*-------)
2            6    0.9833    0.4355   (---------*---------)
3            3    1.5333    0.6429         (-------------*------------)
4           15    0.9400    0.6738     (------*-----)
5            8    1.5875    0.7120                (--------*--------)
6            5    1.3400    0.5177         (----------*----------)
                                    -+---------+---------+---------+-----
Pooled StDev =    0.6124           0.50      1.00      1.50      2.00
```



*Note: There were only 4 data points for Aggregate Type-3 (AL Limestone)

*Note: The red squares depict individual data points and the blue circles depict mean values.

Figure 26 Effect of Aggregate Type on APA Rut Depth (PG 76-22 All Data)

Table 6 Descriptive Statistics for Effect of Aggregate Type on APA Rut Depth (PG 76-22 All Data)

Binder Type	Aggregate Source	N	Mean (mm)	Median (mm)	St. Dev (mm)	Min. (mm)	Max. (mm)
PG 76-22	SF Limestone	9	1.29	1.20	0.53	0.70	2.50
	FL Limestone	6	0.98	0.90	0.44	0.50	1.60
	AL Limestone	3	1.53	1.80	0.64	0.80	2.00
	GA Granite	15	0.94	0.80	0.67	0.30	3.00
	NS Granite	8	1.59	1.50	0.71	0.70	2.90
	Other	5	1.34	1.20	0.52	0.80	2.10

This data has also been plotted individually for both traffic levels as shown in Figures 27 and 28.

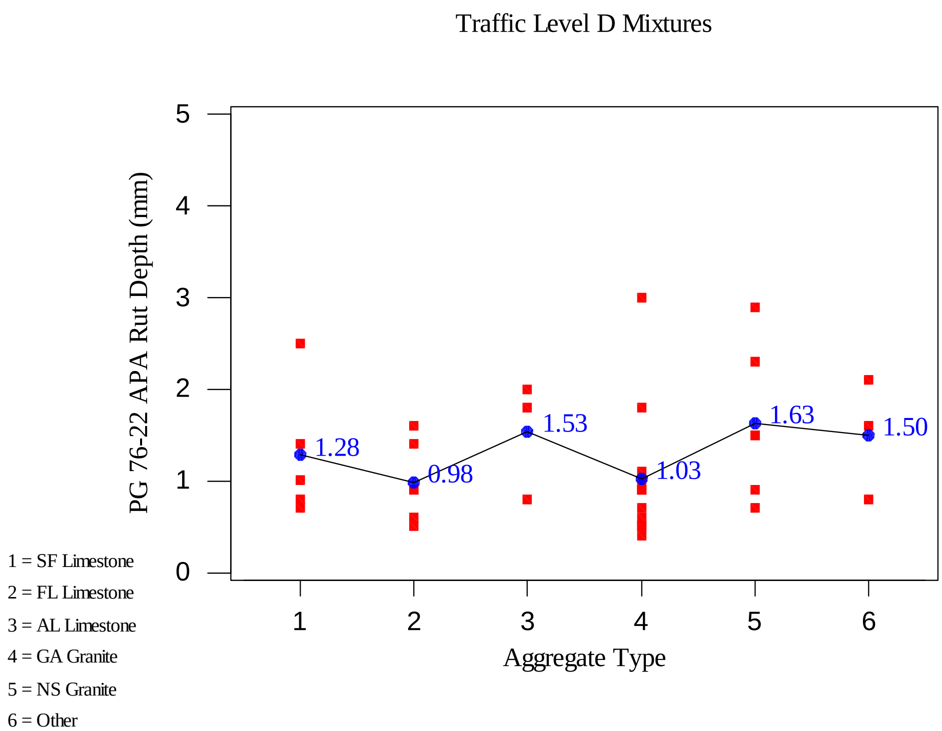


Figure 27 Effect of Aggregate Type on APA Rut Depth (PG 76-22 Traffic Level D Mixtures)

Figure 28 Effect of Aggregate Type on APA Rut Depth (PG 76-22 Traffic Level E Mixtures)

With p-values of 0.067 and 0.183, the results of the ANOVA suggest that the type of aggregate used in the mix does not have a significant effect on the corresponding APA rut depth. However, these results need to be interpreted with care as the number of mixtures with each type of aggregate is not the same. The corresponding 95% confidence intervals for the mean overlap in most cases, which suggest that the mean rut depth of mixtures made with different aggregates is statistically similar.

7.2 EFFECT OF SAND CONTENT ON APA RUT DEPTH

A one-way ANOVA was performed to evaluate the effect of sand content in the mixture on the APA rut depth. Note that this analysis was performed only on the mixtures containing 15% RAP.

Table 7 One Way ANOVA: APA Rut Depth Versus % Sand (PG 67-22 All Data)

```
Analysis of Variance for 67-APA
Source     DF         SS        MS        F        P
% Sand      7    16.168     2.310     6.26    0.000
Error      38    14.025     0.369
Total      45    30.193
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -----+---------+---------+---------+-
 0         28    2.0821    0.6464         (-*)
 5          3    2.1000    0.8544      (----*----)
 7          1    2.0000    0.0000  (-------*--------)
 8          1    4.2000    0.0000                 (-------*-------)
10         10    2.4600    0.3777           (-*--)
12          1    2.5000    0.0000     (--------*-------)
15          1    4.3000    0.0000                 (--------*-------)
16          1    4.9000    0.0000                     (--------*-------)
                                   -----+---------+---------+---------+-
Pooled StDev =   0.6075               1.5       3.0       4.5       6.0
```

Table 8 One Way ANOVA: APA Rut Depth Versus % Sand (PG 76-22 All Data)

```
Analysis of Variance for 76-APA
Source     DF        SS        MS        F        P
% Sand      7     7.205     1.029     3.62    0.004
Error      38    10.792     0.284
Total      45    17.997
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
 0         28    1.0607    0.5080           (-*-)
 5          3    1.0000    0.9539       (----*-----)
 7          1    0.9000    0.0000   (--------*-------)
 8          1    2.9000    0.0000                   (--------*--------)
10         10    1.3500    0.4720            (--*--)
12          1    1.1000    0.0000    (--------*--------)
15          1    3.0000    0.0000                    (--------*--------)
16          1    1.5000    0.0000       (--------*-------)
                                   --+---------+---------+---------+----
Pooled StDev =   0.5329            0.0       1.2       2.4       3.6
```

With p-values of 0.00, the ANOVA results in this suggest that sand content in the mixture has a significant effect on the measured APA rut depth, with higher percentage of sand resulting in higher rut depth. An important point to be kept in mind is that most of the mixtures considered had either 0% sand (28 mixtures) or 10% sand (10 mixtures), with the remaining mixtures containing other percentages of sand. In general, the data shows that increasing the sand content in a mixture would result in higher APA rut data. An evaluation of the data shows that the average rut depth of mixtures with 10% sand is more than the average rut depth of mixtures with 0% sand. This effect seems to be more pronounced in the mixtures with unmodified binder.

8 Difference in APA Rut Depth

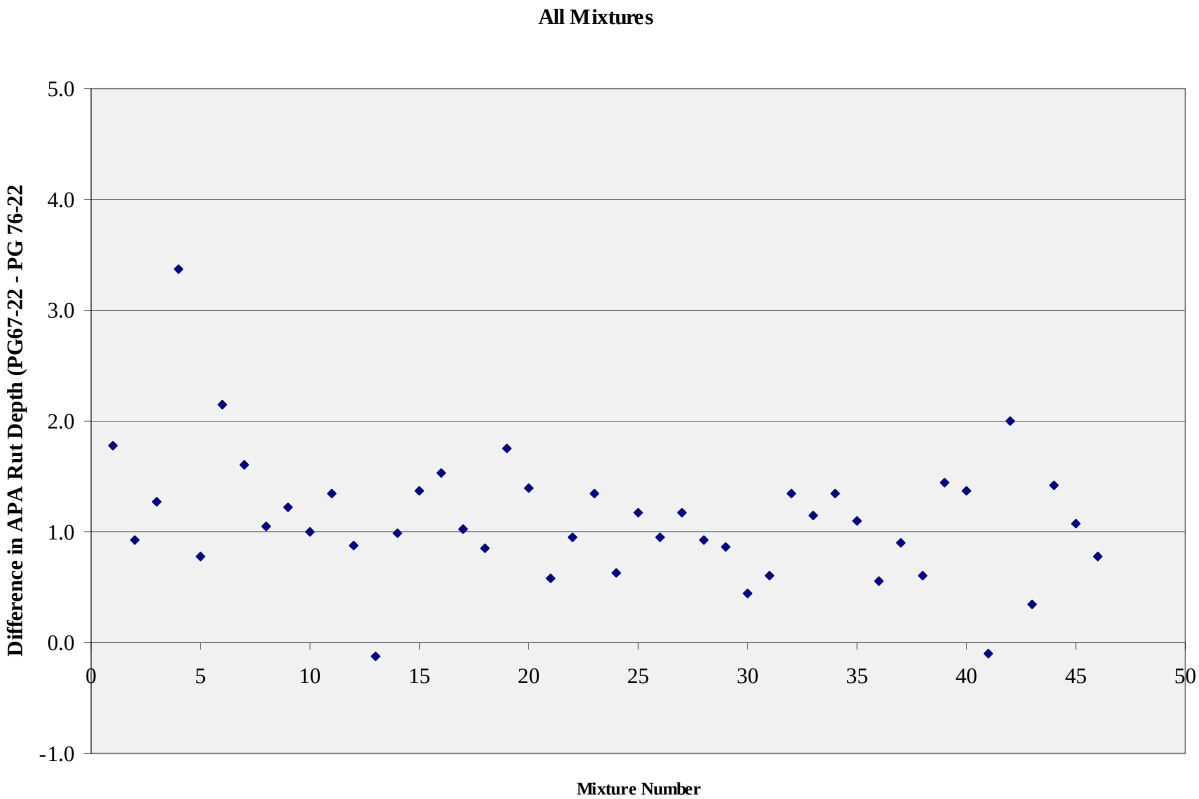


Figure 29 Difference in APA Rut Depth (PG 67-22 – PG 76-22 APA Data)

The difference in APA rut depth between the unmodified and modified is shown in Figure 25. On average, there seems to be a difference of 1mm in the average rut depth. That is, if the same mixture is made with modified and unmodified binder, the modified binder would result in a reduction of 1mm rut depth in APA specimens. In the above figure, note that that there are 2 data points where the APA rut depth for the PG 67-22 (unmodified) binder is slightly lower than then PG 76-22 (polymer modified) binder.

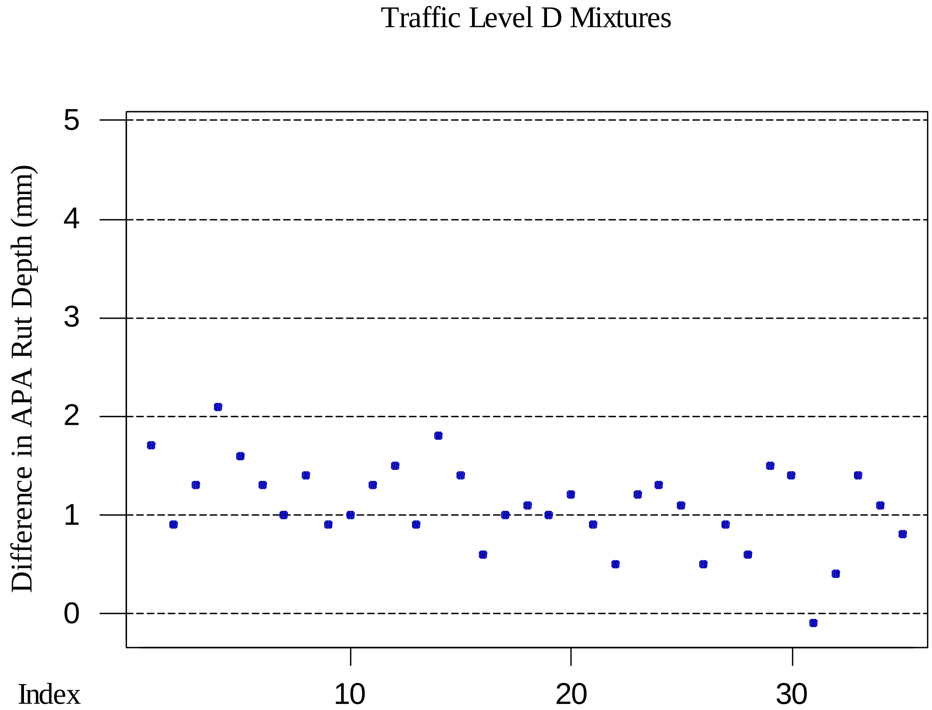


Figure 30 Difference in APA Rut Depth (Traffic Level D Mixtures)

Figure 31 Difference in APA Rut Depth (Traffic Level E Mixtures)

9 DASR Analysis

This section of the analysis was conducted according to the guidelines prescribed by Kim et. al. The Dominant Aggregate Size Range (DASR) was determined for each mixture (gradation) along with the porosity of each mix. The DASR is the interactive range of particles that forms the primary structural network of aggregates. It was hypothesized by the authors that the DASR must be composed of coarse enough particles and its porosity must be no greater than 50% for a mixture to effectively resist deformation and cracking[4]. Subsequently, the percentage of coarse aggregate (%CA) in the mix and the porosity was determined for each of the mixtures analyzed in this study. The results are shown in Figures 32-35.

9.1 UNMODIFIED BINDER (PG 67-22)

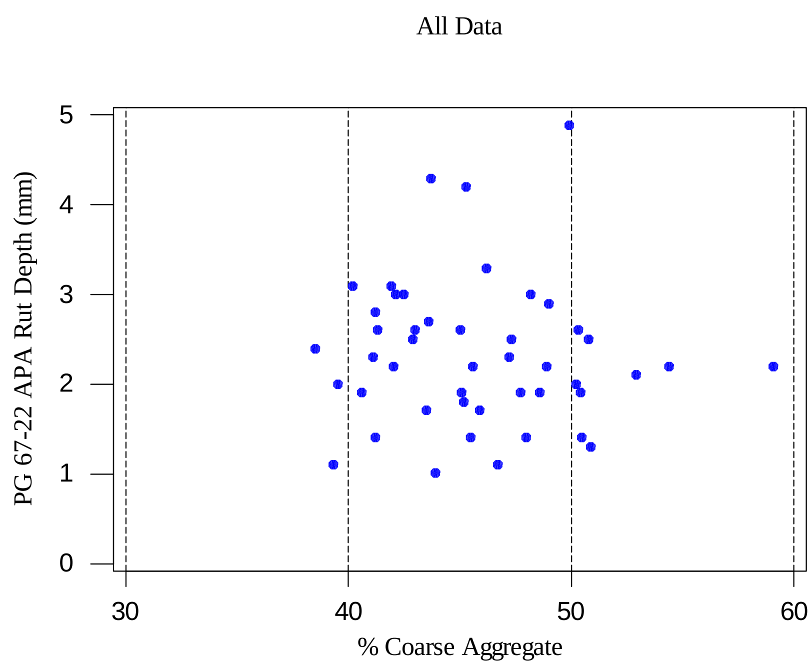


Figure 32 Effect of % CA on APA Rut Depth (PG 67-22 All Data)

[4] Development of Mix Design Guidelines for Improved Performance of Asphalt Mixtures, UF Report 2005, Page-16.

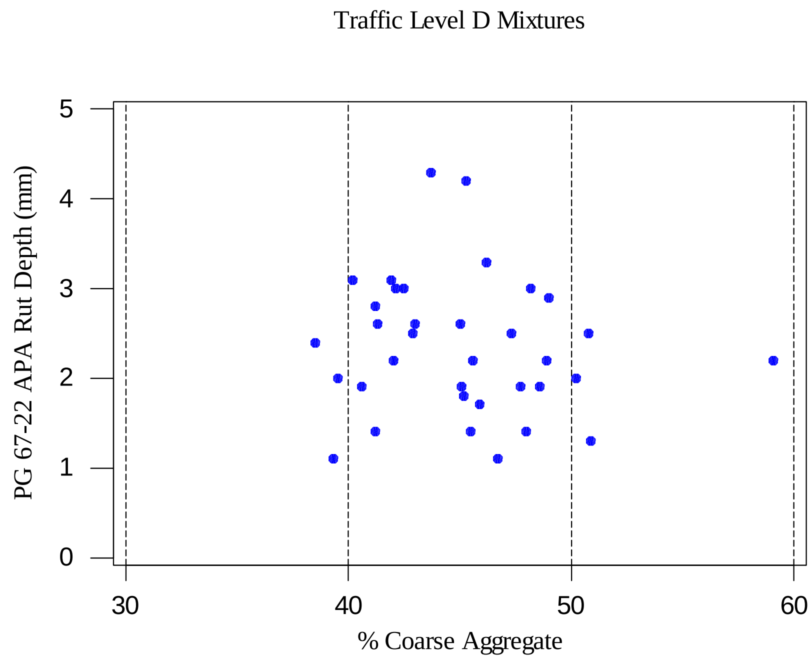


Figure 33 Effect of %CA on APA Rut Depth (PG 67-22 Traffic Level D Mixtures)

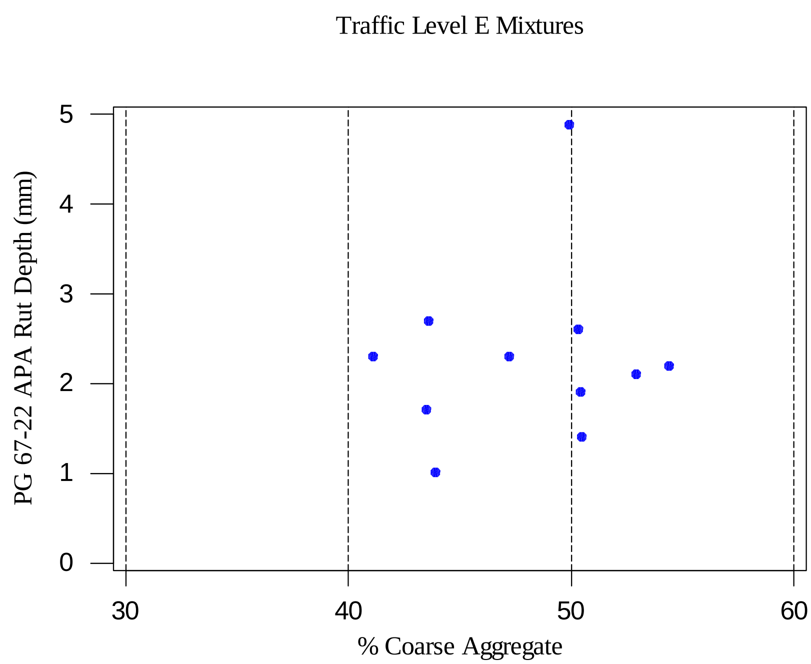


Figure 34 Effect of %CA on APA Rut Depth (PG 67-22 Traffic Level E Mixtures)

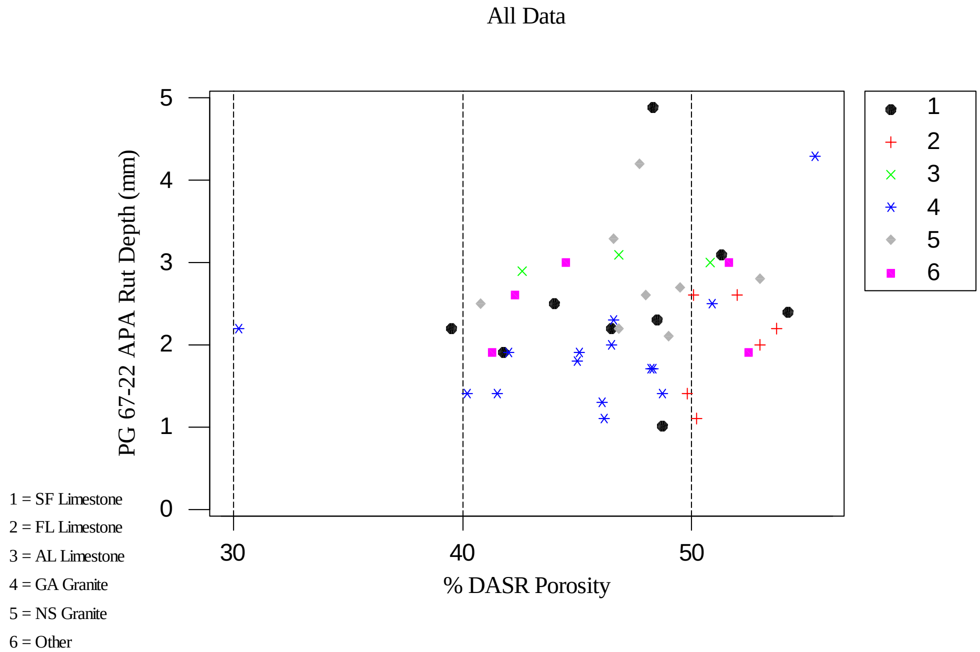


Figure 35 Effect of % DASR Porosity on APA Rut Depth (PG 67-22 All Data)

9.2 MODIFIED BINDER (PG 76-22)

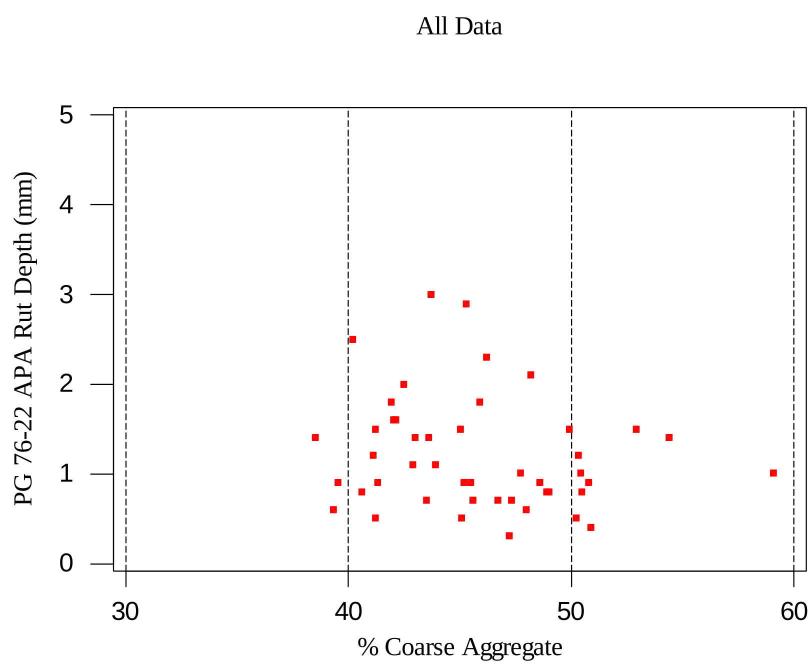


Figure 36 Effect of % CA on APA Rut Depth (PG 76-22 All Data)

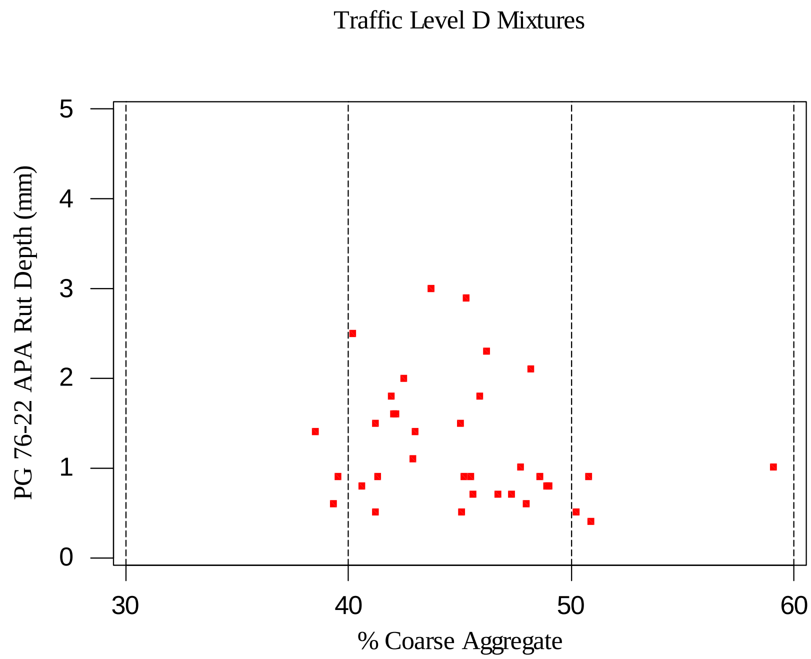


Figure 37 Effect of %CA on APA Rut Depth (PG 76-22 Traffic Level D Mixtures)

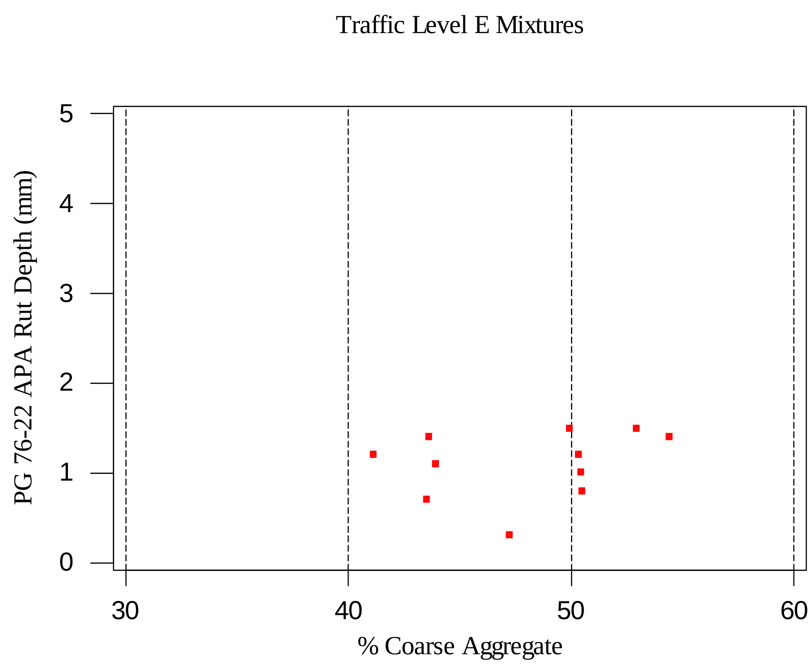


Figure 38 Effect of %CA on APA Rut Depth (PG 76-22 Traffic Level E Mixtures)

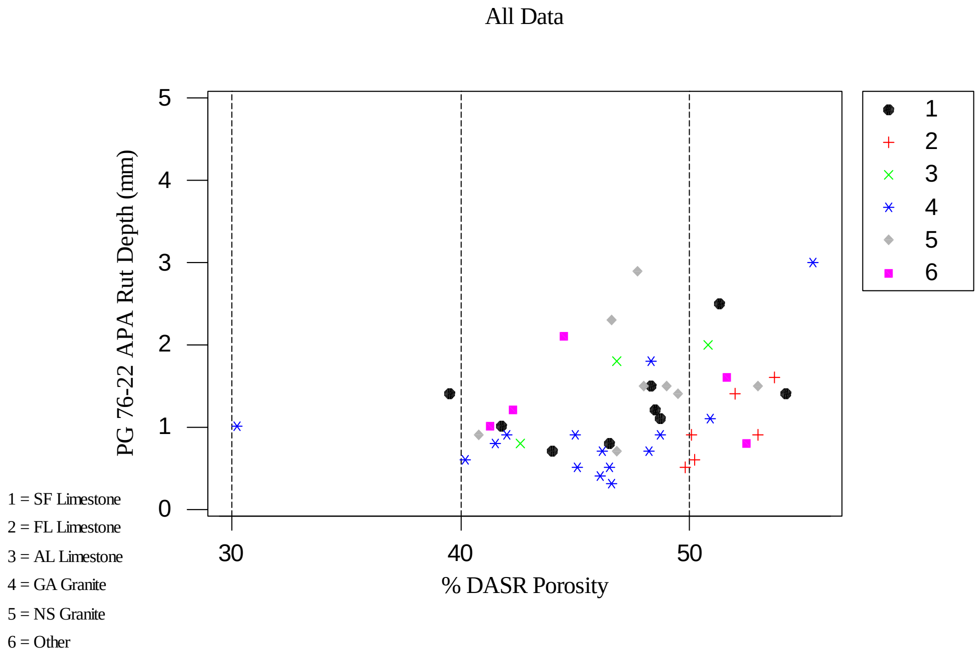


Figure 39 Effect of % DASR Porosity on APA Rut Depth (PG 76-22 All Data)

10 Conclusions

The following conclusions were drawn as a result of this analysis:

1. On average, a reduction of 1mm in APA rut depth can be expected for mixtures with polymer modified binder as compared to the same mixture with unmodified binder.

2. A direct plot of PG 67-22 APA rut data and PG 76-22 rut data reveals a weak relationship (R^2 = 0.51) for all the available mixtures. This relationship is slightly stronger (R^2 = 0.67) for traffic level D mixtures.

3. In general, a higher air void content in the specimen resulted in a higher APA rut depth. However, the data shows a high degree of variability for both modified and unmodified binders for both traffic level D and E mixtures.

4. ANOVA results suggest that increased percentage of sand in the mix result in higher APA rut depth. i.e., increasing the percentage of sand in the mixture results in a mixture with higher rutting potential.

5. ANOVA results suggest that different types of aggregates do not have a significant effect on the APA rut depth. Of all the mixtures considered (with 15% RAP), mixtures with Alabama limestone showed higher APA rut depths. However, it should be noted that there were only 3 such mixtures considered in this data set. In general, mixtures with Georgia granite (15 Mixtures) exhibited lowest APA rut depth followed by South Florida limestone (9 mixtures).

6. No correlation was found between APA rut depth and the mixture VMA, FAA, optimum asphalt content or the % G_{mm} @ $N_{ini.}$

7. Traffic Level E mixtures exhibited slightly lower APA rut depths as compared to Traffic Level D mixtures. However, this difference in rut depth is not significant at a 95% confidence level.

Appendix A

A RAW APA DATA

A.1 APA Data for Unmodified Mixtures

SRNO	Mix Design	NMAS	Main Aggregate	AV-1	AV-2	AV	APA-1	APA-2	APA
1	SP 04-3820A	19	GA granite	2.7	3.0	2.9	2.1	2.6	2.4
2	SP 05-4253A	12.5	FL Limestone	5.1	4.9	5.0	2.7	2.6	2.6
3	SP 05-4266A	12.5	GA granite	4.7	4.3	4.5	1.9	1.1	1.5
4	SP 05-4314A	19	SF Limestone	5.3	4.3	4.8	2.3	1.6	1.9
5	SP 05-4327A	12.5	NS Granite	3.3	3.4	3.4	2.6	2.9	2.8
6	SP 06-4634A	12.5	GA granite	2.5	2.3	2.4	1.0	1.4	1.2
7	SPM 05-3901A	12.5	SF Limestone	5.3	4.5	4.9	5.6	4.2	4.9
8	SPM 05-3944A	19	SF Limestone	3.2	3.0	3.1	2.2	2.3	2.2
9	SPM 05-3991A	12.5	AL Limestone	3.9	3.6	3.8	3.1	2.8	2.9
10	SPM 05-4164A	12.5	NS Granite	4.2	3.8	4.0	2.6	2.4	2.5
11	SPM 05-4169A	12.5	SF Limestone	5.9	5.7	5.8	2.0	2.6	2.3
12	SPM 05-4197A	12.5	AL Limestone	3.8	3.9	3.9	3.6	2.6	3.1
13	SPM 05-4214A	12.5	NS Granite	4.9	5.5	5.2	3.1	3.6	3.3
14	SPM 05-4229A	12.5	AL Limestone	3.4	3.8	3.6	3.6	3.4	3.5
15	SPM 05-4231A	12.5	GA granite	3.9	3.4	3.7	1.7	2.1	1.9
16	SPM 05-4239A	12.5	GA granite	4.2	3.6	3.9	1.9	1.8	1.8
17	SPM 05-4268A	12.5	SF Limestone	3.1	3.6	3.4	1.0	1.0	1.0
18	SPM 05-4293A	12.5	GA granite	5.1	4.7	4.9	2.0	1.8	1.9
19	SPM 05-4296A	12.5	GA granite	5.5	5.4	5.5	4.7	4.0	4.3
20	SPM 05-4304A	12.5	NS Granite	4.1	4.5	4.3	2.5	1.9	2.2
21	SPM 05-4310A	12.5	GA granite	4.6	4.2	4.4	1.8	1.7	1.7
22	SPM 05-4326A	12.5	Several	4.4	4.8	4.6	3.3	2.6	3.0
23	SPM 05-4336A	12.5	SF Limestone	3.4	3.5	3.5	2.5	2.4	2.5
24	SPM 05-4358A	12.5	SF Limestone	4.3	4.6	4.5	2.4	2.0	2.2
25	SPM 05-4371A	12.5	SF Limestone	5.2	5.3	5.3	3.3	2.9	3.1
26	SPM 05-4393A	12.5	AL Limestone	4.3	4.0	4.2	3.4	2.6	3.0
27	SPM 05-4398A	12.5	NS Granite	4.6	4.3	4.5	3.2	2.3	2.7
28	SPM 05-4417A	19	NS Granite	4.8	4.8	4.8	2.1	2.1	2.1
29	SPM 05-4459A	12.5	Multiple	3.1	4.0	3.6	2.3	1.6	1.9
30	SPM 06-4461A	12.5	SF Limestone	3.4	3.6	3.5	2.7	2.1	2.4
31	SPM 06-4509A	19	GA granite	3.1	3.7	3.4	2.0	2.3	2.2
32	SPM 06-4523A	12.5	NS & GA Granite	4.0	3.1	3.6	2.0	1.8	1.9
33	SPM 06-4547A	12.5	FL Limestone	4.5	4.8	4.7	1.2	1.6	1.4
34	SPM 06-4564A	12.5	GA granite	5.0	5.0	5.0	1.1	1.7	1.4
35	SPM 06-4570A	12.5	GA granite	3.8	3.4	3.6	1.8	1.1	1.4
36	SPM 06-4578A	12.5	NS & GA Granite	3.4	3.3	3.4	2.7	2.4	2.6
37	SPM 06-4581A	12.5	NS Granite	4.2	4.2	4.2	2.7	3.0	2.8
38	SPM 06-4585A	12.5	FL Limestone	5.3	5.6	5.5	2.5	2.7	2.6
39	SPM 06-4597A	12.5	NS Granite	5.4	5.2	5.3	3.8	4.6	4.2
40	SPM 06-4608A	12.5	FL Limestone	5.7	5.3	5.5	2.0	2.1	2.0
41	SPM 06-4635A	12.5	GA granite	4.5	4.6	4.6	2.7	2.8	2.7
42	SPM 06-4654A	12.5	GA granite	3.7	3.4	3.6	2.8	2.0	2.4
43	SPM 06-4663A	12.5	FL Limestone	2.4	2.1	2.3	1.2	1.1	1.1
44	SPM 06-4683A	12.5	GA granite	3.0	2.7	2.9	1.2	1.4	1.3
45	SPM 06-4687A	12.5	NS Granite	5.0	5.1	5.1	2.8	1.5	2.1
46	SPM 06-4691A	12.5	FL Limestone	5.2	4.8	5.0	2.3	2.1	2.2
47	SPM 06-4701A	12.5	GA granite	3.7	3.9	3.8	2.0	2.0	2.0
48	SPM 06-4703A	12.5	SF LS & GA Granite	4.1	4.3	4.2	3.6	2.4	3.0
49	SPM 06-4707A	12.5	GA granite	4.4	4.9	4.7	1.8	1.6	1.7
50	SPM 06-4725A	12.5	GA granite	3.5	3.9	3.7	2.3	2.3	2.3
51	SPM 06-4727A	12.5	GA granite	3.6	3.9	3.8	1.2	1.0	1.1
52	SPM 06-4740A	12.5	GA granite	6.2	6.0	6.1	2.9	2.2	2.5
53	SPM 06-4741A	12.5	NS Granite	3.4	3.6	3.5	2.4	2.8	2.6
54	SPM 06-4751A	12.5	GA granite	3.4	3.3	3.4	1.5	1.3	1.4

A.2 APA Data for SBS Modified Mixtures

SRNO	Mix Design	NMAS	Main Aggregate	AV-1	AV-2	AV	APA-1	APA-2	APA
1	SP 04-3820A	19	GA granite	3.8	3.9	3.9	1.5	1.4	1.5
2	SP 05-4253A	12.5	FL Limestone	4.9	5.1	5.0	0.6	1.1	0.9
3	SP 05-4266A	12.5	GA granite	4.6	3.9	4.3	0.5	1.8	1.1
4	SP 05-4314A	19	SF Limestone	4.8	5.5	5.2	0.9	1.2	1.0
5	SP 05-4327A	12.5	NS Granite	3.5	3.1	3.3	1.6	1.4	1.5
6	SP 06-4634A	12.5	GA granite	2.7	2.8	2.8	0.8	0.5	0.6
7	SPM 05-3901A	12.5	SF Limestone	5.4	4.7	5.1	1.7	1.3	1.5
8	SPM 05-3944A	19	SF Limestone	3.9	3.4	3.7	0.9	2.0	1.4
9	SPM 05-3991A	12.5	AL Limestone	4.6	5.1	4.9	0.8	0.8	0.8
10	SPM 05-4164A	12.5	NS Granite	2.7	3.3	3.0	0.8	0.9	0.9
11	SPM 05-4169A	12.5	SF Limestone	5.5	5.1	5.3	1.6	0.9	1.2
12	SPM 05-4197A	12.5	AL Limestone	3.6	3.0	3.3	1.7	2.0	1.8
13	SPM 05-4214A	12.5	NS Granite	4.2	4.2	4.2	2.2	2.5	2.3
14	SPM 05-4229A	12.5	AL Limestone	3.2	3.5	3.4	3.0	2.4	2.7
15	SPM 05-4231A	12.5	GA granite	3.2	2.9	3.1	0.5	0.6	0.5
16	SPM 05-4239A	12.5	GA granite	3.2	3.0	3.1	1.0	0.9	0.9
17	SPM 05-4268A	12.5	SF Limestone	3.6	3.4	3.5	0.8	1.4	1.1
18	SPM 05-4293A	12.5	GA granite	4.6	4.3	4.5	0.8	1.0	0.9
19	SPM 05-4296A	12.5	GA granite	5.1	5.2	5.2	2.9	3.1	3.0
20	SPM 05-4304A	12.5	NS Granite	4.5	4.9	4.7	0.8	0.6	0.7
21	SPM 05-4310A	12.5	GA granite	4.4	3.8	4.1	0.9	0.5	0.7
22	SPM 05-4326A	12.5	Several	4.7	4.1	4.4	2.1	2.2	2.1
23	SPM 05-4336A	12.5	SF Limestone	3.5	3.4	3.5	0.7	0.7	0.7
24	SPM 05-4358A	12.5	SF Limestone	4.0	3.8	3.9	0.8	0.8	0.8
25	SPM 05-4371A	12.5	SF Limestone	3.7	4.5	4.1	2.8	2.3	2.5
26	SPM 05-4393A	12.5	AL Limestone	3.6	4.0	3.8	2.0	2.0	2.0
27	SPM 05-4398A	12.5	NS Granite	4.0	4.3	4.2	1.2	1.6	1.4
28	SPM 05-4417A	19	NS Granite	5.2	4.6	4.9	1.5	1.5	1.5
29	SPM 05-4459A	12.5	Multiple	4.1	5.0	4.6	0.8	0.8	0.8
30	SPM 06-4461A	12.5	SF Limestone	2.7	2.9	2.8	1.5	1.4	1.4
31	SPM 06-4509A	19	GA granite	4.2	4.8	4.5	0.8	1.2	1.0
32	SPM 06-4523A	12.5	NS & GA Granite	3.3	3.0	3.2	0.9	1.0	1.0
33	SPM 06-4547A	12.5	FL Limestone	4.7	4.1	4.4	0.6	0.5	0.5
34	SPM 06-4564A	12.5	GA granite	4.4	4.5	4.5	1.1	0.8	0.9
35	SPM 06-4570A	12.5	GA granite	3.1	3.9	3.5	0.8	0.9	0.8
36	SPM 06-4578A	12.5	NS & GA Granite	5.0	4.2	4.6	1.2	1.3	1.2
37	SPM 06-4581A	12.5	NS Granite	4.0	4.2	4.1	1.7	1.7	1.7
38	SPM 06-4585A	12.5	FL Limestone	4.8	5.7	5.3	1.3	1.6	1.4
39	SPM 06-4597A	12.5	NS Granite	5.4	5.5	5.5	3.1	2.7	2.9
40	SPM 06-4608A	12.5	FL Limestone	5.2	5.7	5.5	1.0	0.9	0.9
41	SPM 06-4635A	12.5	GA granite	4.0	3.8	3.9	0.9	0.9	0.9
42	SPM 06-4654A	12.5	GA granite	3.9	3.4	3.7	2.2	1.9	2.0
43	SPM 06-4663A	12.5	FL Limestone	3.5	2.5	3.0	0.7	0.5	0.6
44	SPM 06-4683A	12.5	GA granite	3.2	2.7	3.0	0.5	0.3	0.4
45	SPM 06-4687A	12.5	NS Granite	5.3	4.9	5.1	1.5	1.4	1.4
46	SPM 06-4691A	12.5	FL Limestone	4.6	4.2	4.4	1.8	1.4	1.6
47	SPM 06-4701A	12.5	GA granite	4.7	4.2	4.5	0.4	0.6	0.5
48	SPM 06-4703A	12.5	SF LS & GA Granite	4.7	4.7	4.7	2.0	1.3	1.6
49	SPM 06-4707A	12.5	GA granite	5.1	4.4	4.8	2.1	1.5	1.8
50	SPM 06-4725A	12.5	GA granite	2.8	2.9	2.9	0.3	0.2	0.3
51	SPM 06-4727A	12.5	GA granite	3.0	3.4	3.2	0.5	1.0	0.7
52	SPM 06-4740A	12.5	GA granite	4.1	3.6	3.9	1.5	0.8	1.1
53	SPM 06-4741A	12.5	NS Granite	3.3	3.4	3.4	1.5	1.6	1.5
54	SPM 06-4751A	12.5	GA granite	2.9	3.3	3.1	0.7	0.5	0.6