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ABSTRACT

Several new processes have been developed with the goal of reducing the mixing and compaction temperatures of hot mix asphalt without sacrificing the quality of the resulting pavement. One of these processes utilizes Evotherm®, an asphalt emulsion produced by MeadWestvaco's Asphalt Innovations division. A laboratory study was conducted to determine the applicability of Evotherm® to typical paving operations and environmental conditions commonly found in the United States, including the performance of the mixes in quick traffic turn-over situations and high temperature conditions. Superpave gyratory compactor (SGC) results indicated that Evotherm® may lower the optimum asphalt content; however, it is currently recommended to determine the optimum asphalt content with a typical PG graded binder, and then substitute the Evotherm® emulsion.

Evotherm® was shown to improve the compactability of mixtures in both the SGC and vibratory compactor. Statistics indicated an overall reduction in air voids. Improved compaction was noted at temperatures as low as 190°F (88°C). The addition of Evotherm® does not statistically affect the resilient modulus of an asphalt mix nor does it increase the rutting potential of an asphalt mix as measured by the Asphalt Pavement Analyzer. The rutting potential did increase with decreasing mixing and compaction temperatures, which may be related to the decreased aging of the binder resulting from the lower mixing and compaction temperatures. There was no evidence of a difference in indirect tensile strength gain with time for the mixes containing Evotherm® as compared to the control mixes, indicating that a Warm Mix Asphalt (WMA) containing Evotherm® can be quickly opened to traffic. The lower compaction temperature used when producing Warm Mix Asphalt with Evotherm® or any WMA additive may increase the potential for moisture damage. Overall, Evotherm® appears to be a viable tool for reducing mixing and compaction temperatures that can be readily added to hot mix asphalt. Reductions in mixing and compaction temperatures are expected to reduce fuel costs, reduce emissions, and widen the winter paving window.

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INTRODUCTION

A number of new processes and products have become available that have the capability of reducing the temperature at which hot mix asphalt (HMA) is mixed and compacted without compromising the performance of the pavement. These new products can reduce production temperatures as much as 30 percent or more. North American asphalt mixes are generally heated to 300°F (149°C) or greater, depending mainly on the type of binder used. Mixes produced with these new products are being produced at temperatures of about 250°F (121°C) or lower. Lower plant mixing temperatures mean fuel cost savings to the contractor and findings have shown that lower plant temperatures can lead to a 30 percent reduction in fuel energy consumption (*1*). Lower temperatures also mean that any emissions, either visible or invisible, that may contribute to health, odor problems, or greenhouse gas emissions, will also be reduced (*2*). The decrease in emissions potentially represents a significant cost savings, considering that 30-50 percent of overhead costs at an asphalt plant can be attributed to emission control (*3*). Lower emissions may also allow asphalt plants to be sited in non-attainment areas, where there are strict air pollution regulations. Having an asphalt plant located in a non-attainment area and producing hot mix with a product that allows for a lower operating temperature will allow shorter haul distances which will improve production and shorten the construction period, thus reducing the delays associated with traffic congestion. Warm Mix Asphalt will also allow longer haul distances and a longer construction season if the mixes are produced close to typical HMA operating temperatures. There is another potential advantage in that oxidative hardening of the asphalt will be minimized with the lower operating temperatures, and this may result in changes in pavement performance, such as reduced thermal cracking, block cracking, and reducing the potential for a tender mix. However, the reduced oxidative aging may increase the potential for rutting.

A number of Warm Mix Asphalt processes have been identified and evaluated. This report presents an evaluation of one such process in particular, Meadwestvaco's Evotherm®, which is an asphalt emulsion. Evotherm® is a chemistry package that includes materials to improve workability, adhesion promoters and emulsification agents. The chemistry is currently delivered with a relatively high asphalt residue (approximately 70 percent). Unlike traditional asphalt binders, Evotherm® is stored at 176°F (80°C). In field trials conducted to date, Evotherm® has generally been pumped directly off a tanker truck (Figure 1). The tanker may be connected to the asphalt line using a single or pair of heated valves. Connecting the tanker to the plant using a pair of heated valves and check valves allows for recirculation. For large scale projects or routine paving it would be stored in a tank at the plant similar to any other emulsion. Temperatures of oil jacketed lines should be reduced to 203 °F (95 °C) prior to pumping the Evotherm® to prevent the emulsion from breaking in the lines. The plant setting for the asphalt content needs to be increased to account for the fact that the binder residue is approximately 70 percent of mass of the Evotherm® emulsion. The water in the emulsion is liberated from the Evotherm® in the form of steam when it is mixed with the hot aggregate. The resulting Warm Mix Asphalt appears like hot mix in terms of coating and color.

Figure 1. a) Heated Valves Allowing Recirculation and b) Tanker Pumping Evotherm Directly into Plant.

OBJECTIVE

The objective of this study was to perform a laboratory study to determine the applicability of Evotherm® technology in Warm Mix Asphalt applications including typical paving operations and environmental conditions commonly found in the United States, and to evaluate the performance of the mixes in quick traffic turn-over situations and high temperature conditions.

RESEARCH APPROACH

Table 1 shows the experimental design for the laboratory evaluation of Evotherm®. The following sections describe the individual tests that are included in the experimental design.

TABLE 1 Experimental Design for Evaluating the Influence of the Evotherm® on Mixture Volumetrics and Performance

	Number of Samples to be Tested							
	Granite				Limestone			
	PG 64-22		PG 76-22		PG 64-22		PG 76-22	
	Control	Evotherm®	Control	Evotherm®	Control	Evotherm®	Control	Evotherm®
Mix Design	9	9	9	9	9	9	9	9
Volumetrics	8	8	8	8	8	8	8	8
Densification	24	24	24	24	24	24	24	24
Resilient Modulus	24	24	24	24	24	24	24	24
APA Rutting	24	24	24	24	24	24	24	24
Moisture Sensitivity	6	6	6	6	6	6	6	6
Strength Change with Time	10	10	10	10	10	10	10	10

Mix Design

Two aggregate types (granite and limestone) and two asphalt binder grades (PG 64-22 and PG 76-22) were used to evaluate the Evotherm® technology. The two binders used for the control mixes were also used as the base asphalt to produce the Evotherm® emulsion. The mix design replicates a 12.5 mm nominal maximum aggregate size Superpave coarse-graded crushed granite mix produced by Hubbard Construction, Orlando, Florida. The mix design gradation and optimum asphalt contents are shown in Table 2. The same target gradation was used for the limestone aggregate.

TABLE 2 Target Gradations and Asphalt Contents

Sieve Size	% Passing		
	JMF[1]	Granite	LMS[2]
19.0	100.0	99.0	100.0
12.5	90.0	87.9	90.9
9.5	83.0	79.9	83.6
4.75	52.0	49.6	52.7
2.36	34.0	32.2	32.6
1.18	25.0	23.6	23.7
0.600	19.0	18.6	17.5
0.300	13.0	14.7	12.3
0.150	5.0	5.3	6.0
0.075	2.9	2.9	3.1
AC, %	5.3	5.1	4.8

1: Job Mix Formula; 2: Limestone

The job mix formula asphalt content was verified for the granite aggregate using N_{design} = 125 gyrations. For the limestone aggregate, a mix design was completed using the same design gyration level to determine an optimum asphalt content. Once the mix designs were verified or conducted at 300°F (149°C), each combination was then compacted at three lower temperatures (265, 230, and 190°F (129, 110, 88°C)). Volumetric properties for each of the 32 mix design combinations (two binder grades, control and Evotherm®, four temperatures) are presented in Tables 3 and 4. The data for both aggregates with PG 76-22, both the control and Evotherm®, compacted at 190°F (88°C) were not obtained due to limited amount of material. Each result represents the average of two samples. From the results of the mix design verifications using the control mixtures, asphalt contents of 5.1 and 4.8 percent were determined for the granite and limestone aggregate, respectively. These asphalt contents were used throughout the remainder of the study, whenever test specimens were made.

Observations from Tables 3 and 4 indicate that the addition of Evotherm® had little effect on the maximum specific gravity (G_{mm}) of the mixture. Previous research has indicated that the Superpave gyratory compactor (SGC) was insensitive to compaction temperature (*4*). In Tables 3 and 4 there are very slight trends of increasing air voids with decreasing temperature for some of the combinations. The addition of Evotherm® resulted in lower air voids than the corresponding control mixture in all possible aggregate, binder, and temperature combinations. The reduction in air voids generally corresponds to a reduction in VMA. The addition of

TABLE 3 Volumetric Mix Design Data for Granite Aggregate

Asphalt	Mix Type	Compaction Temperature, °F	AC, %	G_{mm}	% G_{mm} @ N_i	G_{mb}	Air Voids, %	VMA	VFA
PG 64-22	Control	300	5.1	2.467	88.0	2.365	4.1	13.6	69.6
PG 64-22	Control	265	5.1	2.467	88.2	2.371	3.9	13.3	71.0
PG 64-22	Control	230	5.1	2.467	87.7	2.360	4.4	13.8	68.4
PG 64-22	Control	190	5.1	2.467	87.5	2.356	4.5	13.9	67.6
PG 64-22	Evotherm®	300	5.1	2.465	89.1	2.389	3.1	12.7	75.7
PG 64-22	Evotherm®	265	5.1	2.465	88.9	2.387	3.2	12.8	75.2
PG 64-22	Evotherm®	230	5.1	2.465	88.8	2.384	3.3	12.9	74.5
PG 64-22	Evotherm®	190	5.1	2.465	88.9	2.390	3.0	12.7	76.0
PG 76-22	Control	300	5.1	2.457	88.0	2.369	4.0	14.1	71.5
PG 76-22	Control	265	5.1	2.457	88.5	2.355	4.5	14.6	69.1
PG 76-22	Control	230	5.1	2.457	86.7	2.334	5.4	15.4	64.8
PG 76-22	Control	190	5.1	2.457	NA	NA	NA	NA	NA
PG 76-22	Evotherm®	300	5.1	2.452	89.1	2.378	3.0	13.1	76.9
PG 76-22	Evotherm®	265	5.1	2.452	88.4	2.358	3.8	13.8	72.3
PG 76-22	Evotherm®	230	5.1	2.452	87.3	2.340	4.6	14.5	68.4
PG 76-22	Evotherm®	190	5.1	2.452	NA	NA	NA	NA	NA

NA = No data available

TABLE 4 Volumetric Mix Design Data for Limestone Aggregate

Asphalt	Mix Type	Compaction Temperature, °F	AC, %	G_{mm}	% G_{mm} @ N_i	G_{mb}	Air Voids, %	VMA	VFA
PG 64-22	Control	300	4.8	2.544	85.4	2.433	4.4	15.0	70.8
PG 64-22	Control	265	4.8	2.544	85.1	2.430	4.5	15.1	70.3
PG 64-22	Control	230	4.8	2.544	85.3	2.435	4.3	14.9	71.3
PG 64-22	Control	190	4.8	2.544	85.5	2.439	4.1	14.8	72.1
PG 64-22	Evotherm®	300	4.8	2.547	86.5	2.472	3.0	13.6	78.4
PG 64-22	Evotherm®	265	4.8	2.547	86.1	2.458	3.5	14.1	75.3
PG 64-22	Evotherm®	230	4.8	2.547	86.7	2.477	2.8	13.5	79.6
PG 64-22	Evotherm®	190	4.8	2.547	85.7	2.451	3.8	14.4	73.9
PG 76-22	Control	300	4.8	2.546	85.8	2.444	4.0	14.1	76.1
PG 76-22	Control	265	4.8	2.546	85.8	2.442	4.0	14.7	72.4
PG 76-22	Control	230	4.8	2.546	86.5	2.426	4.7	15.2	69.2
PG 76-22	Control	190	4.8	2.546	NA	NA	NA	NA	NA
PG 76-22	Evotherm®	300	4.8	2.534	86.9	2.462	2.8	14.0	79.7
PG 76-22	Evotherm®	265	4.8	2.534	86.4	2.448	3.4	14.5	76.5
PG 76-22	Evotherm®	230	4.8	2.534	85.6	2.421	4.4	15.4	71.1
PG 76-22	Evotherm®	190	4.8	2.534	NA	NA	NA	NA	NA

NA = No data available

Evotherm® appears to reduce the optimum asphalt content. However, as stated previously, the asphalt contents presented in Table 2 were used for the production of the remaining test samples to reduce the number of variables. Similar reductions were noted in previous research (*5-7*). Beyond the effects of improved compaction, the addition of Evotherm® is not expected to impact the calculation of volumetric properties.

Densification

Once the optimum asphalt contents and volumetric properties for each aggregate/binder combination were determined, test samples were then produced to evaluate the mixes' ability to be compacted over a range of temperatures. These test samples were prepared using oven dried aggregate. Before test samples were made, the anticipated number of test specimens were batched and then randomized for each of the different sets to reduce the variability. This was achieved by compacting a set of six samples per mix at the three lower temperatures mentioned previously (265, 230, and 190°F (129, 110, 88°C)), as well as a set compacted at 300°F (149°C). The mixing temperature was approximately 35°F (14°C) above the compaction temperature. Each sample was aged for two hours at its corresponding compaction temperature prior to compaction. Test samples were compacted using a vibratory compactor, as seen in Figure 2. The vibratory compactor was selected for several reasons. One reason was that the literature suggested that the Superpave gyratory compactor was insensitive to temperature changes, whereas it was believed that constant stress compaction devices, such as the vibratory compactor and the Marshall hammer, would be more sensitive to the effects of temperature. A second reason was that it was found to be easier to produce samples for the Asphalt Pavement Analyzer (APA) with the vibratory compactor than with a Marshall hammer.

Figure 2. Vibratory Compactor used for Compaction of Test Samples.

Test samples, 6 inches in diameter and 3.75 inches tall, were compacted in the vibratory compactor for a time period of 30 seconds. This was the length of time that produced an air void level of 7 percent in preliminary testing using the PG 64-22 control mixture with the granite aggregate. Once the air void level was determined, these same samples were then used to determine the resilient modulus and APA rut resistance of each mix at the various compaction temperatures.

Resilient Modulus

Resilient modulus is a measure of the stiffness of the hot mix asphalt. The resilient modulus was determined according to ASTM D 4123, *Indirect Tension Test for Resilient Modulus of*

Bituminous Mixtures. The testing was conducted at 73°F (23°C) as recommended by Lottman (*8*). Since resilient modulus is a non-destructive test, additional testing was conducted on the same set of test samples for each mix combination.

APA Rutting

Once the resilient modulus testing was completed, each mixture set was placed in the APA to determine the rut resistance of each aggregate/binder combination for the different compaction temperatures. All testing was conducted at 147°F (64°C) to minimize variables in the data. Testing was conducted using a hose pressure of 120 psi and a vertical load of 120 pounds.

Strength Gain

An evaluation of strength change with time was also conducted because of the possible changes in the stiffness of the asphalt due to the lower operating temperatures with the Evotherm®. If the Evotherm® improves the workability of a mixture, there may be concern that the workability would not dissipate prior to being opened to traffic, thus creating the potential for rutting. Ten samples of each mix were prepared for short-term and long-term mix aging per AASHTO PP2, using the PG 64-22 binder and both aggregates. Samples were produced in the Superpave Gyratory Compactor at a compaction temperature of 250°F (121°C). Mixture strength was evaluated based on indirect tensile strength at 77°F (25 °C). The indirect tensile strength of the mixture is sensitive to binder (or mastic) stiffness. Indirect tensile strength testing was performed on samples after the aging periods shown in Table 5.

TABLE 5 Strength Gain Experiment Aging Periods

Set	Short Term Aging (hours) at 230°F (110 °C) (prior to compaction)	Long Term Aging (days) of Compacted Samples at 185°F (85 °C)
1	2	0
2	4	0
3	2	1
4	2	3
5	2	5

Moisture Sensitivity

If the moisture contained in the aggregate does not completely evaporate during mixing due to the low mix temperatures, water may be left in close contact with the aggregate surface, which could lead to an increased susceptibility to moisture damage. Therefore, additional test samples were produced and tested according to ASTM D 4867, *Effect of Moisture on Asphalt Concrete Paving Mixtures*, to assess the potential for moisture susceptibility of each mixture combination. The ASTM procedure is similar to the AASHTO T283 procedure except for the aging times. Several agencies have already eliminated the 72-96 hour cure period found in the AASHTO procedure.

To simulate the actual mixing process of a typical drum plant, a bucket mixer and a propane torch were used to heat the aggregate and mix the samples for making the TSR test samples. This was selected based on a methodology developed to study the effects of residual moisture on compaction (tender mixes) (*9*). The bucket mixer used can be seen in Figure 2. Before the aggregate was combined with the binder, 3 percent water in addition to the absorption value of each aggregate was added to the mix before it was heated. The addition of 3 percent water above the absorption value was selected as typical of stockpile moisture contents. For example, the granite aggregate had an absorption value of 1.1 percent, so a total of 4.1 percent water by aggregate weight was added to the oven dry material before the aggregate was heated in the bucket mixer and the binder was added.

The addition of the aggregate to the bucket mixer took place in two steps. When the entire gradation was added at once, by the time the aggregate was heated to the intended mixing temperature, which was 275°F (135°C), all of the fine material segregated to the bottom of the bucket. So when the binder was added to the aggregate, the fine material was not fully coated. This was alleviated by adding the coarse and fine aggregate separately. The appropriate percentage of moisture was added to the fine aggregate portion, and then set aside. The coarse aggregate was added to the bucket, and appropriate percentage of moisture was introduced to the coarse aggregate (Figure 3) and then it was heated to 250°F (121°C) (Figure 4). Then the fine aggregate portion was added to the bucket and the aggregate was heated back to the intended mixing temperature. When reached, the dust proportion of the blend and the binder was added to the bucket and allowed to thoroughly coat the aggregate. Each bucket mix produced three test samples. During the mixing process, the mix temperature decreased, so each test sample was placed in an oven until the compaction temperature (250°F (121°C)) was reached, usually about 10-15 minutes. This process is shown in Figures 3-5.

Figure 3. Introduction of Moisture to Aggregate for TSR Samples.

Figure 4. Heating of Wet Aggregate to Mixing Temperature.

Figure 5. Warm Mix Asphalt in Bucket Mixer.

TEST RESULTS AND DISCUSSION

Densification

As mentioned earlier, samples were compacted in the vibratory compactor over a range of temperatures. The densification results for both the granite and limestone mixes are shown in Figures 6 and 7, with the individual test results located in the appendix. From observation of the results in Figures 6 and 7, the addition of Evotherm® improves compaction over the control mixture for all binder, aggregate, and temperature combinations. Observation of Figure 6 also shows that the air void content increased from 300°F (149°C) to 265°F (129°C) for the PG 64-22 binder, but did not increase at the compaction temperatures below 265°F (129°C). This is probably due to less aging of the binder resulting from the lower temperatures or from the coarse nature of the mix. Reduced aging of the binder would tend to result in a lower viscosity. To verify if the coarse nature of the mix had an influence on the densification of the mixtures, a fine gradation was evaluated in the vibratory compactor at the different compaction temperatures, and their corresponding air voids were determined. A comparison of the fine and coarse gradations is shown in Figure 8. The results of the fine mix evaluation are shown in Figure 9 and indicate a gradual increase in the air void content with the decrease in compaction temperature. So the coarse nature of the mix is believed to have some influence in the fluctuation of the densification at the lower compaction temperatures. This gradual increase in air voids with decreasing compaction temperature was also observed with the PG 76-22 binder and the coarse gradation.

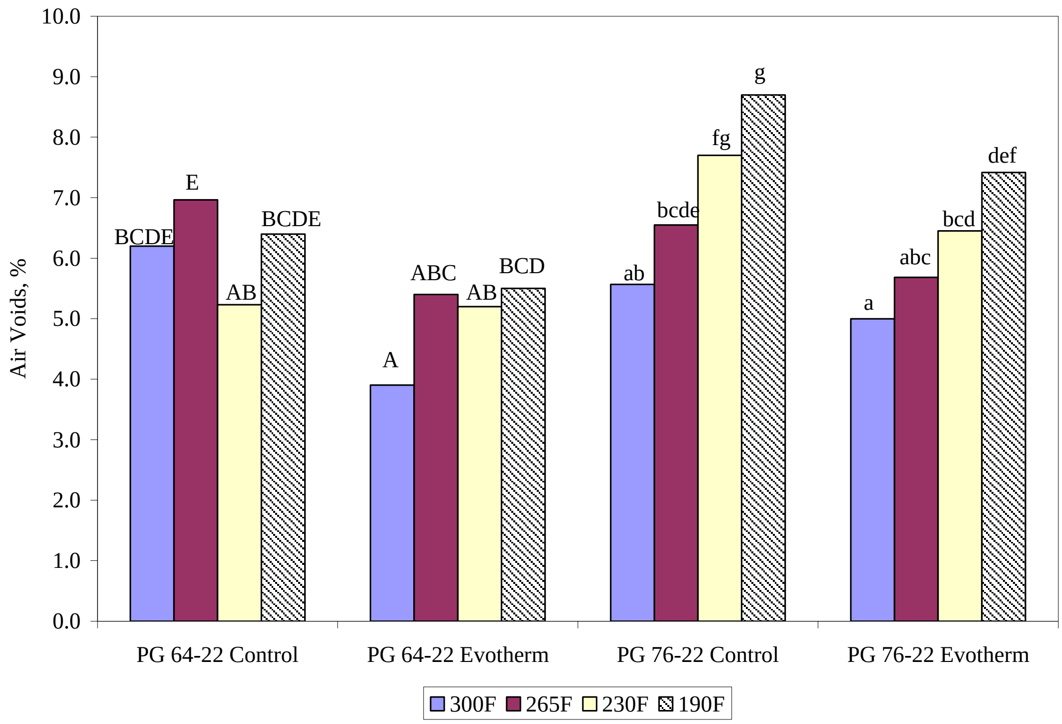

Figure 6. Densification Results over Range of Compaction Temperatures – Granite Mix.

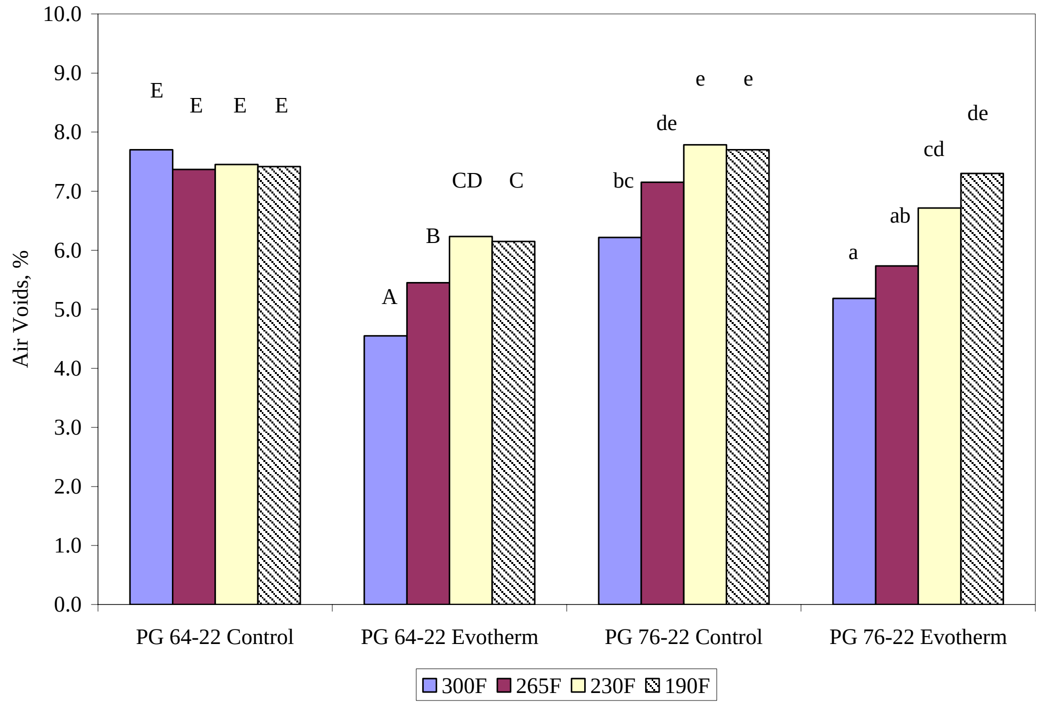

Figure 7. Densification Results over Range of Compaction Temperatures – Limestone Mix.

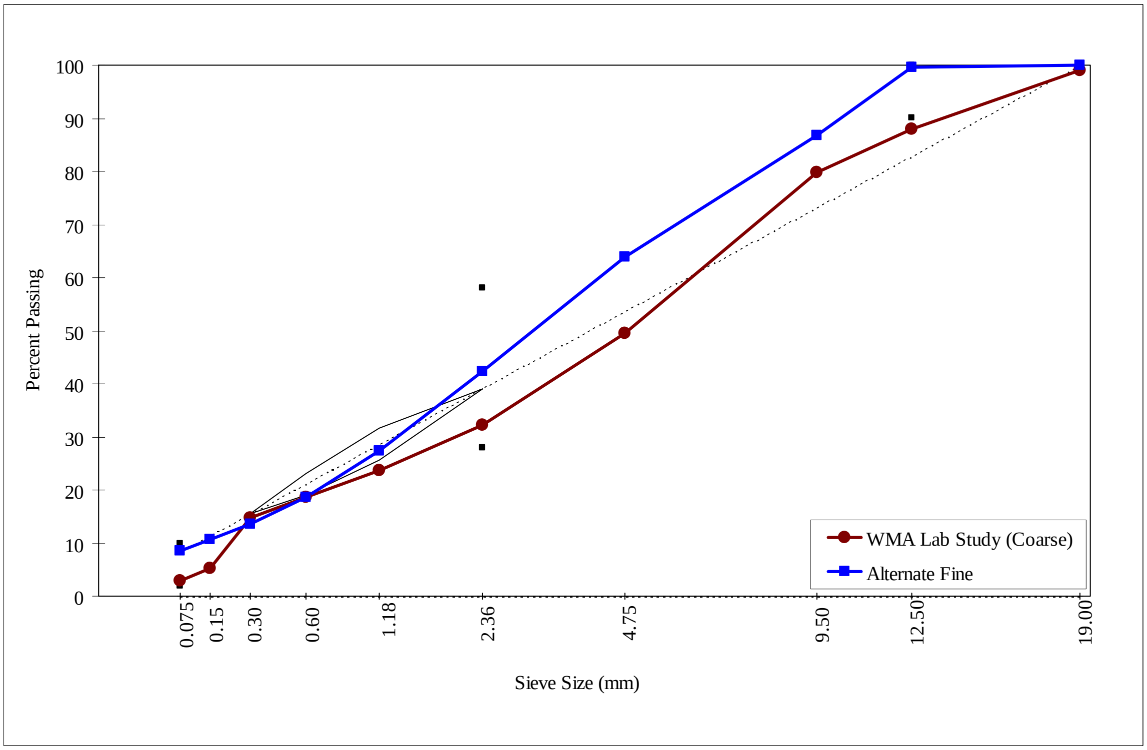

Figure 8. Comparison of Coarse and Fine Mix Gradations.

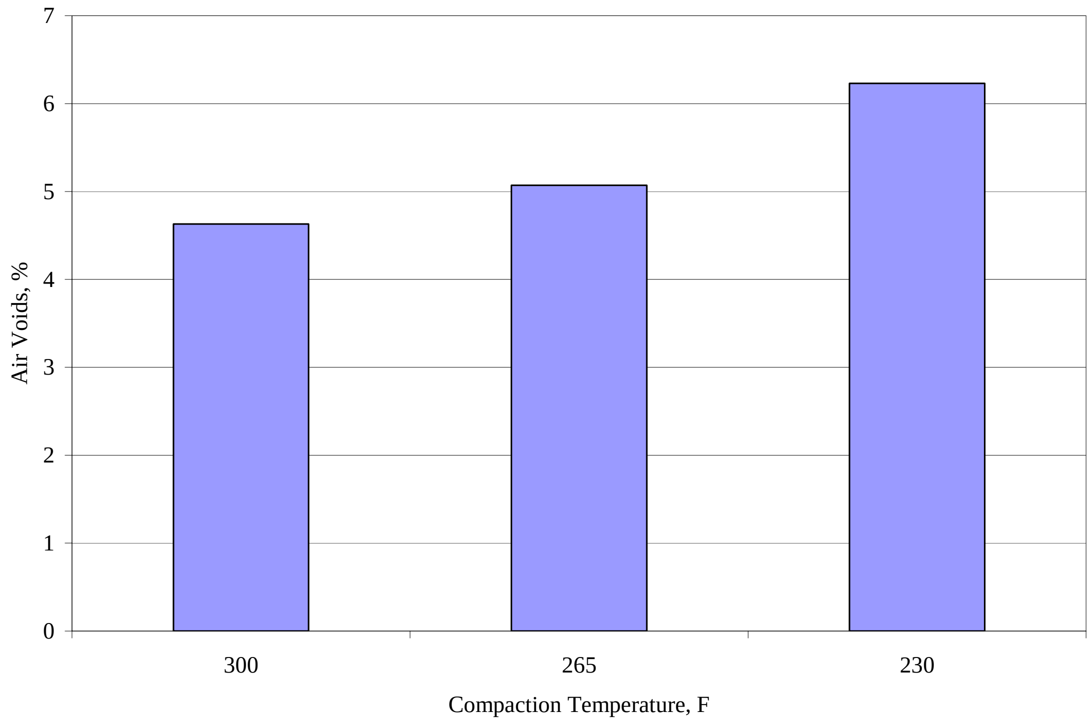

Figure 9. Densification Results over Range of Compaction Temperatures – Fine Mix (no WMA Additive).

Analysis of Variance (ANOVA) was used to analyze the densification data with air voids as the response variable and aggregate type, binder grade, presence of Evotherm®, and compaction temperature as factors. The results from the ANOVA are presented in Table 6. Of the main factors and interactions, all factors and interactions were significant except for the three-way interaction between compaction temperature, the presence of Evotherm®, and aggregate type and the four-way interaction of the factors. The presence of Evotherm® was the most significant factor followed by compaction temperature. A Tukey's post ANOVA test performed on the densification results to compare the means of the different factor level combinations. Tukey's test showed that, overall, the Evotherm® reduced the air void content by an average of 1.3 percent with a 95 percent confidence interval of 1.1 to 1.4 percent. The data was then segregated by binder grade and aggregate type and separate Tukey's analysis performed on each subset. The ranking of the mean air void contents are shown in Figures 6 and 7 in letter form. Upper case letters were used for the PG 64-22 results and lower case letters were used for the PG 76-22 results. The letter "a or A" represents the combination (control or Evotherm® and temperature) that had the lowest average air void content (best compaction). Factor combinations sharing the same letter are statistically not different from one another. For instance, the PG 76-22 limestone control mix at 300°F (149°C) has a ranking of "bc." This indicates that the PG 76-22 limestone mixes containing Evotherm® produced at 265 and 230°F (129 and 110°C) produced air void levels that were not different than the control mix at 300°F (149°C), and that the Evotherm® mix produced at 300°F (149°C) produced lower air voids.

TABLE 6 Analysis of Variance Densification Results

Source	Degrees of Freedom	Sum of Squares	F-Statistic	*p-value*	Percent Contribution	Significant ?[1]
Aggregate (Agg)	1	12.51	38.82	0.000	4.4	Yes
Binder	1	18.01	55.90	0.000	6.4	Yes
Additive	1	76.00	235.93	0.000	26.9	Yes
Temperature (Temp)	3	60.51	62.62	0.000	21.4	Yes
Agg*Binder	1	8.76	27.18	0.000	3.1	Yes
Agg*Additive	1	1.37	4.24	0.041	0.5	Yes
Agg*Temp	3	4.80	4.97	0.003	1.7	Yes
Binder*Additive	1	3.52	10.93	0.001	1.2	Yes
Binder*Temp	3	21.21	21.94	0.000	7.5	Yes
Additive*Temp	3	5.91	6.11	0.001	2.1	Yes
Agg*Binder*Additive	1	1.58	4.89	0.028	0.6	Yes
Agg*Binder*Temp	3	4.64	4.80	0.003	1.6	Yes
Agg*Additive*Temp	3	1.60	1.66	0.178	0.6	No
Binder*Additive*Temp	3	9.16	9.48	0.000	3.2	Yes
Agg*Binder*Additive*Temp	3	1.38	1.43	0.236	0.5	No
Error	160	51.54			18.2	
Total	191	282.50				

Note: [1] indicates significance at the 5 percent level

Resilient Modulus

An ANOVA was performed to determine which factors (aggregate type, binder grade, Evotherm®, and compaction temperature) significantly affected the measured resilient modulus. Unfortunately, the model only had an R^2 value of 22 percent. This indicates that the factor level combinations did not explain the variations in modulus. In part, this may be due to the variability of the test method. The results are presented in Table 7. The poor fit of the model is again indicated by the large sum of squares for error and its corresponding percent contribution. Based on the results, only aggregate type, compaction temperature, and the presence of Evotherm® were significant factors in the determination of resilient modulus.

Main effects plots for resilient modulus are shown in Figure 10. From these plots, several observations can be made. First, the limestone aggregate consistently produced the highest resilient modulus values. All mixes containing Evotherm® had higher resilient modulus over their respective control mixes. It is believed that the increased stiffness is related to the increased sample density achieved with the Evotherm® samples. Also, the resilient modulus generally decreased as the compaction temperature decreased. It is believed that this is influenced by the decreased sample density with decreasing compaction temperatures.

TABLE 7 ANOVA Results for Resilient Modulus

Source	Degrees of Freedom	Sum of Squares	F-Statistic	*p-value*	Percent Contribution	Significant ?[1]
Aggregate (Agg)	1	5.92E+10	6.81	0.010	3.3	Yes
Binder	1	3.35E+09	0.39	0.536	0.2	No
Additive	1	5.43E+10	6.24	0.014	3.0	Yes
Temperature (Temp)	3	1.15E+11	4.39	0.005	6.4	Yes
Agg*Binder	1	2.34E+10	2.69	0.103	1.3	No
Agg*Additive	1	1.69E+08	0.02	0.889	0.0	No
Agg*Temp	3	2.78E+10	1.07	0.365	1.6	No
Binder*Additive	1	6.90E+08	0.08	0.779	0.0	No
Binder*Temp	3	6.59E+09	0.25	0.859	0.4	No
Additive*Temp	3	3.61E+09	0.14	0.937	0.2	No
Agg*Binder*Additive	1	3.30E+10	3.79	0.053	1.9	No
Agg*Binder*Temp	3	1.33E+10	0.51	0.677	0.7	No
Agg*Additive*Temp	3	1.15E+10	0.44	0.725	0.6	No
Binder*Additive*Temp	3	4.15E+09	0.16	0.924	0.2	No
Agg*Binder*Additive*Temp	3	3.25E+10	1.25	0.295	1.8	No
Error	160	1.39E+12			78.2	
Total	191	1.78E+12				

Note: [1] indicates significance at the 5 percent level

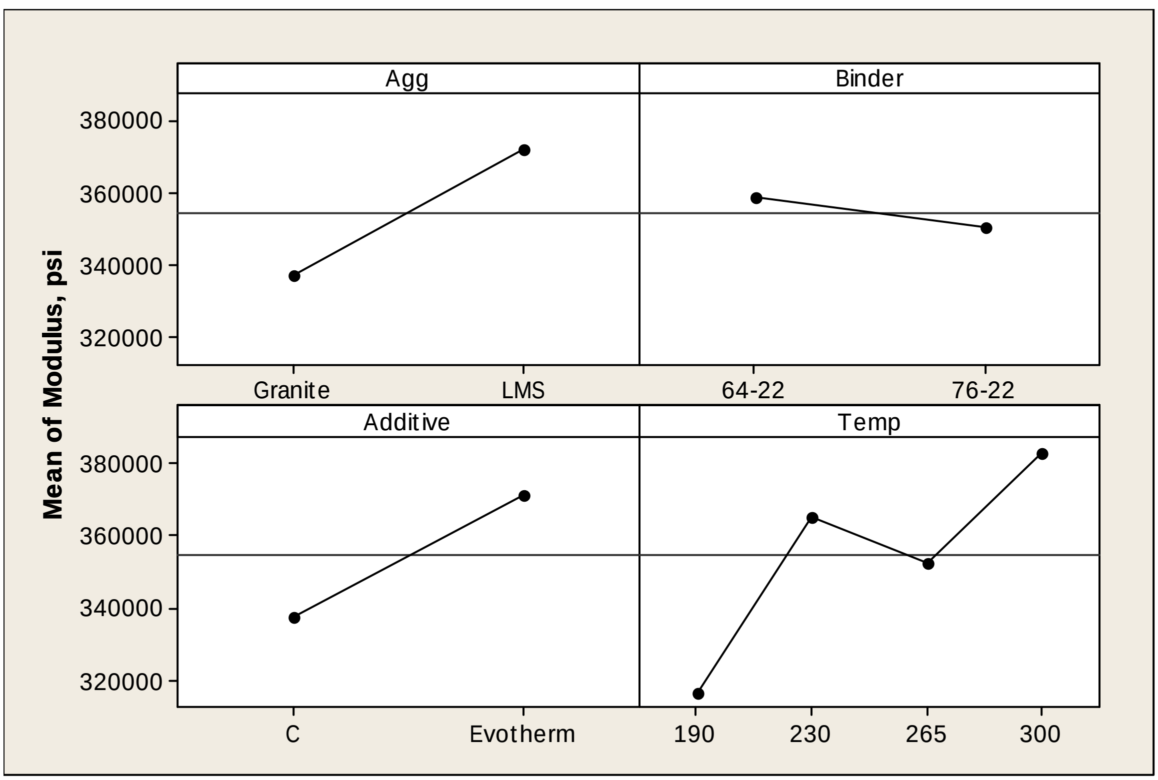

Figure 10. Main Effects Plots for Resilient Modulus.

APA Rutting

Once each set of test samples was tested to determine its resilient modulus value, it was placed in an oven at 147°F (64°C) for a minimum of six hours to ensure that each sample was equilibrated to the APA test temperature. The samples were then placed in the Asphalt Pavement Analyzer to determine their rutting potential at a temperature of 147°F (64°C). The PG 76-22 binder was also evaluated at 147°F (64°C) to minimize testing variability. The rutting results for the granite and limestone aggregates are shown in Figures 11 and 12. The whisker marks in both figures indicate the standard deviation for each set of rut samples.

An ANOVA was performed to determine which factors (aggregate type, binder grade, Evotherm®, and compaction temperature) significantly affect the measured rut depth. Each of the six samples tested in the APA was treated as a replicate. Results from the ANOVA test are presented in Table 8.

The results show that all factors and interactions between binder and compaction temperature, the three-way interactions between aggregate, binder type, and the presence of Evotherm®, and aggregate, Evotherm®, and compaction temperature were significant. As indicated by the percent contribution (Table 8), binder grade had the largest influence on APA rut depth followed by compaction temperature. The presence of Evotherm® did have a significant effect on the measured rut depth. This means that the use of Evotherm® would significantly decrease the rutting potential of an asphalt mixture. The results from a Tukey's post ANOVA test indicated that the addition of Evotherm® should decrease the rut depth of an asphalt mixture by an average of 1.8 mm, with a 95 percent confidence interval of 1.2 to 2.5 mm.

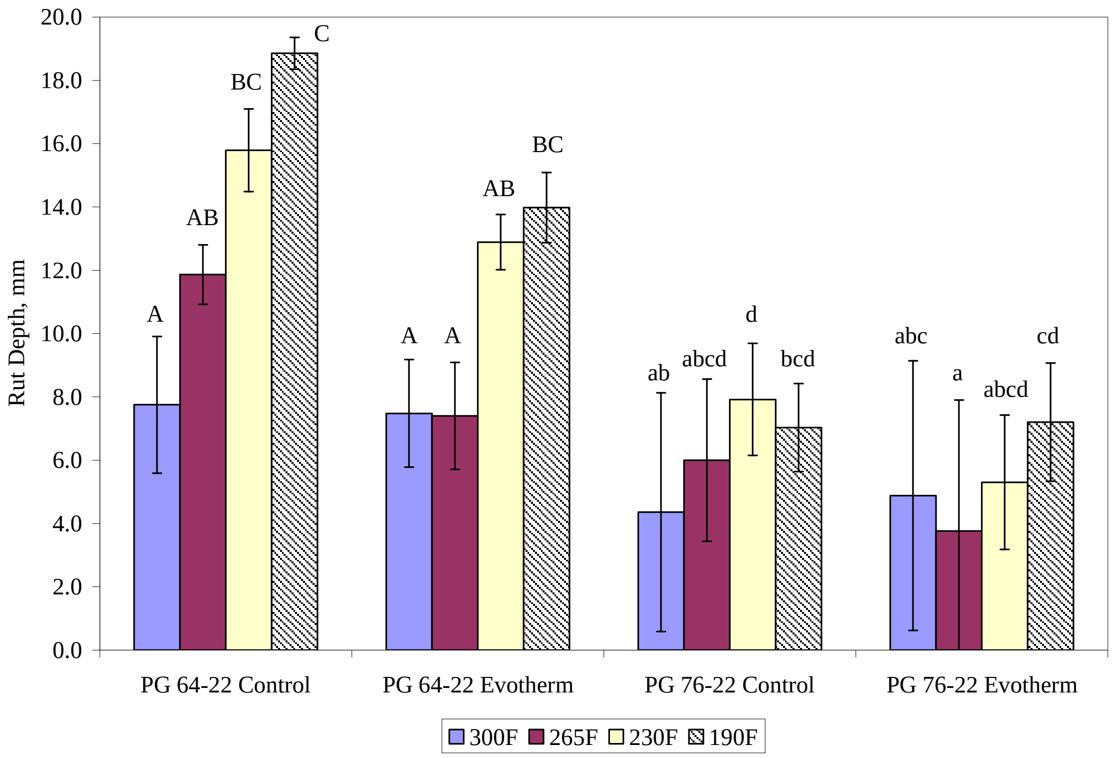

Figure 11. APA Rut Depths for the Granite Aggregate.

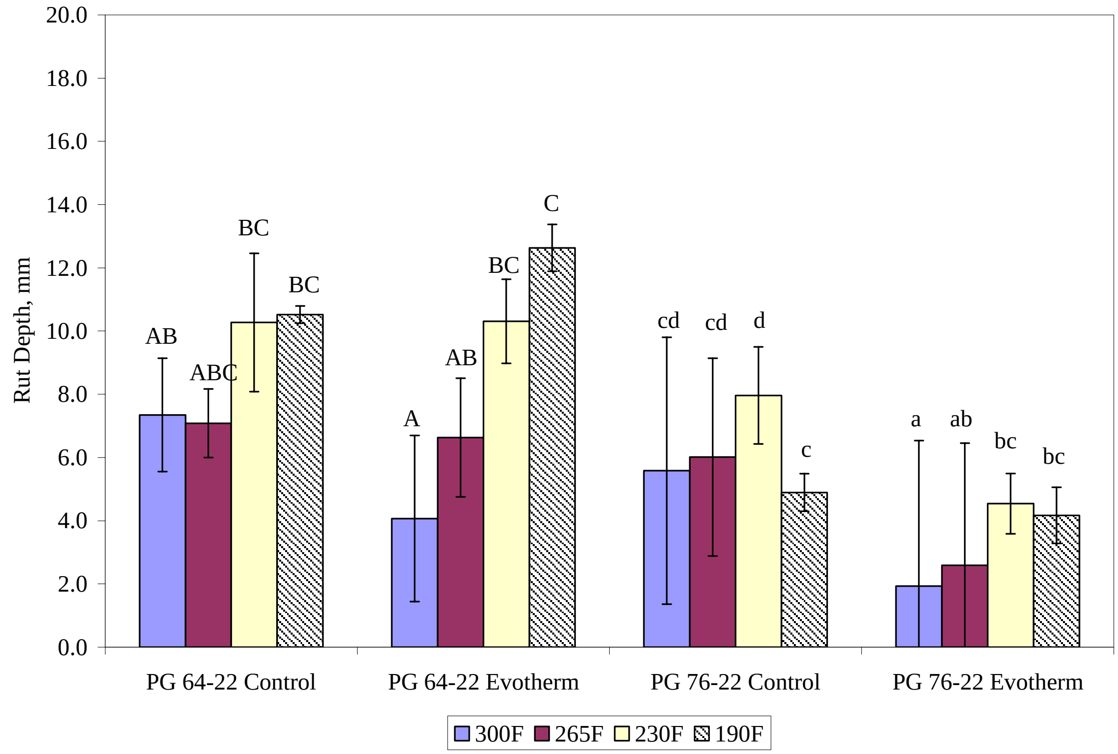

Figure 12. APA Rut Depths for the Limestone Aggregate.

TABLE 8 ANOVA Results for Rut Depth

Source	Degree of Freedom	Sum of Squares	F-Statistic	*p-value*	Percent Contribution	Significant ?[1]
Aggregate (Agg)	1	241.97	42.13	0.000	6.4	Yes
Binder	1	1222.71	212.90	0.000	32.4	Yes
Additive	1	163.02	28.39	0.000	4.3	Yes
Temperature (Temp)	3	694.69	40.32	0.000	18.4	Yes
Agg*Binder	1	63.20	11.01	0.001	1.7	Yes
Agg*Additive	1	2.81	0.49	0.485	0.1	No
Agg*Temp	3	38.58	2.24	0.086	1.0	No
Binder*Additive	1	0.32	0.06	0.814	0.0	No
Binder*Temp	3	228.35	13.25	0.000	6.1	Yes
Additive*Temp	3	22.30	1.29	0.278	0.6	No
Agg*Binder*Additive	1	60.73	10.57	0.001	1.6	Yes
Agg*Binder*Temp	3	10.62	0.62	0.605	0.3	No
Agg*Additive*Temp	3	73.26	4.25	0.006	1.9	Yes
Binder*Additive*Temp	3	11.50	0.67	0.573	0.3	No
Agg*Binder*Additive*Temp	3	17.72	1.03	0.382	0.5	No
Error	160	918.90			24.4	
Total	191	3770.69				

Note: [1] indicates significance at the 5 percent level

Interaction plots for rut depth are illustrated in Figure 13. The interaction plots graphically show how the factors affect the rutting potential. From observation of the interaction plots, several observations can be made. First, the limestone rutted less than the granite. Second, the PG 76-22 decreased the rutting potential over the PG 64-22, especially at the lower compaction temperatures. And third, the addition of Evotherm® decreased the rutting potential over the control mixes.

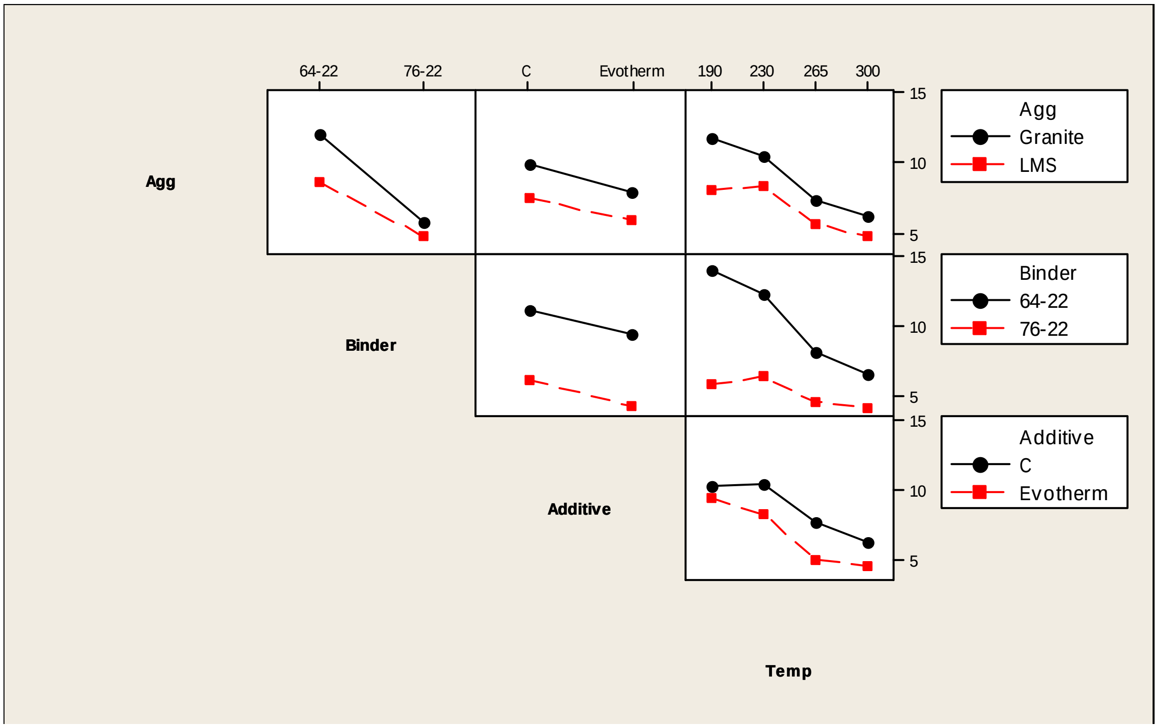

Figure 13. Interaction Plots for Rut Depth.

Further data analysis was performed to determine if there is a significant difference in the rut depths at the four compaction temperatures. Two two-way interactions were significant for the APA rut depth ANOVA, Binder*Temperature and Binder*Aggregate. Both interactions were also significant for the densification results. The data was again subdivided by binder grade and aggregate type (due to the significance of that interaction). The Tukey's method was again used to compare the means of a given subset, e.g. PG 64-22 Limestone. The same letter convention was used to describe the rankings as was used previously described for densification, except now "A or a" indicated the smallest rut depth. The letter rankings are shown in Figures 11 and 12. The results indicate that the Evotherm® mixes produced at 300, 265 or 230°F (149, 129, or 110°C) performed as well as or better than the control mix produced at 300°F (149°C).

One might question why Evotherm® reduced the rutting potential. Rutting in the asphalt layer can consist of one of two components: consolidation or shear flow, or a combination thereof. Therefore, it was hypothesized that the improved compaction provided by the Evotherm® may have reduced the measured rutting in the APA. Recall that the compaction effort was held constant for all of the factor level combinations, allowing the air voids to vary. To test this hypothesis, as a first step, the Pearson correlation was determined to be 0.019 with a *p-value* = 0.798 indicating no correlation between air voids and APA rut depth when considering all of the data. To investigate whether other factors were masking the correlation, the data was subdivided based on the two significant two-way interactions, by binder and aggregate type and by binder and compaction temperature. The results are shown in Tables 9 and 10, respectively. Based on Table 9 there was a significant correlation between sample air voids and APA rut depth for the samples with PG 76-22 binders. This indicates that the improved compaction with the stiffer binder resulting from using Evotherm® reduced the measured rut depth. A similar observation is made in Table 10 for both binder grades at 230°F (110°C) and the PG 76-22 at 265°F (129°C), indicating the improved compaction and resulting reduction in measured rutting resulting from the Evotherm®.

TABLE 9 Correlation Matrix by Binder and Aggregate Type

Binder Grade	Statistic	Aggregate Type	
		Granite	Limestone
PG 64-22	Pearson Correlation	0.222	0.259
	p-value	0.129	0.076
PG 76-22	Pearson Correlation	0.612	0.636
	p-value	0.000	0.000

TABLE 10 Correlation Matrix by Binder and Temperature

Binder Grade	Statistic	Compaction Temperature, °F			
		300	265	230	190
PG 64-22	Pearson Correlation	0.327	0.167	-0.547	-0.078
	p-value	0.119	0.436	0.006	0.716
PG 76-22	Pearson Correlation	0.375	0.743	0.528	0.389
	p-value	0.071	0.000	0.008	0.06

Strength Gain

The strength gain experiment was conducted to evaluate the rutting potential immediately after construction. The results from the strength gain experiment for both aggregates are presented in Figures 14 and 15. The results indicated that the strength varied over the different age times but was fairly consistent between the control mix and the Evotherm® mix at a particular age time, except for the extended five day long term age time for the granite and for the two hour short term age time with the limestone aggregate. The data for the Evotherm® samples generally indicated a reduced aging of the binder (lower tensile strength) with the limestone, however, the Evotherm® demonstrated an increase in tensile strength with the granite aggregate for all cases except for the one day long term age time. Also, based on the rutting data discussed earlier, there is no evidence to support the need for a cure time before traffic can be allowed on the asphalt mixture containing Evotherm®.

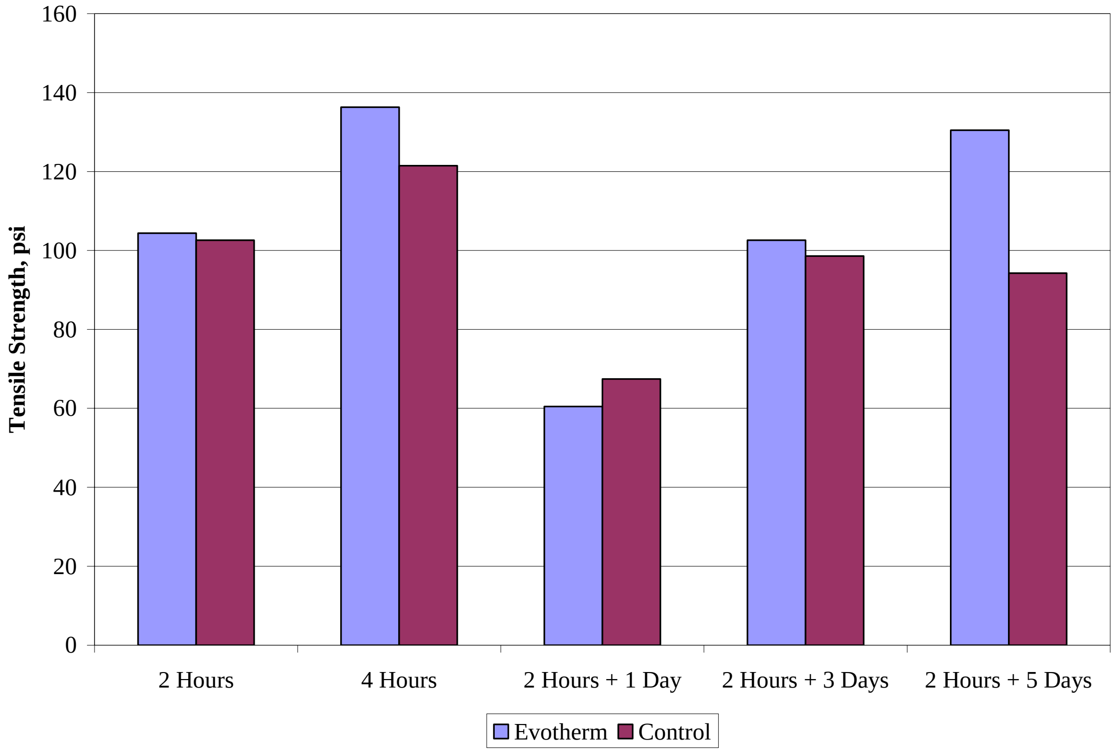

Figure 14. Strength Gain Results – Granite Aggregate.

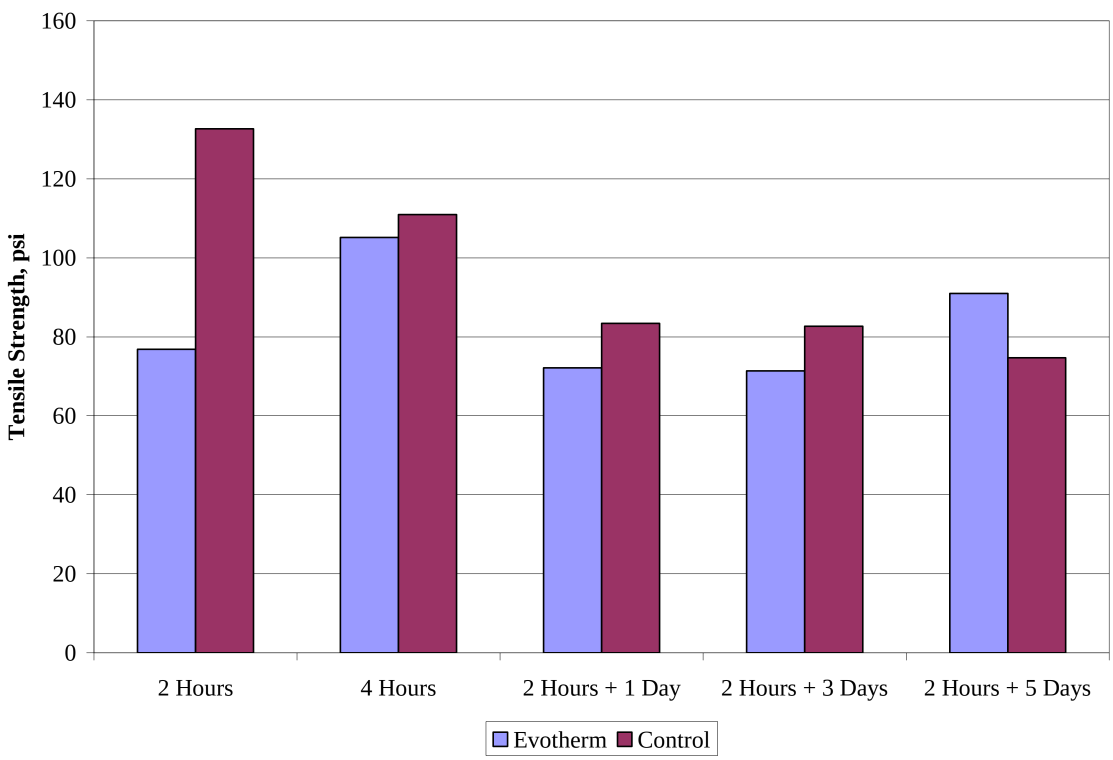

Figure 15. Strength Gain Results – Limestone Aggregate.

Moisture Sensitivity

As was mentioned before, ASTM D 4867 was used to determine the moisture sensitivity test results. The results for both aggregates are shown in Table 9. The test results exhibited some variability in the data from one aggregate type to the next. For example, the Evotherm® used with the PG 76-22 binder increased the resistance to moisture for the granite, but decreased the resistance for the limestone. Observation of the results concluded that the addition of Evotherm® generally improved performance, with respect to the moisture susceptibility, compared to their corresponding control mixture.

Observing the test results in Table 11 individually, only five out of the nine mixes had TSR values that met Superpave criteria. Superpave suggests a TSR value of at least 80 percent. After the initial TSR data were obtained, the data were reported back to MeadWestvaco's Asphalt Innovations. In turn, the chemical package used to produce the Evotherm® was altered somewhat to help increase Evotherm®'s resistance to moisture, especially with the limestone aggregate. Additonal testing for moisture sensitivity was then conducted, with the results presented in Table 12. From the results, the resistance to moisture susceptibility increased by approximately 50 percent, a significant increase. The conditioned samples exhibited no visible stripping, neither adhesive nor cohesive. This demonstrates MeadWestvaco's ability to taylor the chemical package for specific aggregates, if necessary.

TABLE 11 Tensile Strength Results for Granite and Limestone Aggregates

Aggregate	Compaction Temperature, °F	Mix Type	Unsaturated Tensile Strength, psi	Saturated Tensile Strength, psi	TSR, %	Visual Stripping?
Granite	300[1]	PG 64-22 Control	126.6	123.4	0.97	No
Granite	250	PG 64-22 Control	75.9	80.9	1.06	Yes
Granite	250	PG 64-22 Evotherm®	70.8	67.7	0.96	No
Granite	250	PG 76-22 Control	137.3	68.4	0.50	Yes
Granite	250	PG 76-22 Evotherm®	101.3	85.5	0.84	No
Limestone	250	PG 64-22 Control	109.5	71.2	0.65	Yes
Limestone	250	PG 64-22 Evotherm®	75.0	46.8	0.62	Yes
Limestone	250	PG 76-22 Control	97.3	84.7	0.87	Yes
Limestone	250	PG 76-22 Evotherm®	72.3	47.7	0.66	Yes

[1] Produced with oven dry aggregate. Remaining mixtures produced in bucket mixer with damp aggregate as desribed previously

TABLE 12 Tensile Strength Results for Limestone Aggregate – New Evotherm® Formulation

Aggregate	Mix Type	Unsaturated, psi	Saturated, psi	TSR, %	Visual Stripping?
Limestone	PG 64-22 Evotherm®	85.6	93.5	1.09	No

Hamburg Wheel-Tracking Device

To validate the TSR results, test samples were prepared and tested in the Hamburg wheel-tracking device (HWTD). One use of this device is to predict moisture damage of hot mix asphalt. The HWTD also has been found to be sensitive to several factors, including asphalt cement stiffness, length of short-term aging, compaction temperature, and anti-stripping treatments (*10*). All these factors have previously been observed as possible problem areas in the evaluation of warm asphalt mixes, so the test results from the Hamburg wheel-tracking device may be vital in accurately establishing a good-performing warm mix asphalt.

Test results from the Hamburg wheel-tracking device are presented in Table 13. Also included are the corresponding TSR values for each of the mix types. From these test results, the Hamburg test results varied in relation to the test results from the TSR testing. In some cases, the Hamburg confirmed the data determined from the TSR test, while in other cases the Hamburg data showed an improvement in the moisture resistance of a particular mix. This is mainly true for the mixes containing PG 76-22. This is based on the stripping inflection point. When describing the stripping inflection point, it is the number of passes at which the deformation of the sample is the result of moisture damage and not rutting alone, and is typically considered the point at which stripping occurs. The stripping inflection point corresponds to an increase in the rutting rate.

TABLE 13 Hamburg Wheel-Tracking Device Results

Aggregate	Mix Type	Binder	Treatment	Stripping Inflection Point, cycles	Rutting Rate, mm/hr	Unsaturated Tensile Strength, psi	Saturated Tensile Strength, psi	TSR
Granite	Control	PG 64-22	None	6500*	1.841	75.9	88.3	1.16
Granite	Evotherm®	PG 64-22	None	NA	1.708	70.8	67.7	0.96
Granite	Control	PG 76-22	None	NA	0.708	137.3	68.4	0.50
Granite	Evotherm®	PG 76-22	None	NA	0.586	101.3	85.5	0.84
Limestone	Control	PG 64-22	None	2500	4.284	109.5	71.2	0.65
Limestone	Evotherm®	PG 64-22	None	2550	3.178	75.0	46.8	0.62
Limestone	Control	PG 76-22	None	5750	1.535	97.3	84.7	0.87
Limestone	Evotherm®	PG 76-22	None	7375	1.326	72.3	47.7	0.66

Note: * individual sample did not have a stripping inflection point; reported value is average of 10,000 cycles and recorded stripping inflection point of second sample

NA = No stripping inflection point was determined

Illustration of the stripping inflection point is shown in Figure 16. It is related to the resistance of the mix to moisture damage. Stripping inflection points over 10,000 cycles, in a general sense, represent good mixes. A lower stripping inflection point is an indication of a decrease in the resistance to moisture for an asphalt mix.

The rutting rate determined from the Hamburg test results correlated well with the stripping inflection point; as the inflection point increased, indicating an increase in moisture resistance, the rutting rate decreased. Rutting rate is defined as the slope of the secondary consolidation tangent, as seen in Figure 15. The addition of Evotherm® improved the rutting rate in all cases as compared to the control mixes. This corresponds to the findings with the APA.

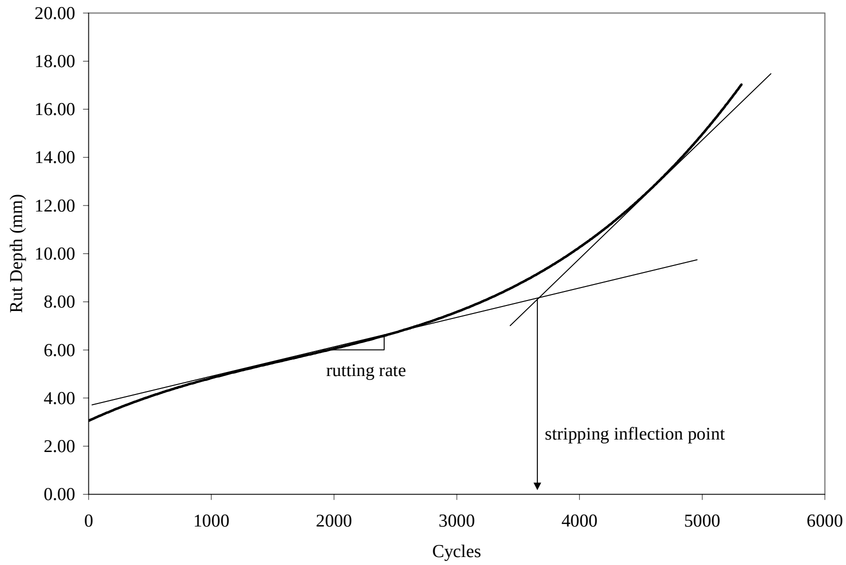

Figure 16. Hamburg Test Results, Defining Rutting Rate and Stripping Inflection Point.

CONCLUSIONS

Based on the results from the lab testing using Evotherm®, the following conclusions were made:

- The addition of Evotherm® lowers the measured air voids in the gyratory compactor for a given asphalt content. While this may indicate a need to reduce the optimum asphalt content, at this time it is believed that additional research is required and that the optimum asphalt content of the mixture determined without the Evotherm® should be used. It should be noted that the optimum asphalt content of the mixture without the addition of the Evotherm® was used for all of the testing (with and without Evotherm®) completed in this study. Reducing the optimum asphalt content may negate the improved compaction resulting from the addition of Evotherm®.
- Evotherm® improved the compactability of the mixtures in both the SGC and vibratory compactor. Statistics indicated an average reduction in air voids up to 1.4 percent. Improved compaction was noted at temperatures as low as 190°F (88°C) for the mixes produced with Evotherm®. Improved compaction is expected to improve performance.
- At a given compaction temperature, the addition of Evotherm® increases the resilient modulus of an asphalt mix compared to control mixtures having the same PG binder.
- The addition of Evotherm® significantly decreased the rutting potential of the asphalt mixes evaluated as compared to control mixtures produced at the same temperature. The rutting potential increased with decreasing mixing and compaction temperatures, and this is believed to be related to the decreased aging of the binder. However, the mixes containing Evotherm® were less sensitive (in terms of rutting) to the decreased production temperatures than the control mixes were. The improved performance of the Evotherm® was, in some cases, significantly correlated to improved compaction.

- The indirect tensile strengths for mixes containing Evotherm® were lower, in some cases, as compared to the control mixes. Other laboratory tests (APA and Hamburg) indicated good rutting resistance for the mixes containing Evotherm®.
- The lower compaction temperature used when producing Warm Mix Asphalt with any such WMA additive may increase the potential for moisture damage. The lower mixing and compaction temperatures can result in incomplete drying of the aggregate. The resulting water trapped in the coated aggregate may cause moisture damage or possibly tender mix. Visual stripping was observed in the control mixes for both aggregates and with the original Evotherm® formula with the limestone aggregate mix produced at 250°F (121°C). Low TSR values were observed with the original Evotherm® formula and the limestone aggregate. However, the new Evotherm® formula increased the tensile strength and eliminated the visual stripping for the limestone aggregate.

RECOMMENDATIONS

Based on the research conducted to date, the following are recommended when using Evotherm® to reduce hot mix asphalt production temperatures:

- The optimum asphalt content should be determined with a neat binder having the same grade as the Evotherm® modified binder. Additional samples should then be produced with the Evotherm® modified binder so the production air void target can be adjusted (e.g. If the air void content with the Evotherm® included was decreased in the lab by 0.5 percent, then the field target air voids should be decreased by 0.5 percent).
- Based on the laboratory compaction and rutting results, a minimum mixing temperature of 265°F (129°C) and a minimum compaction temperature of 230°F (110°C) is recommended. If the mixing temperature is below 265°F (129°C), then the high temperature grade should be bumped by one grade to counteract the tendency for increased rutting susceptibility with decreasing production temperatures. Performance testing can be conducted to predict field performance. Field compaction will dictate the true minimum compaction temperature depending on a number of factors.
- Moisture sensitivity testing should be conducted at the anticipated field production temperatures.
- More research is needed to further evaluate field performance, the selection of the optimum asphalt content, and the selection of binder grades for lower production temperatures.

AKNOWLEDGEMENTS

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APPENDIX

TABLE 14 Air Voids and Resilient Modulus Data, PG 64-22 Granite Control

Aggregate: Granite | Poisson's Ratio: 0.35
Test Temperature: 77° F (25° C) | Maximum Specific Gravity (Gmm): 2.467
Asphalt Content: 5.1%

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Sample Height, (mm)	Resilient Modulus (psi)
18	300	3123.6	1782.0	3150.1	2.283	7.5	79.4	467,171
39	300	3127.9	1790.0	3138.2	2.320	6.0	78.1	294,065
42	300	3134.5	1783.1	3135.4	2.318	6.0	78.8	572,998
49	300	3125.3	1795.2	3133.3	2.336	5.3	79.3	420,863
51	300	3136.3	1795.1	3149.6	2.315	6.1	80.0	215,163
85	300	3121.7	1789.7	3131.6	2.326	5.7	78.7	218,717
					Average:	6.1	79.1	364,830
					Standard Deviation:	0.7	0.7	145,399
8	265	3112.1	1782.4	3123.2	2.321	5.9	78.4	272,652
29	265	3088.1	1772.1	3097.3	2.330	5.5	78.2	239,237
53	265	3129.6	1821.3	3226.3	2.227	9.7	82.8	289,367
67	265	3120.5	1788.2	3150.5	2.291	7.1	79.2	577,025
88	265	3110.3	1780.5	3136.0	2.295	7.0	79.6	281,952
89	265	3117.6	1784.8	3138.0	2.304	6.6	79.2	366,632
					Average:	7.0	79.6	337,811
					Standard Deviation:	1.5	1.7	124,486
101	230	3124.7	1804.6	3127.8	2.361	4.3	77.0	315,579
105	230	3127.0	1787.8	3132.9	2.325	5.8	78.0	310,433
109	230	3122.4	1788.7	3127.6	2.332	5.5	78.5	426,761
122	230	3124.5	1792.3	3131.1	2.334	5.4	77.4	349,150
104	230	3119.1	1794.7	3123.9	2.347	4.9	76.5	485,897
125	230	3127.6	1791.6	3133.4	2.331	5.5	77.0	276,334
					Average:	5.2	77.4	360,692
					Standard Deviation:	0.5	0.7	79,815
108	190	3122.6	1781.8	3131.8	2.313	6.2	77.9	332,202
112	190	3131.5	1783.8	3142.4	2.305	6.6	79.8	230,832
117	190	3123.6	1782.8	3136.9	2.307	6.5	78.1	368,541
127	190	3125.8	1780.9	3140.8	2.299	6.8	79.5	288,445
120	190	3124.2	1787.5	3133.2	2.322	5.9	78.0	432,910
116	190	3123.6	1784.4	3137.0	2.309	6.4	78.0	310,051
					Average:	6.4	78.6	327,164
					Standard Deviation:	0.3	0.9	69,270

TABLE 15 Air Voids and Resilient Modulus Data, PG 64-22 Granite Evotherm®

Aggregate: Granite — Poisson's Ratio: 0.35
Test Temperature: 77° F (25° C) — Maximum Specific Gravity (Gmm): 2.465
Asphalt Content: 5.1%

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Sample Height, (mm)	Resilient Modulus (psi)
1	300	3071.0	1776.9	3076.0	2.364	4.1	76.1	494,925
2	300	3073.2	1778.0	3079.4	2.361	4.2	75.8	255,852
3	300	3073.8	1777.4	3079.0	2.362	4.2	76.4	325,132
4	300	3077.2	1793.3	3083.6	2.385	3.3	75.8	398,841
5	300	3067.4	1774.1	3073.4	2.361	4.2	76.3	422,122
6	300	3067.8	1773.7	3072.1	2.363	4.1	76.5	471,223
					Average:	4.0	76.2	394,683
					Standard Deviation:	0.4	0.3	90,320
3	265	3085.9	1776.6	3094.2	2.342	5.0	76.1	396,105
12	265	3087.2	1773.7	3103.9	2.321	5.8	76.6	721,394
20	265	3082.9	1777.7	3095.8	2.339	5.1	75.5	302,279
21	265	3083.5	1774.2	3092.4	2.339	5.1	75.9	252,856
24	265	3083.0	1773.7	3098.0	2.328	5.6	76.1	264,369
30	265	3071.2	1762.3	3080.9	2.329	5.5	76.0	502,908
					Average:	5.4	76.0	406,652
					Standard Deviation:	0.3	0.4	180,682
1	230	3080.7	1762.8	3088.6	2.324	5.7	76.7	305,878
4	230	3077.7	1752.0	3092.2	2.296	6.8	77.3	256,110
7	230	3087.9	1769.9	3092.1	2.335	5.3	75.8	286,165
14	230	3040.6	1755.2	3046.6	2.354	4.5	75.3	364,771
22	230	3066.7	1769.7	3072.4	2.354	4.5	76.6	360,688
39	230	3089.0	1782.8	3094.6	2.355	4.5	76.1	230,165
					Average:	5.2	76.3	300,630
					Standard Deviation:	0.9	0.7	54,599
2	190	3091.6	1781.2	3099.2	2.346	4.8	76.6	395,008
9	190	3096.4	1777.5	3106.7	2.330	5.5	77.3	265,107
23	190	3097.3	1781.5	3106.5	2.338	5.2	76.3	350,227
25	190	3106.3	1783.6	3116.3	2.331	5.4	77.1	314,235
32	190	3094.9	1779.2	3105.9	2.333	5.4	76.8	417,382
35	190	3061.0	1739.6	3071.3	2.299	6.8	76.3	212,857
					Average:	5.5	76.7	325,803
					Standard Deviation:	0.7	0.4	77,907

TABLE 16 Air Voids and Resilient Modulus Data, PG 76-22 Granite Control

Aggregate:	Granite	Poisson's Ratio:	0.35
Test Temperature:	77° F (25° C)	Maximum Specific Gravity (Gmm):	2.457
Asphalt Content:	5.1%		

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Sample Height, (mm)	Resilient Modulus (psi)
12	300	3100.4	1776.7	3110.8	2.324	5.4	76.8	283,165
24	300	3096.2	1776.7	3103.9	2.333	5.1	77.0	473,716
40	300	3083.6	1765.9	3093.3	2.323	5.5	76.7	304,106
47	300	3093.6	1764.5	3109.1	2.301	6.4	78.5	291,239
53	300	3111.9	1782.3	3120.8	2.325	5.4	77.1	293,749
54	300	3097.7	1774.8	3110.8	2.319	5.6	77.4	440,961
					Average:	5.5	77.2	347,823
					Standard Deviation:	0.4	0.7	85,722
14	265	3092.9	1766.9	3108.5	2.305	6.2	77.4	222,115
32	265	3100.2	1765.6	3119.1	2.291	6.8	78.1	344,769
18	265	3093.0	1763.0	3103.0	2.308	6.1	77.1	278,448
50	265	3101.8	1769.2	3119.5	2.297	6.5	77.9	353,318
45	265	3115.9	1772.6	3137.4	2.283	7.1	78.6	242,972
17	265	3086.3	1762.4	3107.0	2.295	6.6	77.8	265,277
					Average:	6.5	77.8	284,483
					Standard Deviation:	0.4	0.5	53,649
30	230	3073.3	1757.4	3110	2.272	7.5	77.8	286,549
46	230	3098.9	1775.4	3135.4	2.279	7.3	79.6	380,925
8	230	3103.9	1779.9	3141.5	2.280	7.2	80.0	290,077
4	230	3099.0	1770.5	3149.1	2.248	8.5	79.6	222,278
5	230	3115.3	1782.1	3161.2	2.259	8.1	80.8	276,623
6	230	3108.9	1776.8	3144.2	2.274	7.5	79.2	227,764
					Average:	7.7	79.5	280,703
					Standard Deviation:	0.5	1.0	57,270
7	190	3040.9	1738.2	3107.4	2.221	9.6	79.7	261,402
8	190	3116.5	1778.5	3169.4	2.241	8.8	80.3	228,031
9	190	3092.2	1767.8	3123.0	2.282	7.1	78.2	324,739
10	190	3099.6	1768.7	3156.0	2.234	9.1	80.1	273,172
11	190	3082.7	1754.0	3129.9	2.240	8.8	79.3	281,122
12	190	3096.2	1763.9	3149.1	2.235	9.0	80.2	227,410
					Average:	8.7	79.6	265,979
					Standard Deviation:	0.8	0.8	36,558

TABLE 17 Air Voids and Resilient Modulus Data, PG 76-22 Granite Evotherm®

Aggregate:	Granite	Poisson's Ratio:	0.35
Test Temperature:	77° F (25° C)	Maximum Specific Gravity (Gmm):	2.452
Asphalt Content:	5.1%		

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Sample Height, (mm)	Resilient Modulus (psi)
5	300	3075	1767.4	3086.1	2.332	4.9	76.1	302,387
8	300	3052.5	1753.3	3069.9	2.318	5.4	76.6	496,382
13	300	3075.4	1770.3	3090.6	2.329	5.0	77.0	288,764
29	300	3028.5	1740.9	3044.7	2.323	5.3	75.7	314,328
33	300	3069.2	1763.5	3090.1	2.314	5.6	77.7	356,964
36	300	3109.7	1794.2	3112.8	2.358	3.8	76.9	536,167
					Average:	5.0	76.7	382,499
					Standard Deviation:	0.6	0.7	106,852
1	265	3062.2	1766	3077.1	2.336	4.7	76.6	372,379
2	265	3087.5	1770.2	3099.2	2.323	5.3	76.4	351,918
3	265	3059.6	1756.6	3085.9	2.302	6.1	76.9	297,073
4	265	3058.4	1763.1	3083.0	2.317	5.5	76.7	341,626
5	265	3138.9	1797.1	3168.3	2.289	6.6	79.5	355,540
6	265	3078.7	1768.0	3102.9	2.306	5.9	77.4	391,681
					Average:	5.7	77.2	351,703
					Standard Deviation:	0.7	1.2	32,020
6	230	3060.5	1755.2	3090.8	2.291	6.5	77.3	285,614
11	230	3095.9	1774.3	3127.7	2.287	6.7	78.2	406,320
19	230	3129.5	1792.6	3151.5	2.303	6.1	78.9	586,587
26	230	3156.1	1810.8	3170.5	2.321	5.3	78.3	366,839
27	230	3104.6	1773.0	3140.6	2.270	7.4	79.6	207,244
41	230	3016.8	1730.4	3048.7	2.288	6.7	76.1	353,600
					Average:	6.5	78.1	367,701
					Standard Deviation:	0.7	1.2	128,130
10	190	2991.4	1707.9	3037.3	2.250	8.2	77.6	220,903
16	190	2989.7	1704	3021.9	2.269	7.5	77.4	273,251
17	190	2982.5	1707.3	3015.0	2.281	7.0	76.3	351,095
28	190	2959.5	1692.8	2987.2	2.286	6.8	75.1	299,502
34	190	2957.0	1691.5	2993.9	2.270	7.4	75.5	365,624
40	190	2968.5	1696.8	3007.6	2.265	7.6	76.9	252,189
					Average:	7.4	76.5	293,761
					Standard Deviation:	0.5	1.0	56,465

TABLE 18 Air Voids and Resilient Modulus Data, PG 64-22 Limestone Control

Aggregate:	Limestone				Poisson's Ratio:	0.35		
Test Temperature:	77° F (25° C)				Maximum Specific Gravity (Gmm):	2.545		
Asphalt Content:	4.8%							
Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Sample Height, (mm)	Resilient Modulus (psi)
2	300	3074.8	1790.2	3103.3	2.342	8.0	76.9	298,143
7	300	3139.1	1822.5	3151.2	2.363	7.2	76.7	327,752
9	300	3129.7	1824.1	3141.7	2.375	6.7	75.4	497,695
44	300	3121.6	1811.0	3140.1	2.349	7.7	76.9	295,254
70	300	3144.3	1821.6	3167.7	2.336	8.2	76.3	396,668
94	300	3152.2	1824.6	3177.1	2.331	8.4	76.7	420,900
					Average:	7.7	76.5	372,735
					Standard Deviation:	0.7	0.6	80,123
11	265	3119.8	1813.8	3137.2	2.357	7.4	75.9	337,083
21	265	3119.9	1813.1	3139.5	2.352	7.6	76.4	435,035
54	265	3109.0	1810.5	3129.6	2.357	7.4	76.3	287,729
55	265	3114.7	1807.4	3127.7	2.359	7.3	75.5	337,065
69	265	3119.6	1811.0	3136.2	2.354	7.5	76.8	338,496
72	265	3119.0	1810.1	3131.0	2.361	7.2	76.0	303,359
					Average:	7.4	76.2	339,795
					Standard Deviation:	0.1	0.4	51,236
8	230	3113.8	1811.1	3136.7	2.349	7.7	77.1	398,798
24	230	3115.2	1814.8	3135.1	2.359	7.3	76.3	222,463
26	230	3118.2	1816.7	3144.6	2.348	7.7	77.6	302,232
60	230	3117.1	1810.6	3135.8	2.352	7.6	76.6	316,623
78	230	3119.3	1815.8	3135.3	2.364	7.1	76.9	454,714
82	230	3115.5	1817.8	3139.7	2.357	7.4	76.1	390,027
					Average:	7.5	76.8	347,476
					Standard Deviation:	0.2	0.5	83,153
120	190	3116.8	1819.5	3142.3	2.356	7.4	76.6	270,330
121	190	3117.2	1821.9	3143.2	2.359	7.3	77.2	202,146
108	190	3118.8	1815.9	3139.2	2.357	7.4	75.9	409,698
123	190	3115.7	1814.9	3132.6	2.364	7.1	75.8	245,769
118	190	3116.7	1818.0	3145.7	2.347	7.8	77.0	274,062
112	190	3117.7	1817.1	3143.5	2.350	7.6	76.2	219,205
					Average:	7.4	76.5	270,202
					Standard Deviation:	0.2	0.6	73,896

TABLE 19 Air Voids and Resilient Modulus Data, PG 64-22 Limestone Evotherm®

Aggregate:	Limestone				Poisson's Ratio:	0.35		
Test Temperature:	77° F (25° C)			Maximum Specific Gravity (Gmm):		2.547		
Asphalt Content:	4.8%							
Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Sample Height, (mm)	Resilient Modulus (psi)
7	300	3257.9	1918.7	3262.7	2.424	4.8	77.2	347,682
17	300	3253.5	1916.1	3257.4	2.426	4.8	77.3	563,202
25	300	3263.5	1923.4	3267.4	2.428	4.7	76.4	271,011
29	300	3257.4	1922.3	3261.8	2.432	4.5	77.5	537,561
30	300	3260.4	1929.2	3265.3	2.440	4.2	76.2	375,629
37	300	3252.0	1920.0	3254.3	2.437	4.3	76.2	337,883
					Average:	4.5	76.8	405,495
					Standard Deviation:	0.3	0.6	117,647
1	265	3252	1906.2	3260.7	2.401	5.7	77.6	310,068
6	265	3255.7	1913.8	3261.5	2.416	5.2	76.6	279,233
9	265	3254.6	1911.4	3262.5	2.409	5.4	77.5	410,908
11	265	3252.9	1908.3	3257.4	2.411	5.3	77.8	538,571
23	265	3261.8	1914.1	3267.6	2.410	5.4	77.2	430,599
38	265	3253.9	1903.9	3259.1	2.401	5.7	77.1	336,251
					Average:	5.5	77.3	384,272
					Standard Deviation:	0.2	0.4	95,404
8	230	3260	1901.1	3269.9	2.382	6.5	78.6	435,817
12	230	3258.9	1905	3266.1	2.394	6.0	77.7	453,508
28	230	3260.8	1901.6	3268.7	2.385	6.4	78.0	716,368
32	230	3255.7	1905.4	3265.4	2.394	6.0	77.5	379,249
36	230	3260.6	1907.7	3267.6	2.398	5.9	77.6	352,414
42	230	3256.3	1895.9	3264.0	2.380	6.6	78.5	424,074
					Average:	6.2	78.0	460,238
					Standard Deviation:	0.3	0.5	130,948
1	190	3119.5	1821.2	3126.9	2.389	6.2	74.4	297,219
2	190	3126.5	1826.4	3137.1	2.385	6.3	75.4	408,175
15	190	3288.9	1919.1	3297.6	2.386	6.3	78.4	327,303
24	190	3256.5	1906.5	3267.1	2.393	6.0	77.7	311,189
26	190	3253.0	1903.0	3263.1	2.392	6.1	78.9	420,200
35	190	3256.8	1906.4	3266.7	2.394	6.0	78.9	289,257
					Average:	6.2	77.3	342,224
					Standard Deviation:	0.1	1.9	57,353

TABLE 20 Air Voids and Resilient Modulus Data, PG 76-22 Limestone Control

Aggregate: Limestone	Poisson's Ratio:	0.35
Test Temperature: 77° F (25° C)	Maximum Specific Gravity (Gmm):	2.546
Asphalt Content: 4.8%		

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Sample Height, (mm)	Resilient Modulus (psi)
1	300	3143.2	1831.5	3159.8	2.366	7.1	75.5	246,350
11	300	3127.2	1822.9	3135.9	2.382	6.5	76.2	442,517
20	300	3174.6	1863.5	3179.0	2.413	5.2	76.0	587,221
47	300	3126.4	1824.1	3143.3	2.370	6.9	75.9	219,028
4	300	3152.7	1840.6	3160.6	2.388	6.2	76.0	525,287
53	300	3137.3	1839.7	3143.5	2.406	5.5	74.6	239,942
					Average:	6.2	75.7	376,724
					Standard Deviation:	0.7	0.6	162,039
42	265	3137.6	1824.9	3152.6	2.363	7.2	76.8	372,424
19	265	3144.9	1824.2	3157.5	2.359	7.4	76.3	450,538
3	265	3161.8	1838.9	3171.0	2.374	6.8	76.7	400,561
27	265	3152.6	1832.7	3169.0	2.359	7.3	76.1	251,349
18	265	3132.6	1825.7	3144.7	2.375	6.7	76.4	294,689
28	265	3148.0	1829.9	3165.9	2.356	7.5	76.4	385,525
					Average:	7.1	76.5	359,181
					Standard Deviation:	0.3	0.3	73,095
50	230	3163.4	1843.8	3198.6	2.335	8.3	77.5	370,795
35	230	3170.7	1852.2	3185.1	2.379	6.6	76.1	473,852
45	230	3148.9	1828.6	3174.5	2.340	8.1	77.5	365,261
41	230	3171.9	1844.9	3193.0	2.353	7.6	77.6	458,168
5	230	3151.3	1837.9	3176.8	2.354	7.6	77.3	377,125
6	230	3164.3	1829.9	3187.5	2.331	8.5	77.8	400,469
					Average:	7.8	77.3	407,612
					Standard Deviation:	0.7	0.6	47,060
1	190	3184.3	1858.4	3205.8	2.363	7.2	77.5	369,843
2	190	3156.1	1841.3	3193.9	2.333	8.4	77.5	399,010
3	190	3160.3	1845.3	3186.9	2.356	7.5	76.8	287,816
4	190	3154.4	1842.5	3180.9	2.357	7.4	77.4	353,311
5	190	3160.0	1845.5	3185.3	2.359	7.4	77.0	358,094
6	190	3162.6	1847.1	3199.9	2.338	8.2	78.0	402,038
					Average:	7.7	77.4	361,685
					Standard Deviation:	0.5	0.4	41,540

TABLE 21 Air Voids and Resilient Modulus Data, PG 76-22 Limestone Evotherm®

Aggregate:	Limestone			Poisson's Ratio:	0.35			
Test Temperature:	77° F (25° C)			Maximum Specific Gravity (Gmm):	2.534			
Asphalt Content:	4.8%							

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Sample Height, (mm)	Resilient Modulus (psi)
2	300	3250.7	1910.2	3264.3	2.401	5.3	78.7	553,474
16	300	3267	1923.3	3274.3	2.418	4.6	78.4	544,889
19	300	3265.3	1914.8	3275.7	2.399	5.3	78.1	406,991
27	300	3251.8	1906.8	3266.0	2.392	5.6	77.9	496,323
40	300	3243.8	1903.7	3252.4	2.405	5.1	77.6	259,191
41	300	3265.6	1915.6	3275.4	2.402	5.2	78.0	271,465
					Average:	5.2	78.1	422,056
					Standard Deviation:	0.3	0.4	132,139
5	265	3268.8	1920.7	3284.5	2.397	5.4	78.4	363,383
10	265	3244.9	1900.6	3260.6	2.386	5.8	78.2	380,733
22	265	3252.7	1908.8	3273.5	2.383	5.9	78.3	410,012
39	265	3269.0	1913.6	3279.4	2.393	5.5	78.4	406,794
43	265	3268.0	1915.6	3283.4	2.389	5.7	78.7	349,523
48	265	3253.4	1904.5	3271.2	2.380	6.1	78.4	244,733
					Average:	5.8	78.4	359,196
					Standard Deviation:	0.2	0.2	60,868
4	230	3240.8	1894.7	3266.3	2.363	6.8	79.0	407,265
14	230	3256.8	1904.8	3280.4	2.368	6.6	79.0	392,609
18	230	3286.5	1922.3	3310.8	2.367	6.6	80.0	569,679
21	230	3275.1	1911.2	3298.8	2.360	6.9	80.6	379,170
45	230	3259.1	1903.8	3284.1	2.361	6.8	79.7	338,950
46	230	3258.9	1904.2	3281.8	2.366	6.6	79.7	307,892
					Average:	6.7	79.7	399,261
					Standard Deviation:	0.1	0.6	91,148
3	190	3096.2	1810.6	3129.1	2.348	7.3	76.2	361,042
20	190	3108.6	1813	3138.3	2.346	7.4	77.1	298,955
31	190	3170.1	1853.6	3202.8	2.350	7.3	77.5	358,116
33	190	3019.0	1766.6	3045.8	2.360	6.9	73.9	360,414
34	190	3070.7	1796.0	3094.4	2.365	6.7	75.0	443,148
47	190	3138.1	1829.7	3178.5	2.327	8.2	78.0	258,242
					Average:	7.3	76.3	346,653
					Standard Deviation:	0.5	1.6	63,136

TABLE 22 Asphalt Pavement Analyzer Data, PG 64-22 Granite Control

Aggregate:	Granite	Applied Wheel Load (lbs):	120
Test Temperature:	64° F (147° C)	Hose Presure (psi):	120
Asphalt Content:	5.1%	Maximum Specific Gravity (Gmm):	2.467

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Rut Depth, (mm)
18	300	3123.6	1782.0	3150.1	2.283	7.5	10.4
39	300	3127.9	1790.0	3138.2	2.320	6.0	8.1
42	300	3134.5	1783.1	3135.4	2.318	6.0	9.2
49	300	3125.3	1795.2	3133.3	2.336	5.3	7.6
51	300	3136.3	1795.1	3149.6	2.315	6.1	7.0
85	300	3121.7	1789.7	3131.6	2.326	5.7	4.1
					Average:	6.1	7.7
					Standard Deviation:	0.7	2.2
8	265	3112.1	1782.4	3123.2	2.321	5.9	13.4
29	265	3088.1	1772.1	3097.3	2.330	5.5	12.5
53	265	3129.6	1821.3	3226.3	2.227	9.7	9.0
67	265	3120.5	1788.2	3150.5	2.291	7.1	12.1
88	265	3110.3	1780.5	3136.0	2.295	7.0	13.4
89	265	3117.6	1784.8	3138.0	2.304	6.6	10.9
					Average:	7.0	11.9
					Standard Deviation:	1.5	1.7
101	230	3124.7	1804.6	3127.8	2.361	4.3	18.9
105	230	3127.0	1787.8	3132.9	2.325	5.8	10.8
109	230	3122.4	1788.7	3127.6	2.332	5.5	18.1
122	230	3124.5	1792.3	3131.1	2.334	5.4	15.9
104	230	3119.1	1794.7	3123.9	2.347	4.9	19.5
125	230	3127.6	1791.6	3133.4	2.331	5.5	11.6
					Average:	5.2	15.8
					Standard Deviation:	0.5	3.8
108	190	3122.6	1781.8	3131.8	2.313	6.2	19.4
112	190	3131.5	1783.8	3142.4	2.305	6.6	23.9
117	190	3123.6	1782.8	3136.9	2.307	6.5	22.0
127	190	3125.8	1780.9	3140.8	2.299	6.8	20.3
120	190	3124.2	1787.5	3133.2	2.322	5.9	13.6
116	190	3123.6	1784.4	3137.0	2.309	6.4	13.8
					Average:	6.4	18.9
					Standard Deviation:	0.3	4.3

TABLE 23 Asphalt Pavement Analyzer Data, PG 64-22 Granite Evotherm®

Aggregate:	Granite	Applied Wheel Load (lbs):	120
Test Temperature:	64° F (147° C)	Hose Presure (psi):	120
Asphalt Content:	5.1%	Maximum Specific Gravity (Gmm):	2.465

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Rut Depth, (mm)
1	300	3071.0	1776.9	3076.0	2.364	4.1	6.4
2	300	3073.2	1778.0	3079.4	2.361	4.2	7.0
3	300	3073.8	1777.4	3079.0	2.362	4.2	8.4
4	300	3077.2	1793.3	3083.6	2.385	3.3	6.7
5	300	3067.4	1774.1	3073.4	2.361	4.2	8.6
6	300	3067.8	1773.7	3072.1	2.363	4.1	7.7
					Average:	4.0	7.5
					Standard Deviation:	0.4	0.9
3	265	3085.9	1776.6	3094.2	2.342	5.0	6.4
12	265	3087.2	1773.7	3103.9	2.321	5.8	7.0
20	265	3082.9	1777.7	3095.8	2.339	5.1	4.8
21	265	3083.5	1774.2	3092.4	2.339	5.1	8.6
24	265	3083.0	1773.7	3098.0	2.328	5.6	8.3
30	265	3071.2	1762.3	3080.9	2.329	5.5	9.3
					Average:	5.4	7.4
					Standard Deviation:	0.3	1.7
1	230	3080.7	1762.8	3088.6	2.324	5.7	10.1
4	230	3077.7	1752.0	3092.2	2.296	6.8	12.3
7	230	3087.9	1769.9	3092.1	2.335	5.3	14.7
14	230	3040.6	1755.2	3046.6	2.354	4.5	10.1
22	230	3066.7	1769.7	3072.4	2.354	4.5	16.6
39	230	3089.0	1782.8	3094.6	2.355	4.5	13.6
					Average:	5.2	12.9
					Standard Deviation:	0.9	2.6
2	190	3091.6	1781.2	3099.2	2.346	4.8	11.1
9	190	3096.4	1777.5	3106.7	2.330	5.5	16.9
23	190	3097.3	1781.5	3106.5	2.338	5.2	13.1
25	190	3106.3	1783.6	3116.3	2.331	5.4	5.5
32	190	3094.9	1779.2	3105.9	2.333	5.4	19.2
35	190	3061.0	1739.6	3071.3	2.299	6.8	18.1
					Average:	5.5	14.0
					Standard Deviation:	0.7	5.1

TABLE 24 Asphalt Pavement Analyzer Data, PG 76-22 Granite Control

Aggregate:	Granite			Applied Wheel Load (lbs):			120
Test Temperature:	64° F (147° C)			Hose Presure (psi):			120
Asphalt Content:	5.1%			Maximum Specific Gravity (Gmm):			2.457
Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Rut Depth, (mm)
12	300	3100.4	1776.7	3110.8	2.324	5.4	3.8
24	300	3096.2	1776.7	3103.9	2.333	5.1	3.5
40	300	3083.6	1765.9	3093.3	2.323	5.5	6.0
47	300	3093.6	1764.5	3109.1	2.301	6.4	4.4
53	300	3111.9	1782.3	3120.8	2.325	5.4	5.7
54	300	3097.7	1774.8	3110.8	2.319	5.6	2.7
					Average:	5.5	4.4
					Standard Deviation:	0.4	1.3
14	265	3092.9	1766.9	3108.5	2.305	6.2	6.0
32	265	3100.2	1765.6	3119.1	2.291	6.8	5.4
18	265	3093.0	1763.0	3103.0	2.308	6.1	6.0
50	265	3101.8	1769.2	3119.5	2.297	6.5	6.8
45	265	3115.9	1772.6	3137.4	2.283	7.1	7.1
17	265	3086.3	1762.4	3107.0	2.295	6.6	4.7
					Average:	6.5	6.0
					Standard Deviation:	0.4	0.9
30	230	3073.3	1757.4	3110	2.272	7.5	7.1
46	230	3098.9	1775.4	3135.4	2.279	7.3	9.7
8	230	3103.9	1779.9	3141.5	2.280	7.2	9.2
4	230	3099.0	1770.5	3149.1	2.248	8.5	6.0
5	230	3115.3	1782.1	3161.2	2.259	8.1	9.5
6	230	3108.9	1776.8	3144.2	2.274	7.5	6.0
					Average:	7.7	7.9
					Standard Deviation:	0.5	1.8
7	190	3040.9	1738.2	3107.4	2.221	9.6	6.3
8	190	3116.5	1778.5	3169.4	2.241	8.8	9.1
9	190	3092.2	1767.8	3123.0	2.282	7.1	4.1
10	190	3099.6	1768.7	3156.0	2.234	9.1	7.5
11	190	3082.7	1754.0	3129.9	2.240	8.8	5.6
12	190	3096.2	1763.9	3149.1	2.235	9.0	9.6
					Average:	8.7	7.0
					Standard Deviation:	0.8	2.1

TABLE 25 Asphalt Pavement Analyzer Data, PG 76-22 Granite Evotherm®

Aggregate:	Granite	Applied Wheel Load (lbs):	120
Test Temperature:	64° F (147° C)	Hose Presure (psi):	120
Asphalt Content:	5.1%	Maximum Specific Gravity (Gmm):	2.452

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Rut Depth, (mm)
5	300	3075	1767.4	3086.1	2.332	4.9	5.1
8	300	3052.5	1753.3	3069.9	2.318	5.4	5.2
13	300	3075.4	1770.3	3090.6	2.329	5.0	3.9
29	300	3028.5	1740.9	3044.7	2.323	5.3	5.1
33	300	3069.2	1763.5	3090.1	2.314	5.6	5.1
36	300	3109.7	1794.2	3112.8	2.358	3.8	5.0
					Average:	5.0	4.9
					Standard Deviation:	0.6	0.5
1	265	3062.2	1766	3077.1	2.336	4.7	2.9
2	265	3087.5	1770.2	3099.2	2.323	5.3	2.3
3	265	3059.6	1756.6	3085.9	2.302	6.1	5.4
4	265	3058.4	1763.1	3083.0	2.317	5.5	4.4
5	265	3138.9	1797.1	3168.3	2.289	6.6	4.0
6	265	3078.7	1768.0	3102.9	2.306	5.9	3.6
					Average:	5.7	3.8
					Standard Deviation:	0.7	1.1
6	230	3060.5	1755.2	3090.8	2.291	6.5	5.3
11	230	3095.9	1774.3	3127.7	2.287	6.7	4.6
19	230	3129.5	1792.6	3151.5	2.303	6.1	3.3
26	230	3156.1	1810.8	3170.5	2.321	5.3	5.0
27	230	3104.6	1773.0	3140.6	2.270	7.4	6.3
41	230	3016.8	1730.4	3048.7	2.288	6.7	7.3
					Average:	6.5	5.3
					Standard Deviation:	0.7	1.4
10	190	2991.4	1707.9	3037.3	2.250	8.2	6.3
16	190	2989.7	1704	3021.9	2.269	7.5	6.7
17	190	2982.5	1707.3	3015.0	2.281	7.0	8.7
28	190	2959.5	1692.8	2987.2	2.286	6.8	7.5
34	190	2957.0	1691.5	2993.9	2.270	7.4	9.6
40	190	2968.5	1696.8	3007.6	2.265	7.6	4.4
					Average:	7.4	7.2
					Standard Deviation:	0.5	1.9

TABLE 26 Asphalt Pavement Analyzer Data, PG 64-22 Limestone Control

Aggregate:	Limestone			Applied Wheel Load (lbs):			120
Test Temperature:	64° F (147° C)			Hose Presure (psi):			120
Asphalt Content:	4.8%			Maximum Specific Gravity (Gmm):			2.545

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Rut Depth, (mm)
2	300	3074.8	1790.2	3103.3	2.342	8.0	5.4
7	300	3139.1	1822.5	3151.2	2.363	7.2	7.8
9	300	3129.7	1824.1	3141.7	2.375	6.7	7.8
44	300	3121.6	1811.0	3140.1	2.349	7.7	6.8
70	300	3144.3	1821.6	3167.7	2.336	8.2	10.4
94	300	3152.2	1824.6	3177.1	2.331	8.4	5.9
					Average:	7.7	7.3
					Standard Deviation:	0.7	1.8
11	265	3119.8	1813.8	3137.2	2.357	7.4	5.7
21	265	3119.9	1813.1	3139.5	2.352	7.6	4.1
54	265	3109.0	1810.5	3129.6	2.357	7.4	6.3
55	265	3114.7	1807.4	3127.7	2.359	7.3	10.1
69	265	3119.6	1811.0	3136.2	2.354	7.5	10.6
72	265	3119.0	1810.1	3131.0	2.361	7.2	5.7
					Average:	7.4	7.1
					Standard Deviation:	0.1	2.6
8	230	3113.8	1811.1	3136.7	2.349	7.7	7.6
24	230	3115.2	1814.8	3135.1	2.359	7.3	5.0
26	230	3118.2	1816.7	3144.6	2.348	7.7	9.9
60	230	3117.1	1810.6	3135.8	2.352	7.6	8.7
78	230	3119.3	1815.8	3135.3	2.364	7.1	16.1
82	230	3115.5	1817.8	3139.7	2.357	7.4	14.4
					Average:	7.5	10.3
					Standard Deviation:	0.2	4.2
120	190	3116.8	1819.5	3142.3	2.356	7.4	17.4
121	190	3117.2	1821.9	3143.2	2.359	7.3	7.2
108	190	3118.8	1815.9	3139.2	2.357	7.4	15.3
123	190	3115.7	1814.9	3132.6	2.364	7.1	6.9
118	190	3116.7	1818.0	3145.7	2.347	7.8	8.4
112	190	3117.7	1817.1	3143.5	2.350	7.6	8.0
					Average:	7.4	10.5
					Standard Deviation:	0.2	4.6

TABLE 27 Asphalt Pavement Analyzer Data, PG 64-22 Limestone Evotherm®

Aggregate:	Limestone	Applied Wheel Load (lbs):	120
Test Temperature:	64° F (147° C)	Hose Presure (psi):	120
Asphalt Content:	4.8%	Maximum Specific Gravity (Gmm):	2.547

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Rut Depth, (mm)
7	300	3257.9	1918.7	3262.7	2.424	4.8	2.4
17	300	3253.5	1916.1	3257.4	2.426	4.8	5.1
25	300	3263.5	1923.4	3267.4	2.428	4.7	3.2
29	300	3257.4	1922.3	3261.8	2.432	4.5	4.3
30	300	3260.4	1929.2	3265.3	2.440	4.2	4.3
37	300	3252.0	1920.0	3254.3	2.437	4.3	5.1
					Average:	4.5	4.1
					Standard Deviation:	0.3	1.1
1	265	3252.0	1906.2	3260.7	2.401	5.7	9.0
6	265	3255.7	1913.8	3261.5	2.416	5.2	6.9
9	265	3254.6	1911.4	3262.5	2.409	5.4	4.4
11	265	3252.9	1908.3	3257.4	2.411	5.3	4.6
23	265	3261.8	1914.1	3267.6	2.410	5.4	6.7
38	265	3253.9	1903.9	3259.1	2.401	5.7	8.2
					Average:	5.5	6.6
					Standard Deviation:	0.2	1.9
8	230	3260.0	1901.1	3269.9	2.382	6.5	14.0
12	230	3258.9	1905.0	3266.1	2.394	6.0	12.2
28	230	3260.8	1901.6	3268.7	2.385	6.4	6.1
32	230	3255.7	1905.4	3265.4	2.394	6.0	11.3
36	230	3260.6	1907.7	3267.6	2.398	5.9	11.5
42	230	3256.3	1895.9	3264.0	2.380	6.6	6.9
					Average:	6.2	10.3
					Standard Deviation:	0.3	3.1
1	190	3119.5	1821.2	3126.9	2.389	6.2	18.6
2	190	3126.5	1826.4	3137.1	2.385	6.3	8.1
15	190	3288.9	1919.1	3297.6	2.386	6.3	9.5
24	190	3256.5	1906.5	3267.1	2.393	6.0	11.0
26	190	3253.0	1903.0	3263.1	2.392	6.1	14.2
35	190	3256.8	1906.4	3266.7	2.394	6.0	14.4
					Average:	6.2	12.6
					Standard Deviation:	0.1	3.9

TABLE 28 Asphalt Pavement Analyzer Data, PG 76-22 Limestone Control

Aggregate:	Limestone			Applied Wheel Load (lbs):			120
Test Temperature:	64° F (147° C)			Hose Presure (psi):			120
Asphalt Content:	4.8%			Maximum Specific Gravity (Gmm):			2.546
Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Rut Depth, (mm)
1	300	3143.2	1831.5	3159.8	2.366	7.1	9.7
11	300	3127.2	1822.9	3135.9	2.382	6.5	4.3
20	300	3174.6	1863.5	3179.0	2.413	5.2	6.4
47	300	3126.4	1824.1	3143.3	2.370	6.9	4.2
4	300	3152.7	1840.6	3160.6	2.388	6.2	4.7
53	300	3137.3	1839.7	3143.5	2.406	5.5	4.2
					Average:	6.2	5.6
					Standard Deviation:	0.7	2.2
42	265	3137.6	1824.9	3152.6	2.363	7.2	7.6
19	265	3144.9	1824.2	3157.5	2.359	7.4	5.4
3	265	3161.8	1838.9	3171.0	2.374	6.8	5.4
27	265	3152.6	1832.7	3169.0	2.359	7.3	5.5
18	265	3132.6	1825.7	3144.7	2.375	6.7	4.5
28	265	3148.0	1829.9	3165.9	2.356	7.5	7.8
					Average:	7.1	6.0
					Standard Deviation:	0.3	1.3
50	230	3163.4	1843.8	3198.6	2.335	8.3	8.5
35	230	3170.7	1852.2	3185.1	2.379	6.6	9.4
45	230	3148.9	1828.6	3174.5	2.340	8.1	9.8
41	230	3171.9	1844.9	3193.0	2.353	7.6	7.4
5	230	3151.3	1837.9	3176.8	2.354	7.6	6.6
6	230	3164.3	1829.9	3187.5	2.331	8.5	6.0
					Average:	7.8	8.0
					Standard Deviation:	0.7	1.5
1	190	3184.3	1858.4	3205.8	2.363	7.2	3.6
2	190	3156.1	1841.3	3193.9	2.333	8.4	6.2
3	190	3160.3	1845.3	3186.9	2.356	7.5	4.0
4	190	3154.4	1842.5	3180.9	2.357	7.4	5.2
5	190	3160.0	1845.5	3185.3	2.359	7.4	5.4
6	190	3162.6	1847.1	3199.9	2.338	8.2	4.9
					Average:	7.7	4.9
					Standard Deviation:	0.5	1.0

TABLE 29 Asphalt Pavement Analyzer Data, PG 76-22 Limestone Evotherm®

Aggregate:	Limestone	Applied Wheel Load (lbs):	120
Test Temperature:	64° F (147° C)	Hose Presure (psi):	120
Asphalt Content:	4.8%	Maximum Specific Gravity (Gmm):	2.534

Sample Number	Compaction Temperature (°F)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Rut Depth, (mm)
2	300	3250.7	1910.2	3264.3	2.401	5.3	1.8
16	300	3267	1923.3	3274.3	2.418	4.6	1.5
19	300	3265.3	1914.8	3275.7	2.399	5.3	2.0
27	300	3251.8	1906.8	3266.0	2.392	5.6	1.9
40	300	3243.8	1903.7	3252.4	2.405	5.1	2.3
41	300	3265.6	1915.6	3275.4	2.402	5.2	2.0
					Average:	5.2	1.9
					Standard Deviation:	0.3	0.3
5	265	3268.8	1920.7	3284.5	2.397	5.4	3.0
10	265	3244.9	1900.6	3260.6	2.386	5.8	3.5
22	265	3252.7	1908.8	3273.5	2.383	5.9	2.6
39	265	3269.0	1913.6	3279.4	2.393	5.5	3.0
43	265	3268.0	1915.6	3283.4	2.389	5.7	1.6
48	265	3253.4	1904.5	3271.2	2.380	6.1	1.8
					Average:	5.8	2.6
					Standard Deviation:	0.2	0.7
4	230	3240.8	1894.7	3266.3	2.363	6.8	5.4
14	230	3256.8	1904.8	3280.4	2.368	6.6	4.7
18	230	3286.5	1922.3	3310.8	2.367	6.6	4.9
21	230	3275.1	1911.2	3298.8	2.360	6.9	3.9
45	230	3259.1	1903.8	3284.1	2.361	6.8	4.6
46	230	3258.9	1904.2	3281.8	2.366	6.6	3.8
					Average:	6.7	4.5
					Standard Deviation:	0.1	0.6
3	190	3096.2	1810.6	3129.1	2.348	7.3	2.7
20	190	3108.6	1813	3138.3	2.346	7.4	5.2
31	190	3170.1	1853.6	3202.8	2.350	7.3	4.7
33	190	3019.0	1766.6	3045.8	2.360	6.9	3.7
34	190	3070.7	1796.0	3094.4	2.365	6.7	4.1
47	190	3138.1	1829.7	3178.5	2.327	8.2	4.7
					Average:	7.3	4.2
					Standard Deviation:	0.5	0.9

TABLE 30 Indirect Tensile Strength Data, PG 64-22 Granite Control

	Aggregate:	Granite							
	Asphalt Content:	5.1%	Maximum Specific Gravity (Gmm):					2.467	
Sample Number	Short Term Age @ 110°C (230°F) (hrs)	Long Term Age @ 85°C (185°F) (days)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Maximum Load (lbs)	Tensile Strength (psi)
1	2	0	3696.6	2110.1	3723.2	2.292	7.1	3600	104.4
2	2	0	3698.0	2104.0	3722.5	2.285	7.4	3475	100.8
						Average:	7.2	3538	102.6
						Standard Deviation:	0.2	88	2.5
3	4	0	3713.5	2130.9	3740.3	2.307	6.5	5075	147.2
4	4	0	3708.8	2113.4	3737.7	2.283	7.4	3300	95.7
						Average:	7.0	4188	121.5
						Standard Deviation:	0.7	1255	36.4
5	2	1	3718.8	2119.1	3740.9	2.293	7.1	2250	65.3
6	2	1	3715.9	2116.3	3735.2	2.295	7.0	2400	69.6
						Average:	7.0	2325	67.5
						Standard Deviation:	0.1	106	3.0
7	2	3	3696.8	2112.1	3727.2	2.289	7.2	3200	92.8
8	2	3	3691.4	2114.1	3716.0	2.304	6.6	3600	104.4
						Average:	6.9	3400	98.6
						Standard Deviation:	0.4	283	8.2
9	2	5	3698.0	2110.8	3727.6	2.287	7.3	3250	94.3
10	2	5							
						Average:	7.3	3250	94.3
						Standard Deviation:			

TABLE 31 Indirect Tensile Strength Data, PG 64-22 Granite Evotherm®

Aggregate:		Granite								
Asphalt Content:		5.1%	Maximum Specific Gravity (Gmm):						2.465	
Sample Number	Short Term Age @ 110°C (230°F) (hrs)	Long Term Age @ 85°C (185°F) (days)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Maximum Load (lbs)	Tensile Strength (psi)
1	2	0	3760.9	2150.1	3781.6	2.305	6.5	3700	107.3
2	2	0	3685.3	2093.6	3714.8	2.273	7.8	3500	101.5
Average:							7.1	3600	104.4
Standard Deviation:							0.9	141	4.1
3	4	0	3686.1	2101.4	3714.5	2.285	7.3	4700	136.3
4	4	0							
Average:							7.3	4700	136.3
Standard Deviation:									
5	2	1	3753.2	2117.8	3771.2	2.270	7.9	2075	60.2
6	2	1	3764.3	2147.6	3782.8	2.302	6.6	2100	60.9
Average:							7.3	2088	60.5
Standard Deviation:							0.9	18	0.5
7	2	3	3754.7	2145.4	3778.8	2.299	6.7	3575	103.7
8	2	3	3748.2	2146.5	3781.1	2.293	7.0	3500	101.5
Average:							6.9	3538	102.6
Standard Deviation:							0.2	53	1.5
9	2	5	3763.9	2133.3	3785.6	2.278	7.6	4350	126.2
10	2	5	3765.5	2148.6	3783.9	2.303	6.6	4650	134.9
Average:							7.1	4500	130.5
Standard Deviation:							0.7	212	6.2

TABLE 32 Indirect Tensile Strength Data, PG 64-22 Limestone Control

Aggregate:		Limestone								
Asphalt Content:		4.8%	Maximum Specific Gravity (Gmm):						2.545	
Sample Number	Short Term Age @ 110°C (230°F) (hrs)	Long Term Age @ 85°C (185°F) (days)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Maximum Load (lbs)	Tensile Strength (psi)	
1	2	0	3894.8	2278.6	3915.2	2.380	6.5	4600	133.4	
2	2	0	3895.0	2281.7	3921.4	2.375	6.7	4550	132.0	
Average:							6.6	4575	132.7	
Standard Deviation:							0.1	35	1.0	
3	4	0	3890.5	2273.7	3917.6	2.367	7.0	3750	108.8	
4	4	0	3895.5	2281.9	3919.2	2.379	6.5	3900	113.1	
Average:							6.8	3825	110.9	
Standard Deviation:							0.3	106	3.1	
5	2	1	3895.2	2280.7	3919.5	2.377	6.6	3150	91.4	
6	2	1	3897.6	2283.6	3919.9	2.382	6.4	2600	75.4	
Average:							6.5	2875	83.4	
Standard Deviation:							0.1	389	11.3	
7	2	3	3880.9	2264.6	3908.9	2.360	7.3	2900	84.1	
8	2	3	3889.4	2275.3	3915.2	2.372	6.8	2800	81.2	
Average:							7.0	2850	82.7	
Standard Deviation:							0.3	71	2.1	
9	2	5	3896.5	2283.7	3921.8	2.379	6.5	2575	74.7	
10	2	5	3886.1	2273.2	3911.8	2.372	6.8	2575	74.7	
Average:							6.7	2575	74.7	
Standard Deviation:							0.2	0	0.0	

TABLE 33 Indirect Tensile Strength Data, PG 64-22 Limestone Evotherm®

	Aggregate:	Limestone							
	Asphalt Content:	4.8%	Maximum Specific Gravity (Gmm):					2.547	
Sample Number	Short Term Age @ 110°C (230°F) (hrs)	Long Term Age @ 85°C (185°F) (days)	In Air (gms)	In Water (gms)	SSD (gms)	Bulk (Gmb)	VTM, %	Maximum Load (lbs)	Tensile Strength (psi)
1	2	0	3832.1	2246	3879.9	2.345	7.9	2600	75.4
2	2	0	3829.1	2243.9	3869.3	2.356	7.5	2700	78.3
						Average:	7.7	2650	76.9
						Standard Deviation:	0.3	71	2.1
3	4	0	3830.1	2248.6	3881	2.346	7.9	3700	107.3
4	4	0	3831.9	2246.5	3883.7	2.341	8.1	3550	103.0
						Average:	8.0	3625	105.1
						Standard Deviation:	0.2	106	3.1
5	2	1	3832.9	2254.6	3880.8	2.357	7.5	2500	72.5
6	2	1	3832.7	2253.8	3876.3	2.362	7.3	2475	71.8
						Average:	7.4	2488	72.2
						Standard Deviation:	0.1	18	0.5
7	2	3	3834.4	2251.4	3881.1	2.353	7.6	2525	73.2
8	2	3	3834.2	2249.1	3885.4	2.343	8.0	2400	69.6
						Average:	7.8	2463	71.4
						Standard Deviation:	0.3	88	2.6
9	2	5	3839	2241.1	3872.3	2.353	7.6	3200	92.8
10	2	5	3847.1	2246.8	3877.4	2.359	7.4	3075	89.2
						Average:	7.5	3138	91.0
						Standard Deviation:	0.2	88	2.6