EVALUATION OF THE USE OF THE HAMBURG WHEEL-TRACKING DEVICE FOR MOISTURE SUSCEPTIBILITY OF HOT MIX ASPHALT

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16. Abstract

Laboratory testing of hot mix asphalt (HMA) in order to evaluate moisture susceptibility has improved over the past several decades. Within the past eight years, the Hamburg wheel-tracking device (HWTD) has been used in evaluating HMA for moisture susceptibility. There are no standard test methods or specifications established for this testing device. This study evaluated the repeatability of the test, testing configuration, test temperature, and capability to evaluate effects of antistripping additives in HMA.

The HWTD has shown to be repeatable where six replicate tests provided consistent test results. The device yielded repeatable results for mixtures produced with different aggregates and with test specimens fabricated by different compacting devices.

The conventional testing configuration was altered such that cylindrical test specimens fabricated with a Superpave gyratory compactor (SGC) could be used in lieu of rectangular slabs. Results indicate that cylindrical specimens compacted with the SGC could be used for moisture evaluation in the HWTD for comparative evaluation of one material to another.

Typically, testing with the HWTD is performed at 50°C. Six mixtures were fabricated with and without antistripping additives and tested at 40°C and 50°C. Mixtures were modified with hydrated lime and a liquid antistripping additive and all mixed with AC-20. Test results have shown mixtures with hydrated lime to perform the best followed by those modified with liquid antistripping additive and worst were those without any additive at 40°C. Inconsistent trends were seen at 50°C. The HWTD properly predicted performance of the mixtures modified with antistripping additives at 40°C.

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INTRODUCTION

Several transportation agencies throughout the United States evaluate hot mix asphalt (HMA) for moisture susceptibility. Moisture damage is responsible for millions of dollars in reconstruction and maintenance. This type of pavement distress has proven to be a serious problem plaguing asphalt pavements in the United States for several decades, where a large number of research projects have been performed to study moisture damage to hot mix.

Moisture damage or sensitivity is commonly referred to as stripping. This phenomenon is recognized as asphalt stripping from the aggregate surface. Stripping occurs when the adhesive bond between the aggregate surface and asphalt cement is broken (***1***). Moisture damage also weakens the asphalt matrix such that there is lower stability and load carrying capacity. The mechanistic result of moisture damage is a loss in adhesive and cohesive strength. Moisture damage from the loss of adhesive and cohesive properties in HMA will lead to shoving, rutting, and fatigue cracking of asphalt pavement (***2***).

Several laboratory tests have been developed to assess the moisture susceptibility of HMA. Laboratory testing does not entirely simulate field conditions, however, they can provide useful information. These tests developed for the evaluation of moisture damage either assess the stripping of asphalt from the aggregate surface or the loss in strength of cylindrical, compacted HMA. Typically, boiling tests are used to evaluate the stripping of asphalt from aggregate surfaces. HMA is added to boiling water for a specified amount of time and visually inspected to estimate the degree of stripping. Strength testing generally includes the indirect tensile test in which cylindrical, compacted HMA specimens are tested following a conditioning sequence replicating freeze-thaw experienced in-situ (***2, 3***).

The Hamburg wheel-tracking device (HWTD) has been used for several years in Germany to evaluate the moisture susceptibility of HMA. Typically, a pair of rectangular slab samples are tested simultaneously with two steel wheels moving concurrently. Following the introduction of the HWTD in the United States, several other wheel-tracking devices have been developed and used assessing moisture damage.

OBJECTIVES

The objective of this study was to perform a comprehensive evaluation of the HWTD and its potential for use in assessing moisture susceptibility of HMA. This evaluation was performed with the following three phases:

(1) Repeatability of the testing device.

(2) Comparison of rectangular (slab) compacted test specimens versus cylindrical, gyratory compacted test specimens.

(3) Interlaboratory study evaluating temperature and antistripping additive effects

Hamburg Wheel-Tracking Device (HWTD)

The HWTD has been developed and extensively used in Hamburg, Germany, for the evaluation of moisture susceptibility of HMA. This device measures the combined effects of rutting and moisture damage by rolling a steel wheel across the surface of a rectangular slab that is submerged in 50°C water. Figure 1 on page 12 is a picture of the testing device. It tests two rectangular slabs simultaneously with two reciprocating solid steel wheels that have a diameter of 204 mm and a width of 47 mm. The steel wheels move concurrently driven by a crank connected to a flywheel. This type of movement produces a constantly varying velocity where the maximum velocity occurs in the center of the specimen. Rut depth measurements are taken at the center of the specimen. The load applied on each specimen is 703 N where each wheel rolls 230 mm before reversing in direction. A standard test applies a maximum number of 20,000 passes. The data produced by the device are customarily reported versus passes, rather than cycles, in which a cycle is two passes. A linear variable differential transducer measures the rut depth in each slab automatically and continuously with an accuracy of 0.01 mm. A maximum allowable rut depth of 4 mm at 20,000 passes is specified in Hamburg, Germany (***4***).

FHWA and Colorado Department of Transportation (CDOT) have performed extensive amounts of research with the HWTD since 1990. CDOT has developed Colorado Procedure CP-L 5112, "Hamburg Wheel Track Testing of Compacted Bituminous Mixtures," to assess the potential of moisture damage of HMA in Colorado. This specification adopted by CDOT utilizes the HWTD and is unique in that it specifies testing temperatures according to site location and asphalt binder type. A maximum rut depth of 10 mm at 20,000 passes is specified (***5***).

Figure 2 is an illustration of the typical output produced from the test including the test parameters. Data analysis includes the creep slope, stripping inflection point (SIP), and stripping slope. The creep slope relates to rutting primarily from plastic flow. It is the number of passes required to create a 1-mm rut depth. The SIP is the number of passes at the intersection of the creep slope and stripping slope. This intersection is where stripping starts to dominate performance. The stripping slope is a measure of the accumulation of rutting primarily from moisture damage. It is the number of passes required to create a 1-mm rut depth after the SIP (***4***).

REPEATABILITY OF HAMBURG WHEEL-TRACKING DEVICE (HWTD)

The repeatability of the HWTD was assessed through testing two different mixtures. The mixtures comprised of a limestone and gravel aggregate. Table 1 on page 7 lists the gradation and optimum asphalt content (OAC) of the mixtures. Slab and cylindrical test specimens were tested. The slab test specimens were compacted with a linear kneading compactor and the cylindrical test specimens were compacted with a Superpave gyratory compactor (SGC).

For cylindrical specimens, the test specimen configuration was modified such that one test specimen consisted of two SGC specimens. The specimens are secured in the mounting tray with two molds and two spacer plates fabricated with an acrylic material. Figure 3 illustrates a top view of the set up. This figure is not drawn to scale, and all dimensions are in mm. The spacer plates, which aid in securing the configuration, are placed behind each mold at opposite ends. The molds are shaped as rectangles with semicircles cut out approximately 25 mm from the back edge. However, with the spacer plates the semicircles are approximately 40 mm from the back edge of the mounting tray. The specimens are sawed such that they fit into the molds. The specimens are tightly fastened in the mounting tray by tightening the nuts that adjoin a front plate to the mounting tray. Overall, the whole specimen resembles a snowman figure with a contact area among the SGC specimens approximately 51 cm^2 (8.3 x 6.2 cm) and is adequately secured such that movement during testing does not occur other than any degradation resulting from the test. The sawed portion is approximately 5% of the total volume of a single SGC specimen. This configuration with the SGC specimens can be seen in figure 4.

Tables 2 and 3 list the test results for the slabs and cylindrical test specimens. Table 2 provides data for the limestone mixture where test specimens were fabricated at 7±1% air voids. Table 3 shows data for the gravel mixture where test specimens were compacted at 4±1% air voids. Fluctuation of the test specimens' air void content was not initially intended. The slabs were compacted first and their air void contents were duplicated with the cylindrical test specimens. There was a limited amount of material obtained for each mixture; therefore, it was not possible to fabricate new test specimens. Failure criteria was established at a rut depth of 20 mm or maximum application of 20,000 passes. Six tests were performed for each mix type and test specimen configuration. These tables also provide the statistical mean and standard deviation.

The HWTD tests two specimens simultaneously. The test is stopped when a failure criterion has been reached, which was either 20 mm rut depth or 20,000 passes in this study. Two specimens almost never fail at the same number of passes with a 20 mm rut depth. However, it is possible for the test to continue until 20,000 passes for both test specimens. The number of passes to failure, N_f shown in the tables mentioned above, was estimated with the regression data from the stripping slope.

Figures 5 and 6 illustrate the test results produced by the HWTD. Figure 5 displays the test results for the limestone mixture and Figure 6 shows the test results for the gravel mixture. These plots illustrate the rut depth versus the number of passes of the steel wheels. The HWTD test results for the slab and gyratory compacted, cylindrical specimens have shown to be very repeatable. As shown in tables 2 and 3, the standard deviation calculated for each parameter has been found to be reasonably small with moderate variation. The different method of compaction did not have any effects on the repeatability of testing with the HWTD. The HWTD has shown to provide good repeatability with replicate testing.

Slab Compacted Versus Cylindrical, Gyratory Compacted

This section of the report compares the performance of rectangular slabs with cylindrical test specimens. The use of cylindrical specimens has been found to be simple and more convenient than the use of rectangular slabs. Typically, the rectangular, slab test specimens are compacted with a linear kneading compactor. These test specimens require the use of plaster to be secured in the mounting tray prior to testing. A test performed with rectangular, slab test specimens will take approximately 3 days. A day is required for specimen fabrication, another for curing of the plaster, and finally a third for testing. Compaction of test specimens generally takes between 15 and 20 minutes with a kneading linear compactor.

The cylindrical test specimens are fabricated with a SGC. The SGC is used to compact specimens for the Superpave asphalt mixture design and available nationwide. The use of these specimens do not require plaster in the testing configuration. In the modified configuration, specimens are secured in acrylic molds as shown in figure 4 and also seen in the testing device in figure 1. A test performed with cylindrical test specimens will take approximately 2 days. A day for specimen fabrication and the next for testing. Compaction of test specimens typically takes between 5 and 10 minutes with the SGC.

The comparison of compaction methods was evaluated with the data used in the previous section for the repeatability analysis. Tables 2 and 3 list the data and figures 5 and 6 illustrate the test results for both compaction methodologies. A summary of the standard deviation calculated for each test parameter is listed in table 4. In most cases, the standard deviation for the limestone, slab mixtures were greater than that of the limestone, cylindrical specimens. The results for the gravel mixture varied where one type of compaction did not predominately show greater variability. Table 4 also lists the standard deviation calculated for the combined data. The combined data grouped the test results from both compaction methodologies for each mixture. In most cases, the standard deviation for the combined data increased. It is apparent that there are differences in variability for the slab and cylindrical compacted tests specimens. However, based on the illustrations in figures 5 and 6 the performance of the mixtures were the same. The only significant difference can be seen with the SIP for the gravel mixtures in figure 6. The SIP is significantly greater for the cylindrical compacted test specimens. The SGC molded test specimens can be used for moisture damage evaluation in the HWTD for comparative evaluation of one material to another. The test results from the cylindrical molded specimens cannot be directly compared to the slab molded specimens.

Interlaboratory Study

An interlaboratory study was conducted following an extensive evaluation of the HWTD. The HWTD was evaluated for its repeatability and for the use of cylindrical test specimens with a modified testing configuration in lieu of rectangular, slab test specimens. The purpose of this interlaboratory study included the evaluation of test temperature and the capability of the HWTD to detect the use of antistripping additives in HMA. Moisture damage or stripping is a reoccurring problem throughout Texas and antistripping additives are routinely used to improve the performance of HMA. Therefore, it is critical to know whether the HWTD can differentiate mixtures treated with antistripping additives.

The HWTD is commonly used in Hamburg, Germany, to approve and accept HMA, where typically an asphalt binder similar to a soft AC-20 is used (*6*). However, it is important to note that typical HMA used and developed in Germany is stone matrix asphalt, otherwise referred to as SMA. A characteristic of SMA is a high amount of fine material or the use of mineral filler (8 to 12% passing the 0.075 mm sieve). This type of mixture also includes the use of stabilizers to prevent draindown. The use of mineral fillers and stabilizers will stiffen the asphalt binder such that performance of HMA with unmodified asphalt binders is similar to that of polymer-modified binders (*7, 8*). An AC-20 is generally used throughout Texas. Typically, tests with the HWTD are performed at 50°C. However, it is believed that this test temperature may be too extreme for HMA produced using AC-20. The softening point of AC-20 is typically less than 50°C. Asphalt binders or HMA with asphalt binders tested at temperatures beyond their softening point will exhibit poor qualities as asphalt binders undergo property changes upon reaching their softening point. The softening point is the point where the asphalt binder cannot support the weight of a steel ball and starts flowing from the ring-and-ball test. A test temperature of 40°C has been used and test results compared to that found at 50°C.

Materials Selection

Six mixtures were evaluated in this part of the study. The mixtures composed of six different aggregate types and one asphalt binder. The asphalt binder used in this study was an AC-20. Table 1 lists the different aggregate types used with source location throughout Texas. The asphalt binder type was the same for all the mixtures such as to reduce the variability between mixtures.

The OAC and aggregate gradation for each mixture are listed in table 1. The limestone and gravel mixtures were designed according to Texas Department of Transportation (TxDOT) specifications for a Type-D mixture. The other mixtures were designed according to TxDOT specifications for a Type-C mixture. The Type-C design yields a coarser mixture which can be seen from the gradations in table 1.

Test Temperature and Antistripping Additive Evaluation

The HWTD evaluates the susceptibility of HMA to moisture damage. It is believed that the stripping potential of HMA is significantly reduced through the use of antistripping additives. Research studies have proclaimed the benefits of antistripping additives for many years. Testing devices and methodologies measuring the moisture susceptibility of HMA must be capable of detecting the effects of antistripping additives on mixture performance. In this part of the study, mixtures were modified with antistripping additives and tested with the HWTD. The additives used were hydrated lime and a liquid antistripping agent. The antistripping additives were evaluated along with the testing temperature. Mixtures were modified and tested at 40 and 50°C. All test specimens were fabricated with a SGC and with an air void content of 7±1%. Two replicate tests were performed for each mixture.

Table 5 lists the test results from the tests performed at 40 and 50°C. The data is grouped according to test temperature and type of antistripping additive used. Test results have shown better performance from the mixtures tested at 40°C. More importantly, improved effects from the antistripping additives in the mixtures were not always seen at 50°C. Properties measured by the HWTD of the mixtures modified with the antistripping additives did not always show improvement in comparison to the mixtures with no antistripping additives. This fact is important and questions the effectiveness of the HWTD to accurately assess moisture damage for mixtures with AC-20 at the testing temperature of 50°C.

In most cases, significant improvements can be seen for the mixtures tested at 40°C as a result of treatment with antistripping additives. Figures 7 through 12 illustrate the test results for all the mixtures tested at 40 and 50°C. Typically, the trend of the data for all the mixtures tested at 40°C were grouped above that tested at 50°C. More importantly, the results for the 40°C tests always ranked from mixtures with hydrated lime, liquid additive, and thirdly no antistripping additive as shown in figure 7. The data from the 50°C did not always rank in the same order. In most cases, the test parameters from 40°C in table 5 show that the mixtures modified with hydrated lime performed the best and was followed by the mixtures modified with liquid additive. The mixtures performing the worst were the mixtures with no modification. The N_f was determined through regression analysis of the stripping slope data. However, the mixtures modified with hydrated lime did not reach the SIP (as shown in figure 7) and thus the N_f could not be calculated. Therefore, '>20,000' was used in the table for this parameter and signifies that the mixtures did not fail up to 20,000 passes.

Figure 13 illustrates the trend of the creep slope data from the mixtures with no antistripping additive to the mixtures modified with hydrated lime. It can be seen that the trend of the creep slope increases with modification at 40°C. The trend of the data from the 50°C tests shows a decline in performance with modification. The 40°C trend line is typically expected since it is believed that antistripping additives improve the performance of HMA. However, this may also be showing the filler effects of the hydrated lime since creep slope relates to rutting as mentioned earlier. The mixtures with hydrated lime always shown the least amount of rutting and never reached the SIP. The same trend seen in figure 13 occurs with the stripping slope data with the mixtures with liquid antistripping additive and those without any additive.

It is apparent that 50°C may be too extreme and performance measured by the HWTD may not be accurate at this test temperature for mixtures with AC-20. However, it is important to remember that these mixtures were composed of an AC-20 asphalt binder in which the typical softening point is below 50°C. Mixtures with asphalt binders consisting of greater viscosity, hence higher softening points, may be tested at greater temperatures. HMA is composed of mineral aggregate and asphalt binder. The asphalt binder is a key component of HMA; thus, a mixture tested beyond its softening point where it is not stable will lead to misleading test results with the HWTD. A test temperature of 40°C appears to be appropriate for mixtures composed of AC-20, which is what a majority of the HMA throughout Texas is produced with.

CONCLUSIONS

The use of wheel-tracking devices evaluating hot mix asphalt (HMA) throughout the United States has increased since 1990. A few transportation agencies have developed test methods and specifications incorporating the use of these devices. The Texas Department of Transportation has begun performing research investigating the possible use of wheel-tracking devices in predicting performance of HMA. Specifically, the Hamburg wheel-tracking device (HWTD) has been targeted for the evaluation of moisture susceptibility.

The use of a new testing device initially requires research investigating repeatability and the capability to properly predict performance. Based on laboratory testing the following has been concluded:

- The HWTD has shown good repeatability among test replicates. Two types of mixtures were used in this evaluation in which test specimens were compacted with a linear kneading compactor and a SGC. The different method of compaction and different type of HMA did not effect the repeatability with the HWTD.
- Testing is typically performed with rectangular test specimens requiring the use of a linear kneading compactor for fabrication. The testing configuration was modified such that cylindrical test specimens compacted with a SGC could be used in lieu of the rectangular test specimens. Test results were compared and shown that the SGC-molded test specimens can be used for moisture evaluation with the HWTD in the comparative evaluation of one material to another. However, test results from cylindrical-molded specimens cannot be directly compared to that of the slab-molded specimens.
- Typically, testing is performed at 50°C. Mixtures with and without antistripping additives and AC-20 were tested at 40 and 50°C. Performance of the mixtures tested at 40°C all improved with the use of additives. However, this was not always the case with testing at 50°C. It is apparent that 50°C may be too extreme for testing mixtures with AC-20, and results may be misleading.
- Test results from 40°C have shown mixtures with hydrated lime to perform the best followed by those modified with liquid antistripping additive and the worst to be those without any additive at 40°C. This trend was expected since the use of additives improve the moisture susceptibility of HMA and was consistently seen for all mixtures tested at 40°C. The HWTD is capable of detecting the use of antistripping additives in HMA yielding improved performance in moisture susceptibility.

TABLE 1

Aggregate Gradation in Percent Passing and Optimum Asphalt Content for Each Mixture Used in this Study

Characteristics for Mixtures Used in Repeatability and Compaction Evaluation

Sieve Size, mm (in)	Limestone Mixture	Gravel Mixture
12.5 (1/2)	100.0	100.0
9.5 (3/8)	93.6	94.3
4.75 (#4)	64.8	67.1
2.0 (#10)	40.6	39.6
0.425 (#40)	19.8	19.4
0.180 (#80)	6.9	10.4
0.075 (#200)	2.0	6.6
OAC	5.8 %	5.3 %

Characteristics for Mixtures Use in Interlaboratory Study

Sieve Size, mm (in)	Limestone	Granite Mountain	Basalt	Gravel	Gravel w/LMS Scr.	Gravel w/GR Scr.
25.0 (1)	100.0	100.0	100.0	100.0	100.0	100.0
22.4 (7/8)	100.0	100.0	100.0	100.0	100.0	100.0
16.0 (5/8)	100.0	98.9	98.4	96.0	100.0	100.0
9.5 (3/8)	92.8	82.4	80.3	75.3	91.1	90.1
4.75 (#4)	64.0	52.7	53.6	54.5	60.7	57.3
2.0 (#10)	38.0	35.3	36.0	37.5	37.2	37.0
0.425 (#40)	19.6	19.5	22.0	22.8	20.1	17.4
0.180 (#80)	9.9	8.5	6.7	11.6	10.2	7.4
0.075 (#200)	5.0	4.1	2.4	3.5	6.3	2.0
OAC	5.3 %	4.6 %	4.6 %	5.0 %	5.3 %	5.5 %

Note: OAC — Optimum Asphalt Content
Scr. — Screenings

TABLE 2

Test Results for Mixtures Composed of Limestone Aggregate at 7±1% Air Voids

Sample ID	Rut Depth, mm @ 5,000 Cycles	10,000 Cycles	15,000 Cycles	20,000 Cycles	N_f Passes	Creep Slope Passes	Stripping Slope Passes	SIP Passes
				Rectangular Slab				
1	3.88	8.77	13.35	17.80	17,039	3,614	746	3,251
2	2.33	8.02	14.81	19.11	19,947	4,227	822	5,278
3	4.27	9.07	12.75	17.34	20,289	2,671	949	2,481
4	2.58	8.91	14.07	19.18	18,707	4,808	788	4,343
5	1.77	6.42	10.96	15.31	23,796	5,336	1013	5,246
6	3.22	8.18	11.20	15.11	17,204	5,484	727	3,661
Mean	3.01	8.23	12.86	17.31	19,497	4,357	841	4,043
Std. Dev.	0.96	0.98	1.54	1.78	2,499	1,081	115	1,120
				Superpave Gyratory Compactor (Cylindrical)				
1*	2.10	4.71	9.77	18.01	28,824	3,932	1230	7,657
2	2.22	7.12	15.08	*failed*	18,783	4,008	681	7,013
3	2.82	8.75	17.78	*failed*	18,662	2,898	760	5,391
4	2.68	9.18	18.87	*failed*	16,991	3,166	680	5,100
5	3.03	12.73	19.79	*failed*	15,138	2,670	589	4,965
6	2.29	9.92	18.89	*failed*	15,102	3,789	503	6,392
Mean	2.61	9.54	18.08	*failed*	16,935	3,306	643	5,773
Std. Dev.	0.31	1.84	1.63	*failed*	1612	513	88	797

* Test results not included in statistical analyses, probable outlier.

TABLE 3

Test Results for Mixtures Composed of Gravel Aggregate at 4±1% Air Voids

Sample ID	Rut Depth, mm @ 5,000 Cycles	10,000 Cycles	15,000 Cycles	20,000 Cycles	N_f Passes	Creep Slope Passes	Stripping Slope Passes	SIP Passes
				Rectangular, Slab				
1	5.47	*failed*	*failed*	*failed*	9,915	2,422	333	4,747
2	5.92	*failed*	*failed*	*failed*	10,653	1,917	381	4,784
3	3.92	15.59	*failed*	*failed*	11,885	2,488	420	5,120
4	6.86	18.79	*failed*	*failed*	9,698	2,112	342	4,351
5	6.76	18.99	*failed*	*failed*	7,990	2,426	224	4,289
6	3.46	16.38	*failed*	*failed*	9,770	3,140	282	5,059
Mean	5.40	17.44	*failed*	*failed*	9,985	2,418	330	4,725
Std. Dev.	1.43	1.71	*failed*	*failed*	1,278	417	70	347
				Superpave Gyratory Compactor (Cylindrical)				
1	3.52	6.90	*failed*	*failed*	13,954	2,945	303	9,436
2	3.00	8.68	*failed*	*failed*	13,507	2,887	293	8,934
3	3.40	13.26	*failed*	*failed*	12,131	2,085	295	7,607
4	3.46	10.38	*failed*	*failed*	12,066	1,901	282	7,831
5	2.73	4.47	19.51	*failed*	14,772	4,201	279	10,302
6*	2.63	3.66	6.72	*failed*	19,792	4,708	362	14,196
Mean	3.22	8.74	*failed*	*failed*	13,286	2,804	290	8,822
Std. Dev.	0.31	2.99	*failed*	*failed*	1,051	814	9	1,004

* Test results not included in statistical analyses, possible outlier.

TABLE 4

Standard Deviation of Data for Limestone and Gravel Test Specimens

Test Parameter	Standard Deviation		
	Limestone Rectangular Slab Test Specimens	Limestone Cylindrical Test Specimens	Combined Rectangular Slab & Cylindrical
5,000 Passes	0.96	0.31	0.74
10,000 Passes	0.98	1.84	1.62
15,000 Passes	1.54	1.63	3.16
N_f	2,499	1,612	2,492
Creep Slope	1,081	513	1,008
Stripping Slope	115	88	146
SIP	1,120	797	1,327
	Gravel Rectangular Slab Test Specimens	Gravel Cylindrical Test Specimens	Combined Rectangular Slab & Cylindrical
5,000 Passes	1.43	0.31	1.54
10,000 Passes	1.71	2.99	5.26
N_f	1,278	1,051	2,084
Creep Slope	417	814	677
Stripping Slope	70	9	54
SIP	347	1,004	2,268

TABLE 5

Test Results for Mixtures Tested at Different Test Temperatures and with Different Antistripping Additives

Test Temp.	N_f	Creep Slope	Stripping Slope	SIP	N_f	Creep Slope	Stripping Slope	SIP	N_f	Creep Slope	Stripping Slope	SIP
Limestone Mixtures												
	No Additive				**Liquid Additive**				**Hydrated Lime**			
40 C	19,519	4,856	459	12,026	25,266	5,469	777	12,768	>20,000	8,871	NA	NA
50 C	8,128	1,542	255	4,051	6,538	888	209	3,455	7,536	972	259	3,622
Mixtures w/Corpus Christi Gravel and Gravel Screenings												
	No Additive				**Liquid Additive**				**Hydrated Lime**			
40 C	5,607	907	163	3,158	13,400	3,471	744	9,565	>20,000	3,427	NA	NA
50 C	1,639	124	74	597	2,801	252	105	1,507	4,820	285	NA	NA
Mixtures w/Corpus Christi Gravel and Limestone Screenings												
	No Additive				**Liquid Additive**				**Hydrated Lime**			
40 C	10,222	2,082	279	6,010	15,465	1,511	491	9,052	>20,000	5,252	NA	NA
50 C	2,106	253	70	1,110	3,463	273	169	929	10,093	900	443	5351
Granite Mountain Mixtures												
	No Additive				**Liquid Additive**				**Hydrated Lime**			
40 C	21,883	2,979	640	13,310	27,644	4,780	1,050	12,192	>20,000	9,919	NA	NA
50 C	9,443	1,542	255	6,079	5,107	888	209	2,996	16,425	1,520	NA	NA
Basalt Mixtures												
	No Additive				**Liquid Additive**				**Hydrated Lime**			
40 C	14,250	1,926	446	5,456	31,073	3,626	1,402	9,275	>20,000	7,026	NA	NA
50 C	13,579	1,762	640	4,800	6,222	977	167	3,683	12,324	1,305	449	6,255
Mixtures w/Atlanta Gravel												
	No Additive				**Liquid Additive**				**Hydrated Lime**			
40 C	>20,000	9,815	NA	NA	>20,000	5,770	NA	NA	>20,000	10,465	NA	NA
50 C	8,216	679	381	4,264	9,677	638	391	4,686	>20,000	2,989	NA	NA

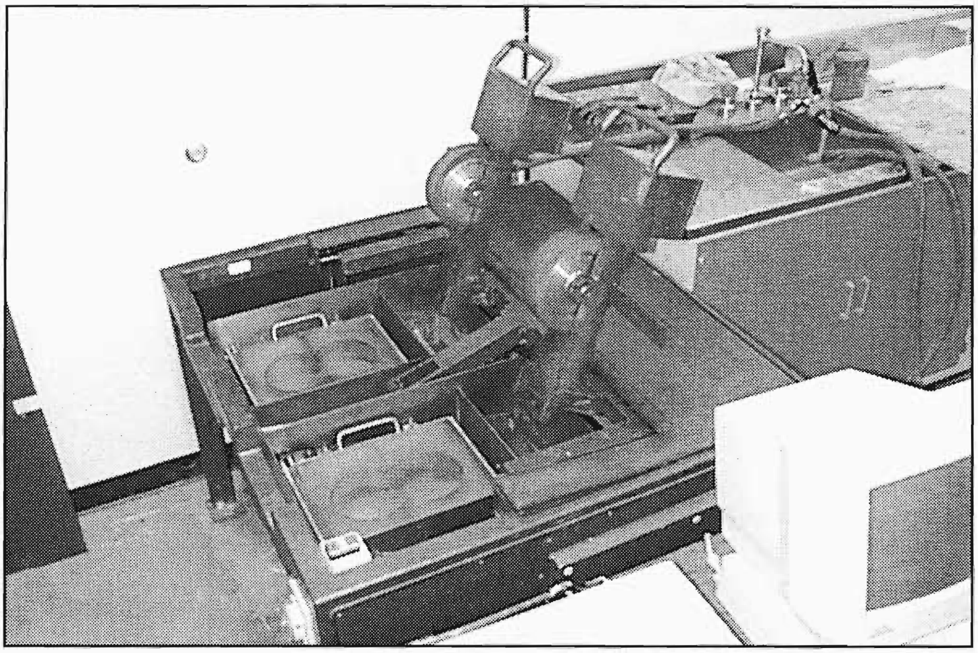


FIGURE 1: Hamburg Wheel-Tracking Device (HWTD)

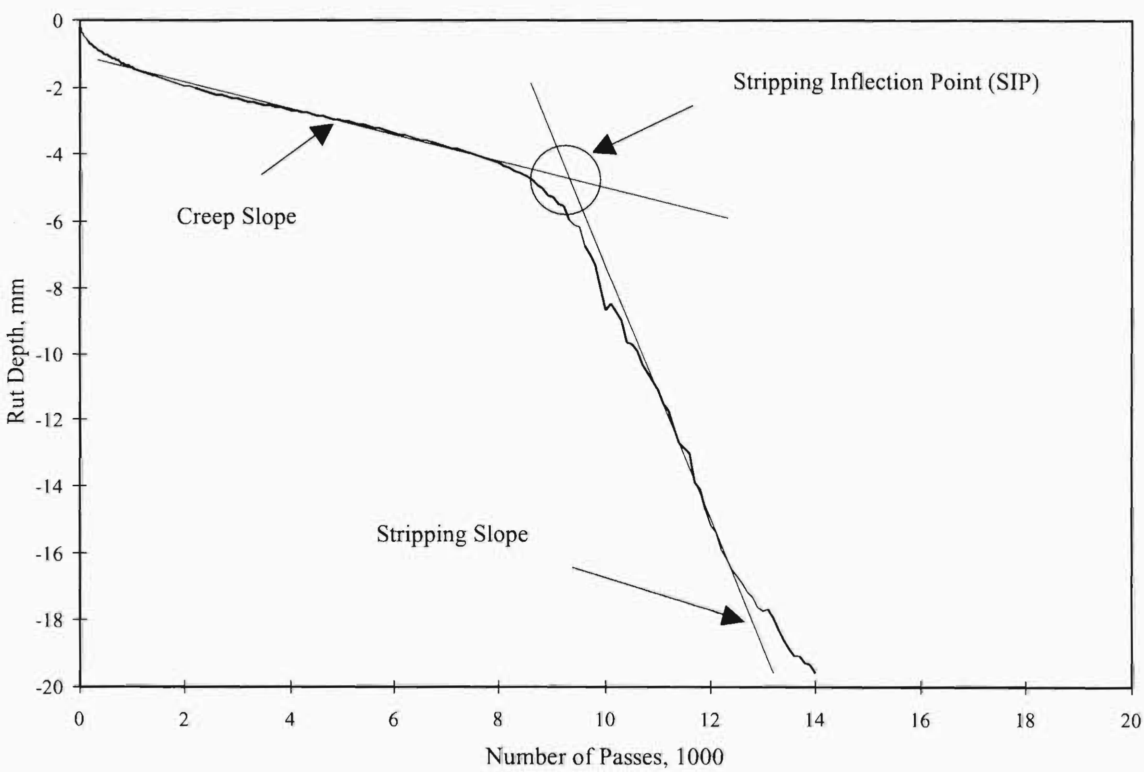
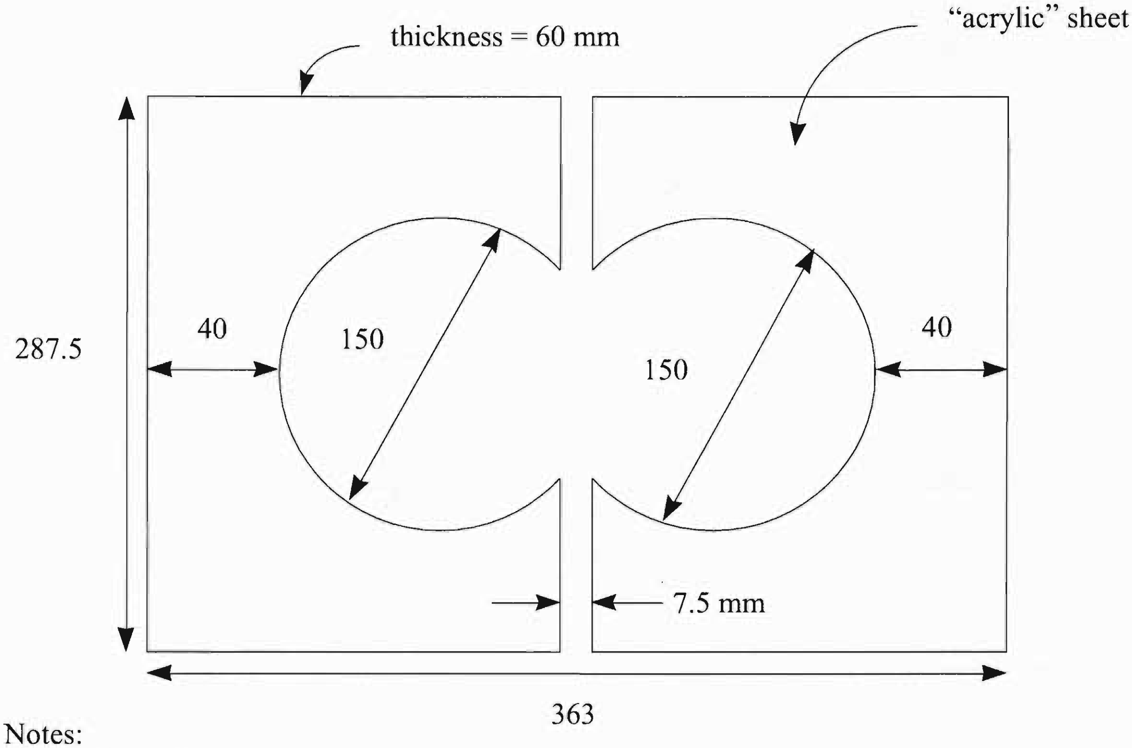


FIGURE 2: Test Results from the Hamburg Wheel-Tracking Test ***(4)***



Notes:
1. not to scale
2. dimensions in millimeters

FIGURE 3: Top View of Superpave Gyratory Specimen Configuration for the Hamburg Wheel-Tracking Device (HWTD)

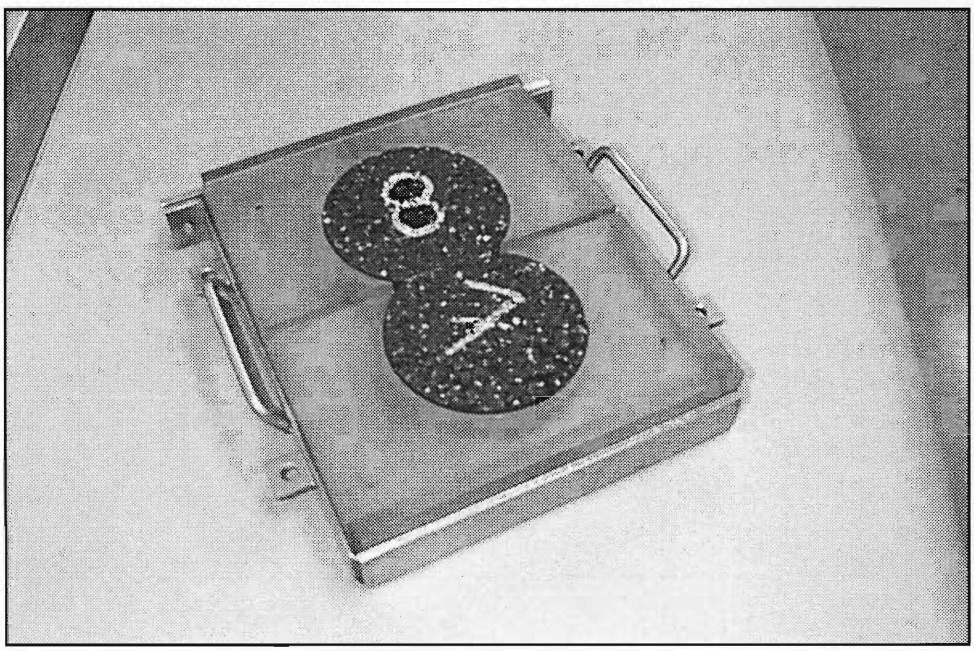


FIGURE 4: Specimen Configuration for the Hamburg Wheel-Tacking Device with Superpave-Gyratory-Compacted Test Specimens

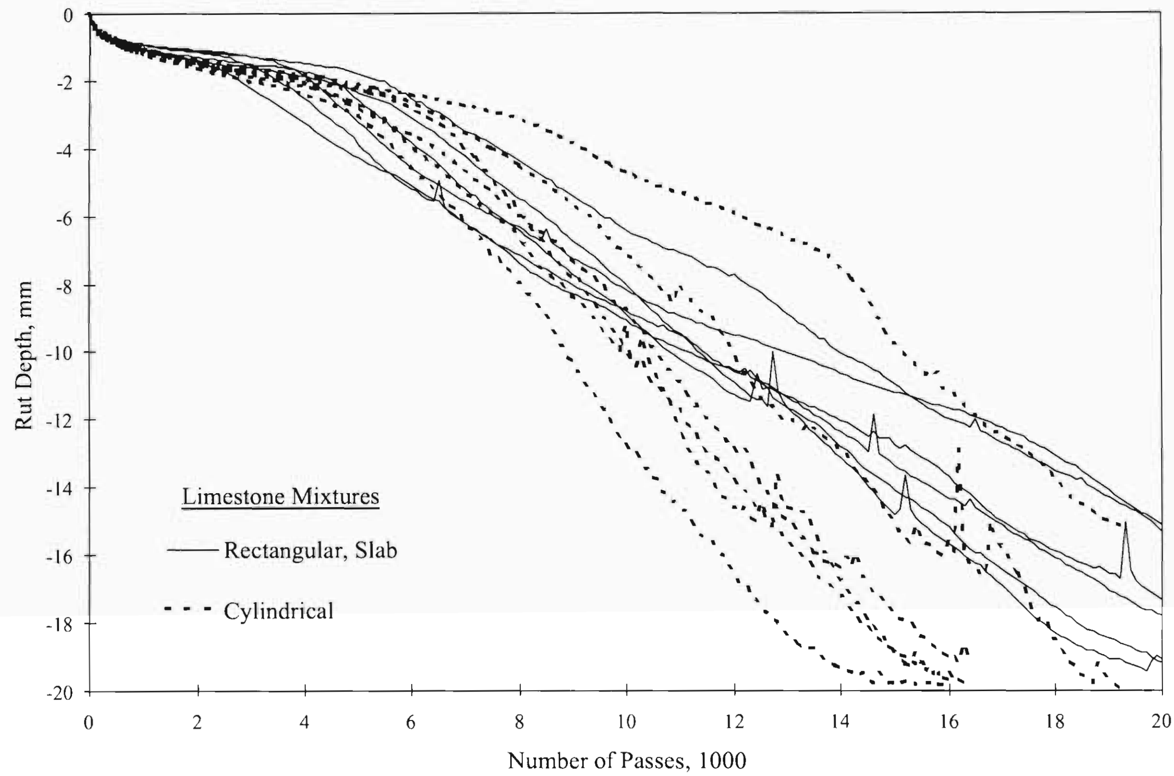


FIGURE 5: Combined Test Results for the Rectangular Slab and Cylindrical Test Specimens of the Limestone Mixture

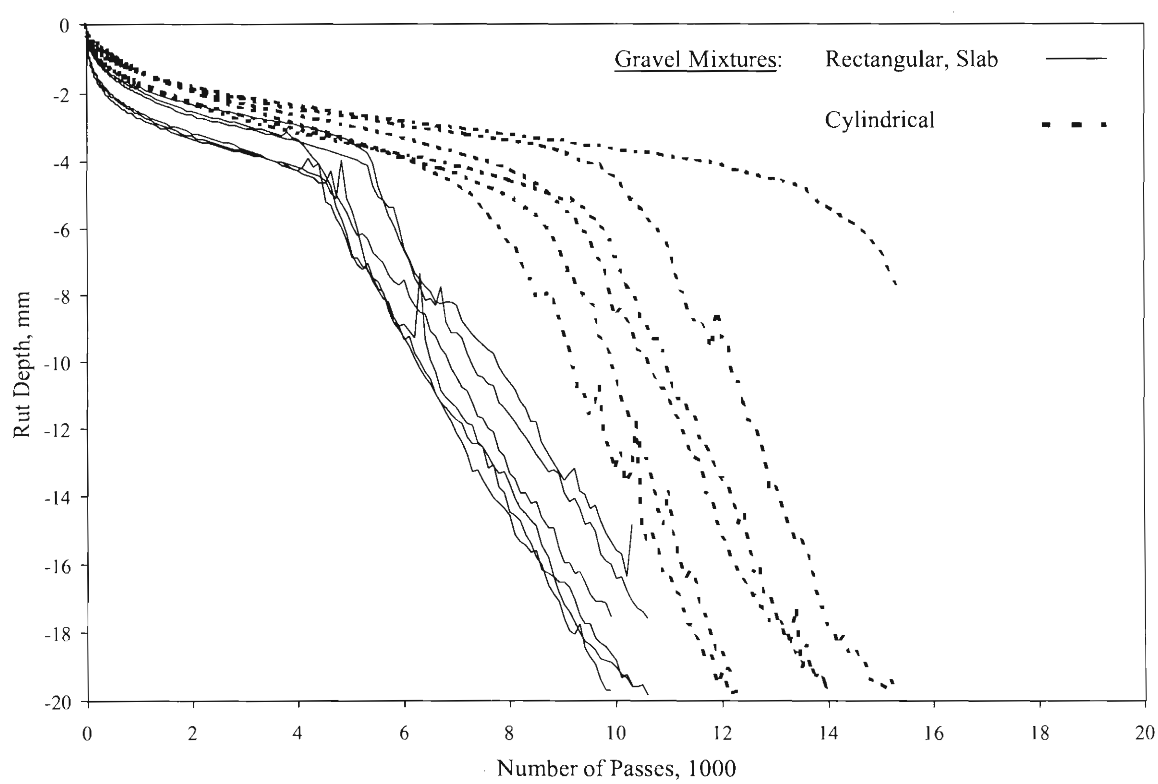


FIGURE 6: Combined Test Results for the Rectangular Slab and Cylindrical Test Specimens of the Gravel Mixture

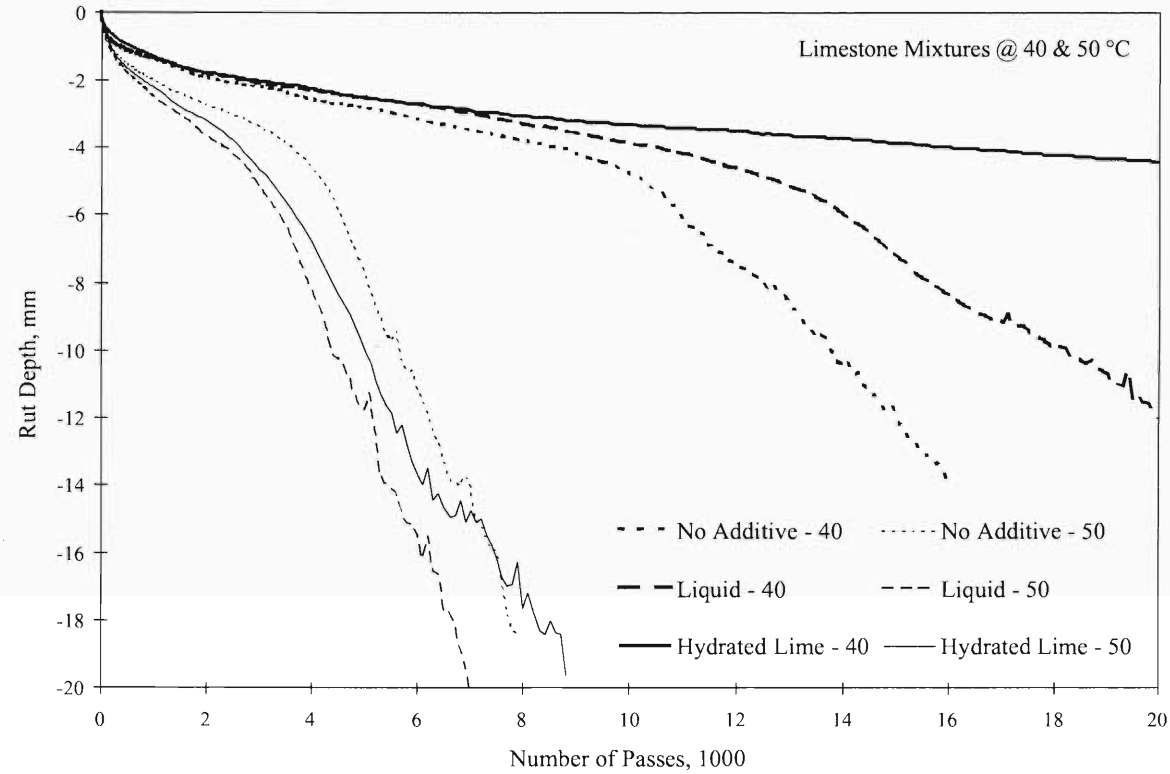


FIGURE 7: Test Results for Limestone Mixtures Tested at 40°C and 50°C

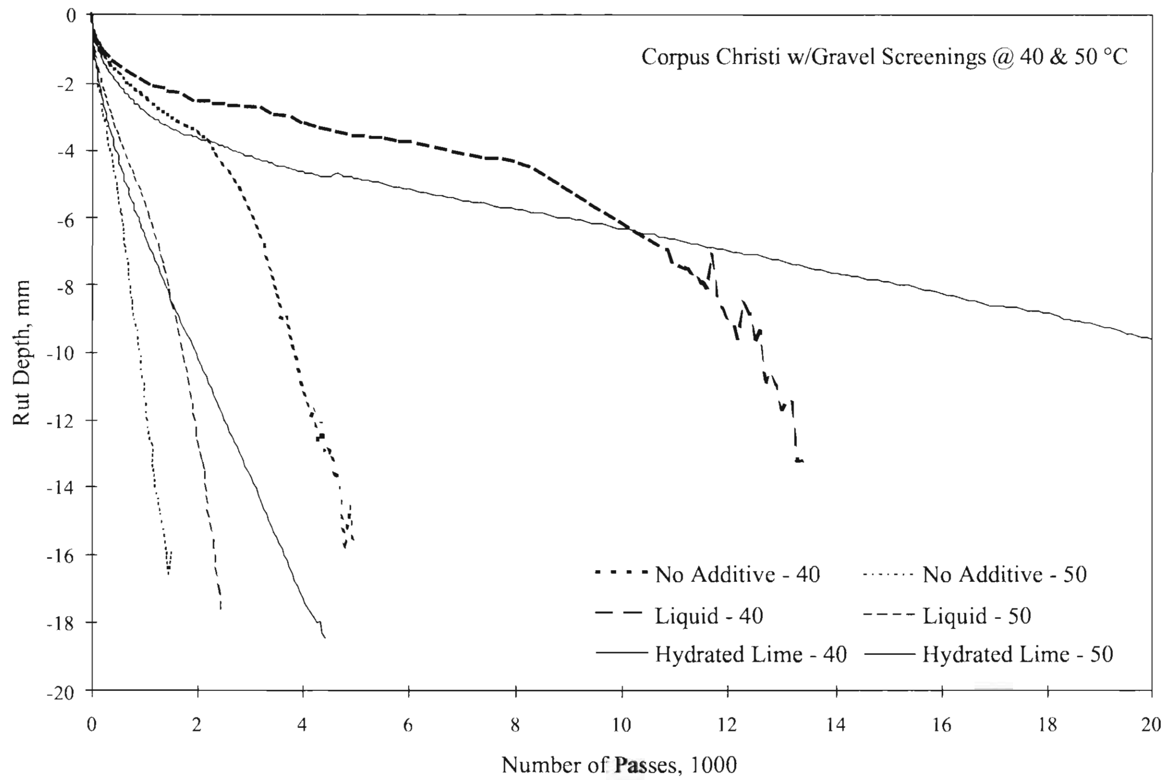


FIGURE 8: Test Results for Mixtures with Corpus Christi Gravel and Gravel Screenings Tested at 40°C and 50°C

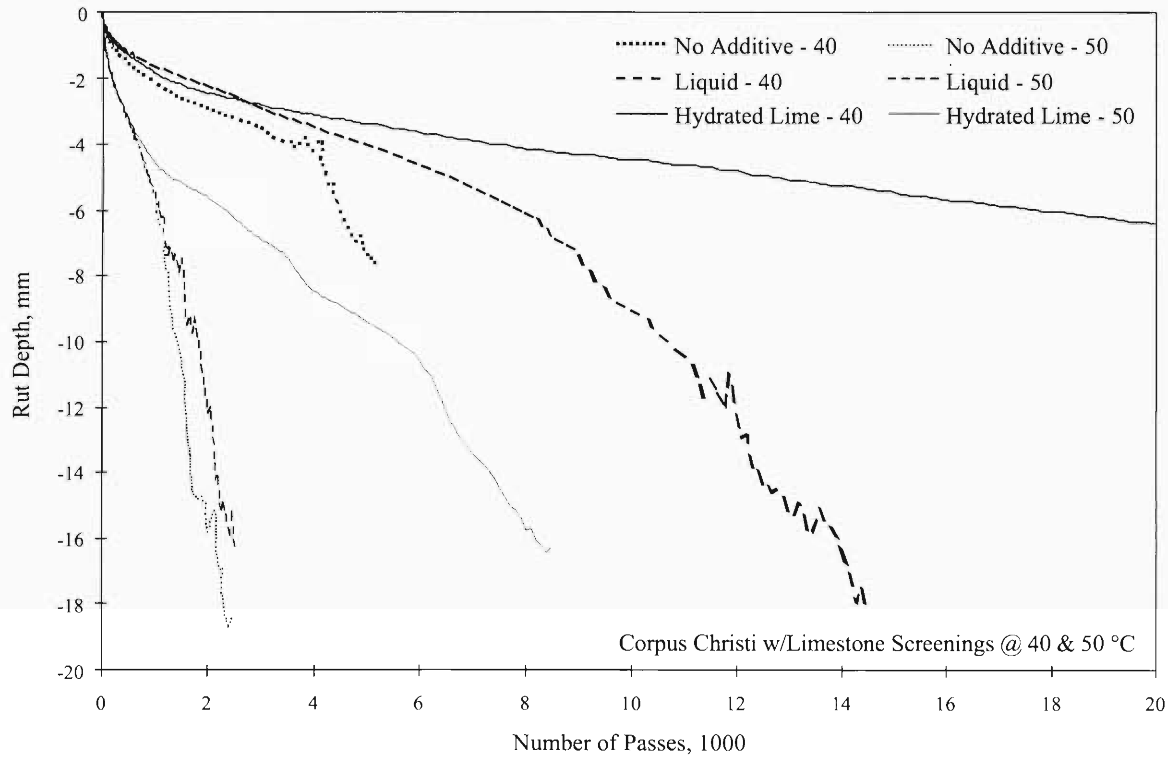


FIGURE 9: Test Results for with Corpus Christi Gravel and Limestone Screenings Tested at 40°C and 50°C

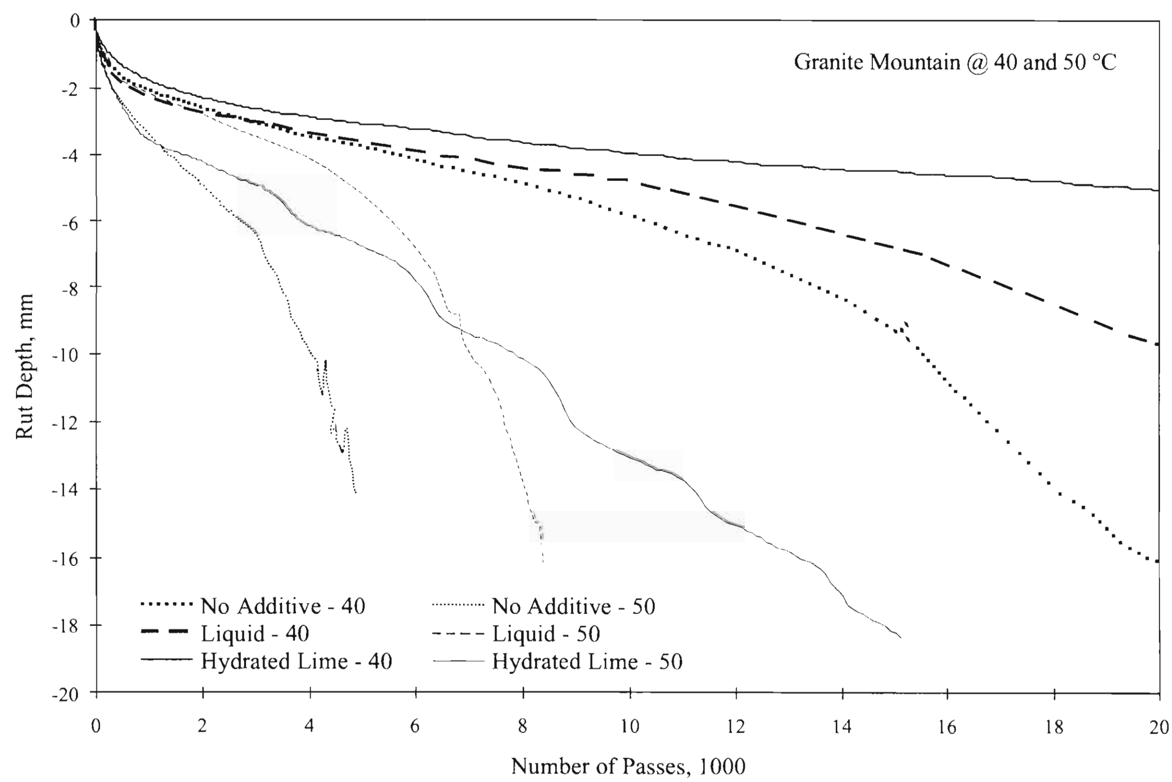


FIGURE 10: Test Results for Granite Mountain Mixtures Tested at 40°C and 50°C

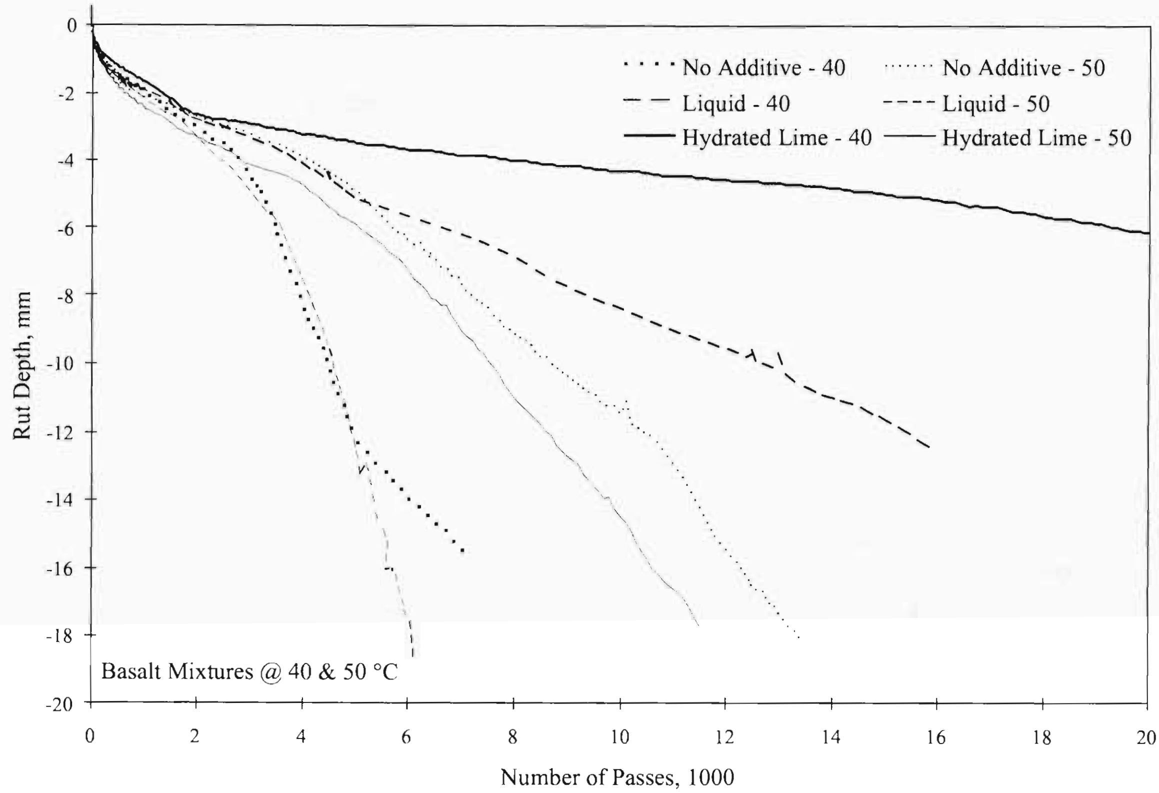


FIGURE 11: Test Results for Basalt Mixtures Tested at 40°C and 50°C

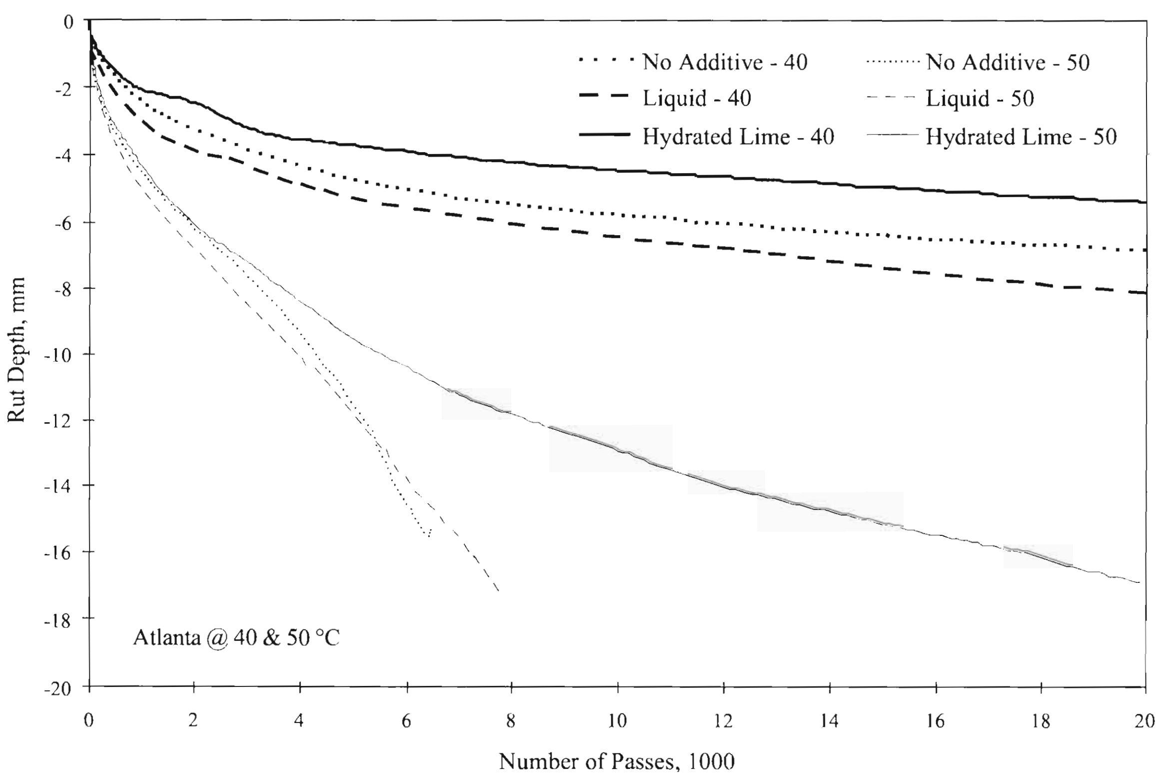


FIGURE 12: Test Results for Atlanta Mixtures Tested at 40°C and 50°C

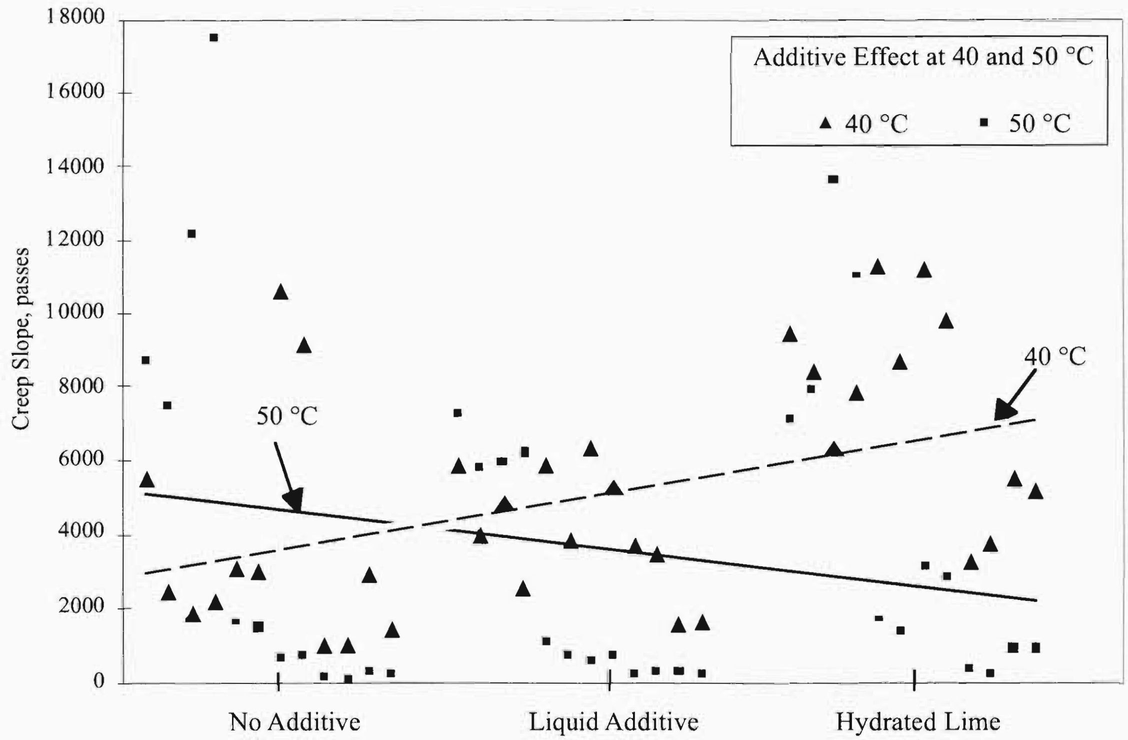


FIGURE 13: Trend Line of Creep Slope Data with Antistripping Additive

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