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EVALUATION OF THE MIXTURE VERIFICATION TESTER FOR DETERMINING THE RUTTING SUSCEPTIBILITY OF HOT-MIX ASPHALT

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ABSTRACT

The objective of this study was to evaluate whether or not the Mix Verification Tester (MVT) could be used to determine the rutting susceptibility of HMA mixtures during production in a similar manner to which ALDOT currently uses the Asphalt Pavement Analyzer (APA) to evaluate HMA mix designs. A series of mini-experiments were performed to refine the MVT test procedure. The first mini-experiment compared the rut depths of 75 mm and 115 mm tall gyratory samples. The second mini-experiment compared the measured rut depth of same height samples tested with a 100 lb vertical load and 100 psi hose pressure versus those tested with a 120 lb vertical load and 120 psi hose pressure. Based on the mixes tested in the mini-experiments, the MVT is sensitive to aggregate angularity and binder grade. From the mini-experiments two conclusions were drawn: 115 mm tall samples produced significantly larger rut depths than 75 mm tall samples, and samples tested with a 120 lb vertical load and 120 psi hose pressure produced significantly larger rut depths than samples tested with a 100 lb vertical load and 100 psi hose pressure. In both cases, the slope of the best fit line was approximately 1.0, indicating a simple offset in rut depth between the testing conditions. The increased rut depths from the taller sample heights (+0.86 mm) approximately offsets the decreased rut depths from the lower vertical load and hose pressure (-0.83 mm).

Field samples were taken from three mix types to compare the MVT and APA. Samples were compacted hot in the field and reheated prior to compaction. Lab-produced material was tested to provide comparisons with ALDOT's current criterion. It was determined that there was a significant difference between rut depths obtained using the MVT and APA. The MVT gave an average greater rut depth of 2.45 mm than the APA. There is not a simple offset between the MVT and APA rut depths. In this research, the best fit line for comparable samples had a slope of 0.689. There was no significant difference in rutting susceptibility measured by the APA of HMA specimens compacted hot in the field to N_{Design} and HMA specimens compacted to 4 ±0.5 percent air voids from the same mix that has been reheated. A maximum rutting criteria of 6.75 mm for 115 mm tall samples compacted to N_{Design} and tested in the MVT using a 100 lb vertical load and 100 psi hose pressure is comparable to ALDOT's current maximum rutting criteria of 4.5 mm for 75 mm tall samples produced from laboratory-produced mix compacted to N_{Design} at optimum asphalt content (approximately 4 percent air voids).

The MVT shows promise for field QC/QA but is not directly comparable to the APA. Additional research is required to see if the MVT can be related to field performance.

1.0 INTRODUCTION

Rutting susceptibility is a major concern for hot-mix asphalt (HMA). Rutting of HMA pavements can be a serious problem, and before the mid 1980’s, there was not a device to effectively test rutting susceptibility in HMA pavements. In the mid 1980’s the Georgia loaded-wheel tester (GLWT) was developed in a cooperative research study between the Georgia Department of Transportation (GDOT) and the Georgia Institute of Technology (*1*). The GLWT is a wheel-tracking device that can test for rutting susceptibility of asphalt mixtures. The GLWT typically tests samples by applying a 100 lb wheel load onto a pneumatic linear hose pressurized to 100 psi. The asphalt samples being tested are tracked for 8,000 loading cycles (a cycle consisting of one back and forth movement) or 16,000 passes (*1*). After the 8,000 cycles are complete, the asphalt specimens are then measured for rut depths to determine rutting susceptibility. Rut depths are determined by measuring the rut depth of samples before they are loaded and after the 8,000 cycles are completed.

In 1996, Pavement Technology, Inc. manufactured the first Asphalt Pavement Analyzer (APA). This device is a modification of the GLWT and also tests for rutting susceptibility of HMA pavements. The APA uses the same standards as the GLWT and has the ability to test six gyratory or three beam compacted specimens at a time (*1*).

The Alabama Department of Transportation (ALDOT) uses the APA for verification of HMA mix designs. At the time this report was prepared, ALDOT did not have any field quality control and quality assurance (QC/QA) specifications for rutting susceptibility of HMA. This means that there is no criterion to directly measure rut susceptibility of HMA mix being placed on the roadway during production.

The Mix Verification Tester (MVT) is a device developed by Pavement Technology Inc. for testing rut susceptibility of field mixes. The MVT uses the same standards as the APA, but is only capable of testing two gyratory or one beam compacted specimen at a time. The MVT was developed to be used in a field laboratory because of its smaller size and weight. The MVT could be an ideal device for ALDOT to use for QC/QA testing if it compares consistently with the APA.

The objectives of this study were to compare the rutting data obtained using the APA with the rutting data obtained using the MVT, and to develop criteria for testing rutting susceptibility in the field.

Figure 1 Mix Verification Tester

2.0 EXPERIMENTAL PLAN

Currently, ALDOT's maximum rutting criteria for the APA is 4.0 mm and is based on six gyratory samples that are 75 mm in height and are compacted to $N_{Design.}$ N_{Design} was chosen because the mix will already be compacted to $N_{Design,}$ thus not requiring additional compacted specimens. NCHRP 9-17 indicated that gyratory samples compacted to 4 percent air voids compared better with field performance than samples compacted to 7 percent air voids (*2*). During mix design, samples at optimum asphalt content that are compacted to N_{Design} should produce 4 percent air voids. For rutting susceptibility to be used as a QC/QA specification, tests results must be produced relatively quickly, preferably the same day, so the contractor may make adjustments to the mix as necessary. Therefore, it would be desirable to use field mix samples compacted to N_{Design} at a height of 115 mm for determining maximum allowable rutting criteria for field QC/QA in the MVT. Two mini-experiments were developed to refine the test procedures. Later field samples were tested to compare the results from the MVT with the APA.

2.1 Mini-Experiments

Two mini-experiments were used in this study. Three gradations were used in these mini experiments. They each had a nominal maximum size of 3/4." The gradations were classified as a granite coarse, gravel coarse, and a gravel fine. The granite and gravel coarse each had mixes prepared with a binder grade of PG 76-22 and PG 67-22. The gravel fine had mixes prepared with a binder grade of PG 67-22. Since two binder grades were used for the gravel and granite coarse gradations a total of five different mixes were prepared. The three gradations used for the five different mixes for the mini experiments are given in Table 1.

Table 1 Gradations for Mixes

Percent Passing for Three Different Gradations Used			
Sieve Size	**Granite Coarse**	**Gravel Coarse**	**Gravel Fine**
1.0 in	100	100	100
¾ in	100	99	100
½ in	95	96	95
3/8 in	86	85	85
#4	51	51	69
#8	32	32	56
#16	21	22	41
# 30	16	16	31
# 50	12	12	22
# 100	10	10	12
# 200	6.4	7.0	7.3

The mini experiments were conducted to compare rut depths resulting from different sample heights and from different hose pressures and vertical wheel loads. ALDOT-401 specifies an APA hose pressure of 100 psi and a vertical wheel load of 100 lbs. Research conducted as part of NCHRP 9-17, *Accelerated Laboratory Rutting Tests: Asphalt Pavement Analyzer*, recommended a hose pressure of 120 psi and a vertical wheel load of 120 lbs (*2*). NCHRP 9-17 did not compare the two pressure and wheel load combinations. The hose pressure of 120 psi and a vertical wheel load of 120 lbs were recommended based on testing performed by the Virginia Transportation Research Council (VTRC) on WesTrack samples (*3*). VTRC adopted the 120 psi hose pressure and the 120 lb vertical wheel load and testing was usually conducted at 49 ° C. The higher vertical load and hose pressure would tend to make the rutting test more severe. The manufacturer of the APA and MVT was concerned that many air compressors would not consistently supply 120 psi of air pressure, particularly those used in field labs. They were also concerned that the higher air pressure will cause more maintenance problems with the machines. The test temperature used was selected based on ALDOT-401 (*4*). ALDOT-401 recommends rut testing be conducted at the climatic base PG binder high temperature.

The mini experiments compared nine replicates (eighteen specimens) for each mix from Table 1. Three replicates of each mix were compacted to a height of 115 ± 5 mm and tested at a 120 lb vertical wheel load and a 120 psi hose pressure. The next three replicates of each mix were also compacted to a height of 115 ± 5 mm, but were tested at a 100 lb vertical wheel load and 100 psi hose pressure. The final three replicates of each mix were compacted to a height of 115 ± 5 mm and then sawed to 75 mm and tested at a 100 lb vertical wheel load and 100 psi hose pressure. All eighteen specimens were prepared at an air void level of 4 ± 0.5. All nine replicates were tested at 67ºC to determine if the higher test temperature recommended adequately accelerated the test such that the higher hose pressure and wheel load may not be needed. Since there were two different grades, 76-22 and 67-22, of PG binder used in the mixes, the differences in their rut depths were compared to see how the difference in binder grade affected the rutting of the mixes.

A total of 8,000 cycles were applied to the specimens, which takes about two hours and twenty minutes on the MVT. The MVT automatically collected the rut data from the specimens, but manual measurements were also taken to ensure rut measurements would not be lost in case a problem developed with the automatic rut depth collection during the testing of the specimens.

2.2 Results of Mini Experiments

The average rut depths from five mixes, used in the lab mini experiments, rutted on the MVT are given in Fig. 2. As shown in Fig. 2, the mixes evaluated provided a wide range of rut depths. The rut depths for these mixes were sensitive to the aggregate type and the binder used. The gradations were the same for the granite and gravel coarse mixes. Granite is the more angular aggregate of the two and this helped the granite mix to be the more rut resistant than the gravel mix. The PG 76-22 binder also showed to be more rut resistant than the PG 67-22, which was expected because of the effect of the binder stiffness.

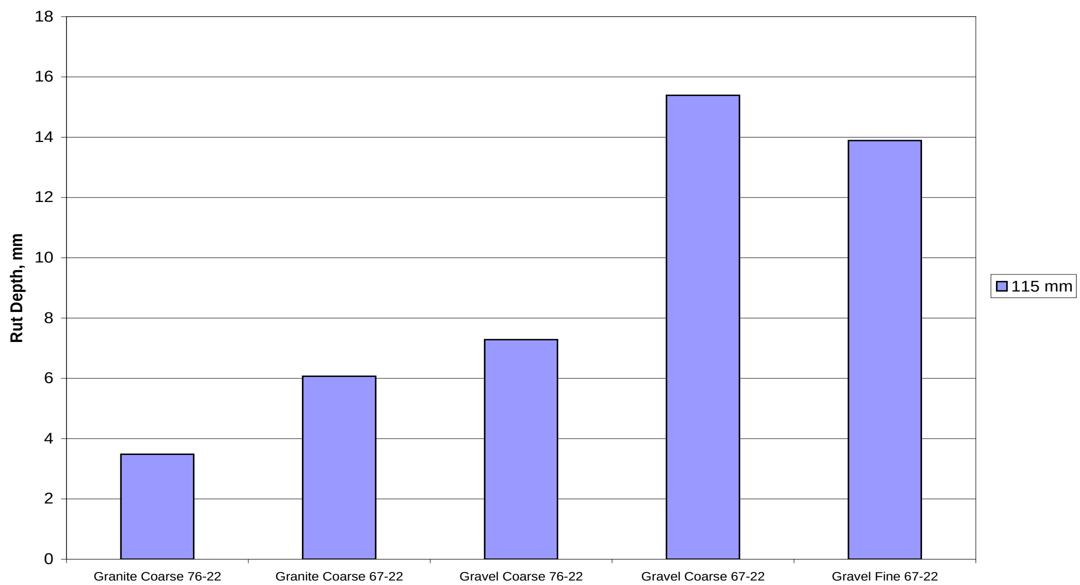

Figure 2 Average MVT Rut Depths at 8,000 Cycles

An analysis of variance using Minitab statistical software was performed to compare the rut depths resulting from different height specimens tested using the same wheel load of 100 lb and hose pressure of 100 psi *(5)*. This analysis gave a *p*-value of 0.174 indicating that there was not a significant difference in rut depths between the 75 mm and 115 mm specimens tested in the MVT. From the data in Table 2 and Fig. 3, there was about a 0.85 mm difference in rut depths between the two different height samples with the 115 mm samples giving the greater rut depths.

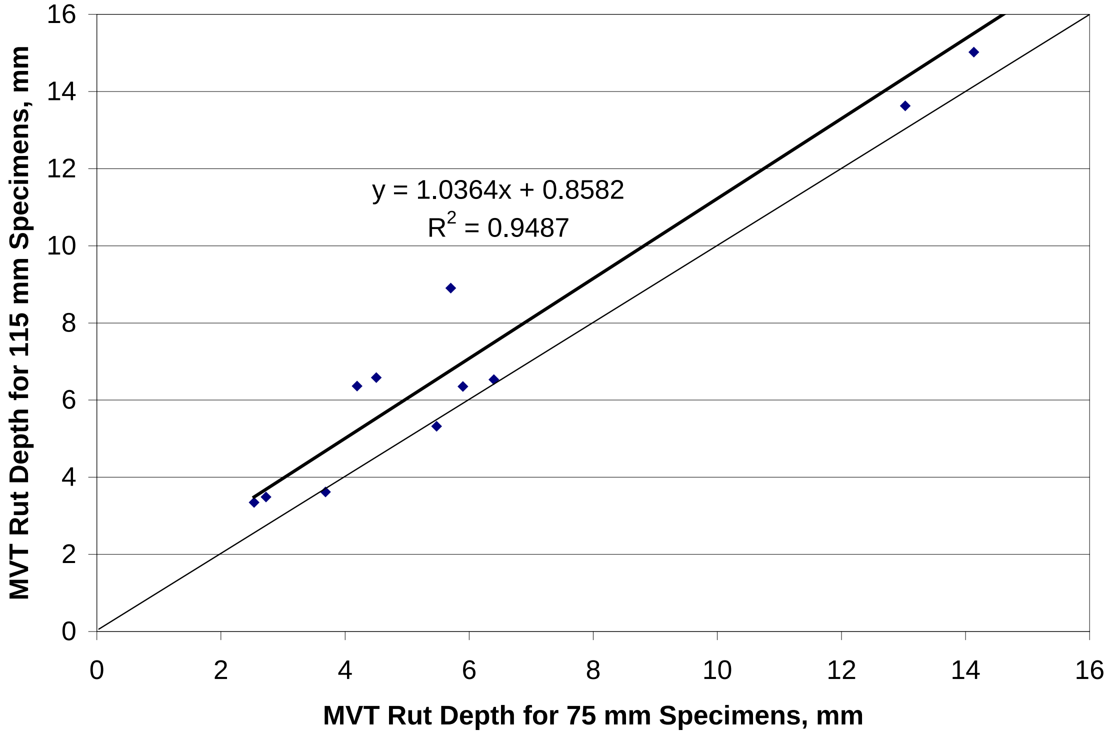

Figure 3 Rut Depth Difference between 75 mm and 115 mm Sample Height

When comparing the difference of rut depths between a wheel load of 120 lbs with a hose pressure of 120 psi and a wheel load of 100 lbs with a hose pressure of 100 psi, using a sample height of 115 mm, a paired *t*-test with a value of 0.0197 showed a significant difference in rut depths between the two wheel loads and two hose pressures as shown in the data in Table 3 and Figure 4. From Figure 3, the higher wheel load and hose pressure produces about 0.80 mm more rut depth than the lower wheel load and hose pressure.

Table 2 Rut Difference Data Between 75 mm and 115 mm Specimens

Mix	Binder Grade	Height, mm	Replicate[1] 1	2	3	Average, mm	Standard Deviation, mm	t-test p-value	Significant?
Granite Coarse	PG 67-22	75	5.48	5.9	6.4	5.93	0.46	0.772	No
		115	5.32	6.36	6.53	6.07	0.66		
Granite Coarse	PG 76-22	75	2.54	2.73	3.69	2.99	0.62	0.304	No
		115	3.35	3.49	3.62	3.49	0.14		
Gravel Coarse	PG 67-22	75	13.03	14.14	15.07	14.08	1.02	0.364	No
		115	13.63	15.02	17.53	15.39	1.98		
Gravel Coarse	PG 76-22	75	4.2	4.51	5.71	4.81	0.80	0.056	No
		115	6.37	6.59	8.91	7.29	1.41		

[1] *A replicate represents the average of two SGC samples tested simultaneously in the MVT.*

Table 3 Rut Depth Data Between 100 lb/100 psi and 120 lb/120 psi

Mix	Binder Grade	Pressure/Load, psi/lbs	Replicate[1] 1	2	3	Average, mm	Standard Deviation, mm	t-test p-value	Significant?
Granite Coarse	PG 67-22	100	5.32	6.36	6.53	6.07	0.66	0.0114	Yes
		120	10.74	11.98	8.8	10.51	1.60		
Granite Coarse	PG 76-22	100	3.35	3.49	3.62	3.49	0.14	0.0037	Yes
		120	5.93	5.23	4.92	5.36	0.52		
Gravel Coarse	PG 67-22	100	13.63	15.02	17.52	15.39	1.97	0.3426	No
		120	17.51	17.2	15.6	16.77	1.03		
Gravel Coarse	PG 76-22	100	6.37	6.59	8.91	7.29	1.41	0.7761	No
		120	6.41	6.71	7.9	7.01	0.79		

[1] *A replicate represents the average of two SGC samples tested simultaneously in the MVT.*

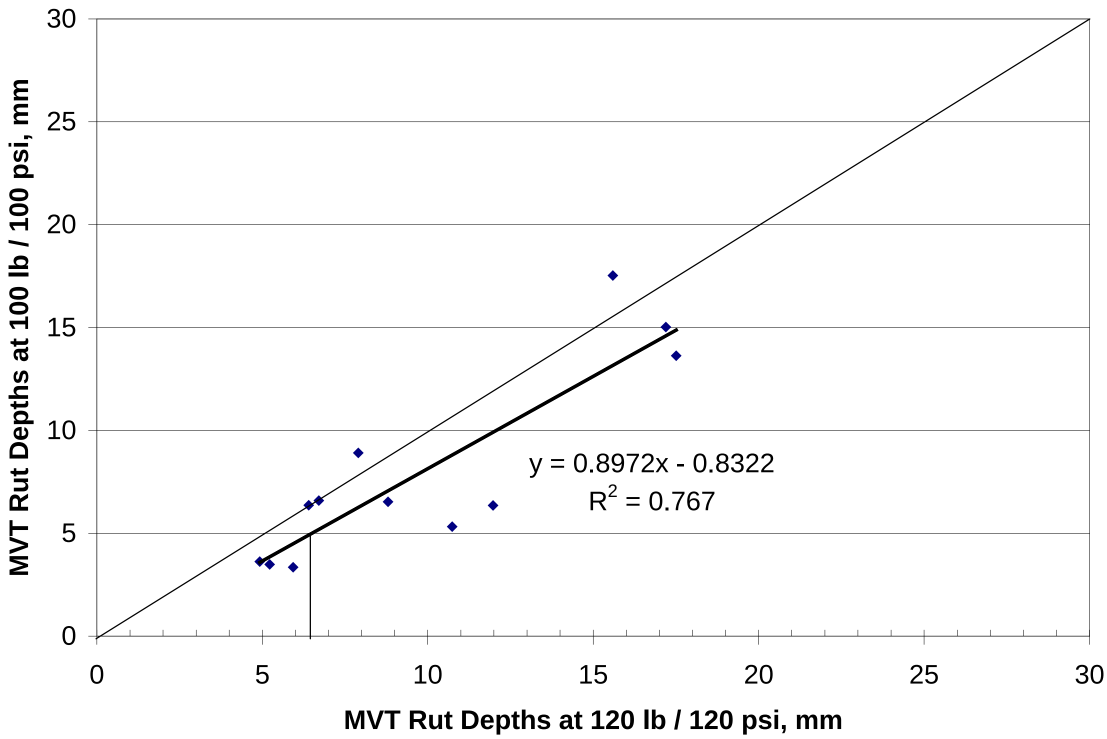

Figure 4 Rut Depth Difference Between 100 lb/100 psi and 120 lb/120 psi

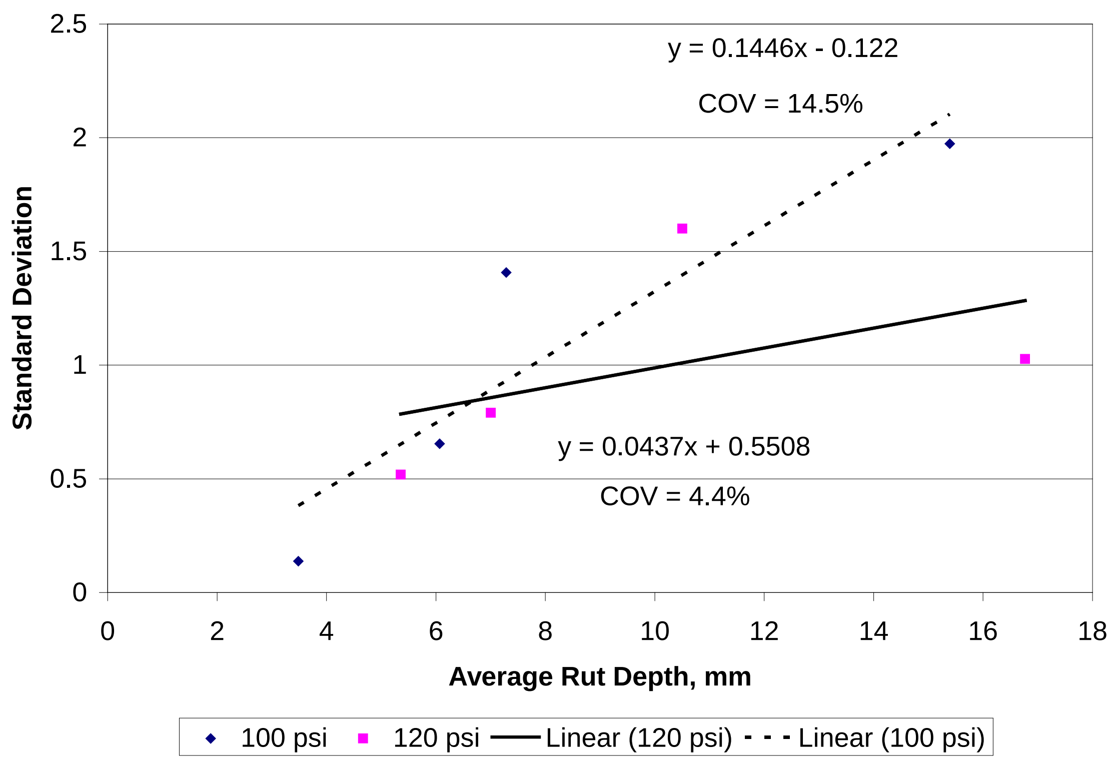

Figure 5 Standard Deviation as a Function of Rut Depth

Variability of the MVT test results are shown as a function of rut depth for both loading conditions in Fig. 5. Figure 5 shows that a higher wheel load and hose pressure provides less variability as indicated by the lower coefficient of variation. The coefficient of variation is the standard deviation divided by the mean expressed as a percentage. It is also represented by the slope of the line in Fig. 5. One of the points in Figure 4 looks to be a possible outlier. The standardized residuals from regression analysis were used to determine if the point was an outlier. Most standardized residuals lie in the interval of -3 and 3 (*6*). If the standardized residual is located outside this interval then it can be viewed as an outlier. For this point in the data, the standardized residual was determined to be 13.84 which is outside the given interval. It was determined that the point in the data was an outlier. The higher rut depths for these specimens could have been caused from these specimens having the weakest aggregate with the less stiff binder. Since this point is an outlier, then the other three points lie along the same line as the 100 lb wheel load and 100 psi hose pressure. This indicates that the wheel load and hose pressure combinations may have similar variability. From this experiment it was recommended that the 100 lb wheel load and 100 psi hose pressure be used for rut testing for a couple of reasons. Further, if the MVT is used in a field laboratory, a smaller air compressor can be used to produce the lower pressures because some field labs will not be able to equip themselves with larger compressors for economic reasons. Also, using the lower load and pressure will result in less wear and tear on the MVT.

From the mini experiments performed on the MVT using the five different mixes, test conditions were established for rut testing using the MVT in the field. It is recommended that the sample height be 115 mm since this is the height normally produced for a design specimen and the testing temperature be based on the climatic PG grade of the binder used in the mix. It was also recommended that the wheel load be 100 lbs and the hose pressure be 100 psi.

3.0 FIELD EXPERIMENTS

Mix samples obtained from field projects were also used for determining rut depth susceptibility using the MVT and APA. Three field mixes were examined for this part of the research study. There was a 1-inch maximum aggregate size SMA, a half-inch maximum aggregate size SMA, and a half-inch maximum aggregate size fine-graded Superpave mix. Four samples were taken of each mix and each sample was taken on a different day. The mix was obtained from East Alabama Paving (EAP) located in Opelika, Alabama. A small laboratory, including the MVT and a Brovold SGC were set up on site. Twelve specimens were compacted to N_{Design} using the gyratory compactor from each sample of mix taken. The mix was allowed to age for one hour at 325ºF before compaction. The bulk specific gravity of the compacted specimens was then determined using AASHTO T166, after they had had time to cool to room temperature. From the twelve gyratory compacted specimens, six were then tested on the APA at NCAT and the other six (3 replicates) were tested on the MVT at the EAP lab. The APA and MVT were set to test with a 100 lb vertical wheel load and a 100 psi hose pressure and the testing temperature was set to 67ºC. These are the variables used in the testing criteria in ALDOT 401 (*4*).

Another experiment was also performed using the three mixes from EAP. When the samples were taken, three extra five gallon buckets of mix were sampled and taken back to the NCAT lab. The mix from each sample was later reheated and split out to prepare gyratory specimens. Six gyratory compacted specimens were made using the Brovold gyratory compactor with an air void percentage of 4 ± 0.5 percent. Two theoretical maximum density (TMD) tests were also conducted on the reheated mix using AASHTO T209. These compacted specimens were then tested for rutting susceptibility on the APA. The APA was set to test with a 100 lb vertical wheel load and a 100 psi hose pressure and the testing temperature was set to 67ºC as required by ALDOT 401.

Samples of the aggregate that was used in the three mixes were also obtained from EAP. The aggregate was then taken to NCAT and separated into individual sizes. The aggregates were recombined to match the job mix formulas and each mix was reproduced in the NCAT lab. The mixes were compacted to 100 gyrations to match the job mix specifications using the Brovold gyratory compactor. Twelve specimens were compacted for each mix. After compaction, the samples were then cut to a height of 75 mm and then bulked to obtain the air voids of the sample. The samples were then tested for rutting susceptibility using the APA and the MVT. The APA and MVT were set to test with a 100 lb vertical wheel load and a 100 psi hose pressure. The testing temperature was set to 67ºC.

3.1 Results of Field Experiments

The field mix samples taken and compacted at EAP were compared and analyzed. Fig. 6 shows the rut depths obtained from the MVT and APA for the three different field mixes.

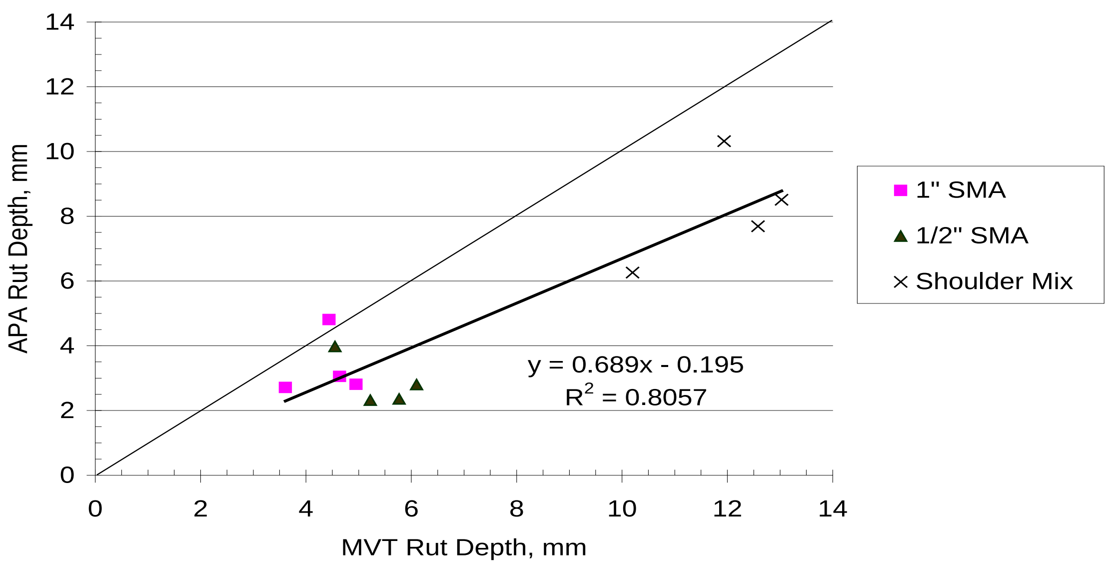

Figure 6 Measured Rut Depth for Field Mixes, MVT vs. APA

Table 4 APA and MVT Rut Depths for Field Compacted Specimens

Sample	APA Rut Depth, mm[1]	MVT Rut Depth, mm[2]
1” SMA-1	4.81	4.44
1’ SMA-2	2.71	3.61
1” SMA-3	2.81	4.95
1” SMA-4	3.05	4.64
1/2'” SMA-1	2.80	6.10
½” SMA-2	2.36	5.77
½” SMA-3	2.32	5.22
½” SMA-4	3.98	4.55
Fine Graded-1	8.51	13.03
Fine Graded-2	6.26	10.20
Fine Graded-3	10.32	11.94
Fine Graded-4	7.69	12.58
Average, mm	4.80	7.25
Standard Deviation, mm	2.75	3.58
t-test *P*-Value	0.0003	

[1]*Represents the average of six specimens (one test)*

[2]*Represents the average of six specimens (three tests)*

A paired *t*-test was conducted on the data presented in Table 4 and Figure 6. From the paired *t*-test, it was determined that there was a significant difference between the ruts depths for the MVT and APA. The p-value obtained was 0.0003. The MVT produced a rut depth average 2.45 mm higher than the APA.

The loose mix that was taken back to NCAT was reheated and compacted to an air void percentage of 4 $\pm$ 0.5. The results for the rutting susceptibility between the recompacted samples and those compacted in the field are given in Figure 7.

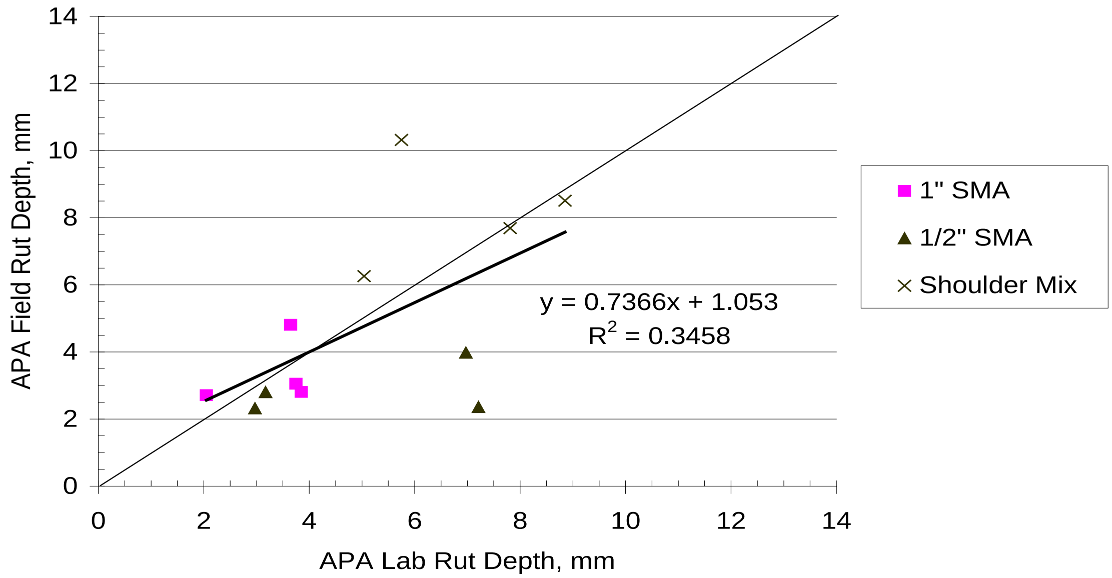

Figure 7 Reheated vs. Non-reheated Rut Depths Tested in APA

From a paired *t*-test run on this data, it was determined that there was no significant difference between the rut depths of the samples compacted without reheating at the contractor's plant and those reheated and compacted back at the NCAT lab. The *p*-value obtained was 0.3363 and the data are shown in Table 5. It was thought that the lab compacted mix would be more rut resistance because of the binder stiffening from the reheating of the mix. It has to be taken into account that the lab compacted mix was compacted to a height of 115 mm at an air void level of 4.0 $\pm$ 0.5% and the field compacted samples were compacted to N_{Design} with an average air void level of 3.2%. From Fig. 7, the fine graded mix specimen lying further away from the line of equality is Fine Graded Sample-3. For this sample, the average air voids were 5.2% for the field specimens, which may explain why the rut depths of this sample were 2 mm larger than the other samples of the same mix.

Table 5 Rut Depths for Field Compacted and Reheated Lab Compacted Specimens

Sample	Rut Depth, mm Field Compacted	Rut Depth, mm Reheated Lab Compacted
1" SMA-1	4.81	3.65
1' SMA-2	2.71	2.05
1" SMA-3	2.81	3.85
1" SMA-4	3.05	3.75
½" SMA-1	2.80	3.17
½" SMA-2	2.36	7.21
½" SMA-3	2.32	2.97
½" SMA-4	3.98	6.97
Fine Graded-1	8.51	8.85

Fine Graded-2	6.26	5.04
Fine Graded-3	10.32	5.75
Fine Graded-4	7.69	7.81
Average, mm	4.80	5.09
Standard Deviation, mm	2.75	2.19
t-test *p*-Value	0.3363	

Figure 8 provides a graph of the average rut depths for the field and lab mixes fro the three different mixes. Field mixes are plant mixed samples compacted at EAP when the mix was sampled, and the lab mixes are the samples compacted at NCAT from laboratory prepared mix matching the JMF produced with the aggregate taken from EAP. Also provided in the graph is ALDOT's criterion for rut depth. ALDOT has an APA rut maximum depth criteria that is 4.0 mm for laboratory mix designs. When compared to the MVT, the MVT gives a larger rut depth than the APA as seen from the graph. From Fig. 8, the MVT's average rut depth is approximately 6.25 mm when compared to ALDOT's criteria of 4.0 mm. This suggests that if ALDOT were to adopt the MVT for field quality control using 115 mm gyratory samples compacted to N and tested using a 100 lb wheel load and 100 psi hose pressure, the maximum rut depth criteria should be 6.25 mm to be compatible with the current mix design criterion of 4.0 mm using the APA.

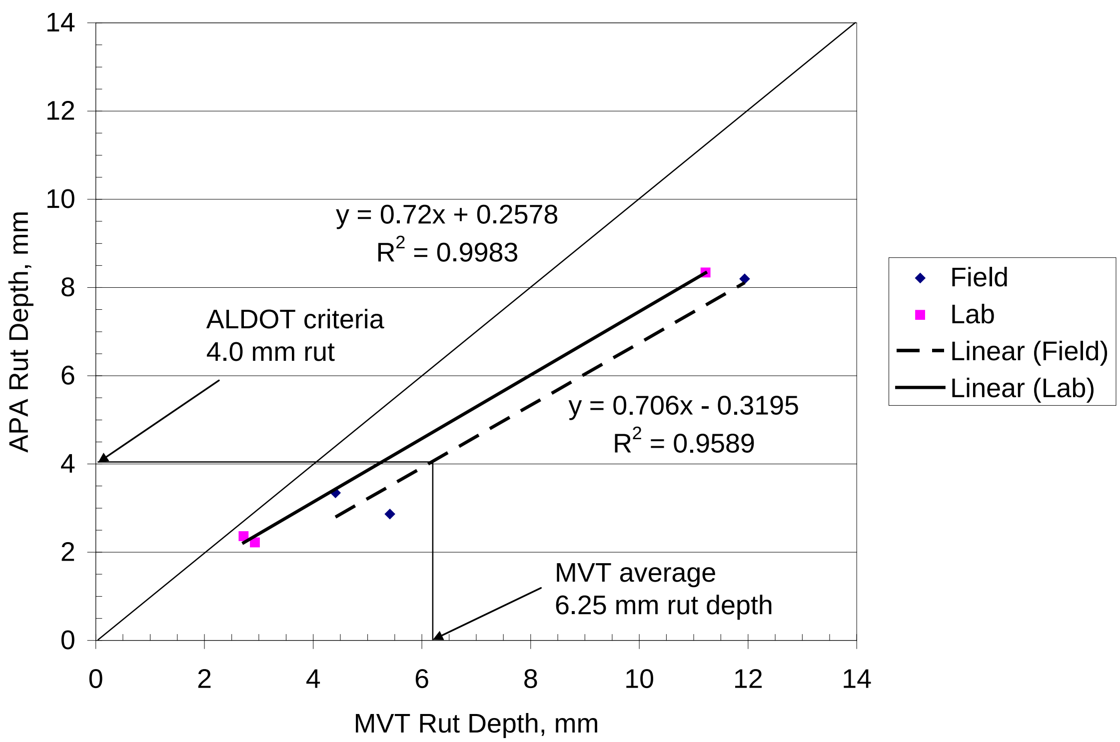

Figure 8 ALDOT APA Rut Depth Criteria

4.0 CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to compare the rutting susceptibility of HMA specimens using the MVT with that of the APA. The study was performed for ALDOT to determine if the MVT could be used as a device for determining rutting susceptibility for QC/QA testing in field laboratories. The MVT is a smaller version of the APA and would be ideal for field laboratories if it compared well with the APA.

Mini experiments were performed at the NCAT laboratory using the MVT. From these experiments several conclusions were drawn. For the first mini experiment, the rutting susceptibility of HMA specimens with different heights was determined. Specimens with a height of 75 mm were compared with those of a height of 115 mm. These two heights were chosen because 75 mm is the height of specimens originally used for ALDOT rutting susceptibility testing and 115 mm is the height of specimens compacted to N_{Design} during QC/QA testing. When testing was completed for these specimens, it was determined that the height of specimen for determining rutting susceptibility was not significant.

For the second mini experiment, two different wheel loads and hose pressures were used in determining rutting susceptibility in HMA specimens. A 100 lbs wheel load and 100 psi hose pressure was the first criteria chosen because these are the wheel load and hose pressures used by ALDOT for determining rutting susceptibility in HMA specimens. This combination was compared with a wheel load of 120 lbs and a hose pressure of 120 psi. This criterion was chosen because of the recommendation given in NCHRP 9-17 and based on testing performed by the VTRC on WesTrack samples. When testing was completed for these specimens, it was determined that the wheel load and hose pressure combination were significant. The 120 lb wheel load and 120 psi hose pressure caused an approximate rut depth of 0.80 mm greater than those tested using the 100 lb wheel load and 100 psi hose pressure.

From the mini experiments performed on the MVT, it is recommended that the sample height be 115 mm since this is the height normally produced for a design specimen. Also it is recommended that the 100 lb wheel load and 100 psi hose pressure be used for rutting susceptibility testing. This is because some field labs can not equip themselves with large air compressors, and if the MVT is used in a field laboratory, a smaller air compressor can be used to produce the lower pressures. This in turn will be more economical for those field labs. Also, using the lower load and pressure will result in less wear and tear on the MVT.

For the field experiments of this study, three different field mixes were compared for rutting susceptibility using the MVT and the APA. It was determined that there was a significant difference between rut depths obtained using the MVT and APA. The MVT gave an average rut depth of 2.45 mm greater than the APA. It was also determined that there is no significant difference in rutting susceptibility between HMA specimens compacted when the mix is produced and HMA specimens compacted from the same mix that has been reheated. From this study it can be seen that the MVT has potential to be used for rutting susceptibility testing in the field. More design research is needed on the

MVT to better correlate it with the APA. More research needs should also be done on a wide range of HMA mixes before it is used by states for QC/QA testing.

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