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Investigation of Proposed AASHTO Rut Test Procedure Using the Asphalt Pavement Analyzer

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Supplementary Notes

Abstract:

The Virginia Department of Transportation uses the Asphalt Pavement Analyzer with beam specimens to test and approve asphalt mixtures for rut resistance. Some agencies use cylindrical specimens that impart distinct testing advantages such as the ease of fabrication. This study attempted to develop a correlation between measurements using beams and cylindrical specimens. A secondary purpose was to locate and test mixes that had rutted in the field so that the precise laboratory criteria that define rutting could be determined.

The tentative AASHTO procedure using cylindrical specimens with 4 percent air voids provided poor correlations with the conventional beam test results. A second testing using 8 percent air voids provided a better correlation, but the testing of cylindrical specimens was more variable than the testing of beam specimens. Therefore, the researchers recommended that VDOT continue testing beam specimens for approval and research. Correlations were developed that will allow the automated system of rut measurement to be used for future testing. VDOT pavements were found to develop negligible rutting, so the attempt to identify failed sections and ultimately failure criteria were not successful.

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(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

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ABSTRACT

The Virginia Department of Transportation uses the Asphalt Pavement Analyzer with beam specimens to test and approve asphalt mixtures for rut resistance. Some agencies use cylindrical specimens that impart distinct testing advantages such as the ease of fabrication. This study attempted to develop a correlation between measurements using beams and cylindrical specimens. A secondary purpose was to locate and test mixes that had rutted in the field so that the precise laboratory criteria that define rutting could be determined.

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INTRODUCTION

Superpave, the asphalt mix design procedure adopted by the Virginia Department of Transportation (VDOT) and most other states in the late 1990s was designed to consist of a volumetric design procedure accompanied by a performance test(s). The gyratory compaction process that has been in use provides volumetric information used to indicate the general acceptability of a mix. However, a test that indicates the potential performance of a mix in terms of rutting, durability, etc., was not ready when the initial recommendations were made by the contractors and expert task groups of the Strategic Highway Research Program.

Rutting, also known as permanent deformation, can be defined as the accumulation of small amounts of unrecoverable strains as a result of applied loading to a pavement.[1] Rutting occurs when the pavement under traffic loading consolidates and/or there is a lateral movement of the hot-mix asphalt (HMA). The lateral movement is a shear failure and generally occurs in the upper portion of the pavement surface. As a result of rutting, the pavement service life is reduced. If the rutting depth is significant, water may accumulate in the rutted area, which can lead to vehicle hydroplaning.

The three constituents of HMA are aggregate, binder, and air. All three can have an effect on rutting of an HMA pavement. Aggregate makes up about 90 percent of a dense-graded HMA. The shape and texture of the aggregate can influence the performance of the mixture. In general, a rough-textured cubical-shaped aggregate performs better than a smooth, rounded aggregate. The rougher texture and cubical shape aid in providing aggregate interlock. This aggregate interlock reduces the potential for rutting as movement of the aggregate under loading is reduced by the interlocking mechanism. The binder is also an important factor in rutting. At higher temperatures, the asphalt binder becomes less viscous. This lower viscosity produces a less stiff pavement that can be susceptible to lateral movement attributable to traffic loads. Compaction during construction is a vital part of producing a more durable pavement. The final constituent is air. If a mixture has a high air content, it can be susceptible to rutting in the sense that it will compact more under traffic loading. However, if the air content is too low, there is probably too much binder in the mixture. Too much binder produces a less stiff pavement and increases the probability of rutting (R.C. Williams, D. Hill, and M.P. Rottermond, unpublished data).

Other factors that influence rutting in HMA pavements include truck speed, contact pressure, HMA layer thickness, and truck wheel wander. As truck speeds are decreased on an HMA pavement, the stresses are increased because of longer pavement contact times. These higher stresses increase the probability of rutting. The contact pressure also influences the performance of the pavement. Higher tire pressures create higher stresses in the pavement. A thicker HMA layer is better able to resist rutting in the sense that the layer is usually stiffer. Finally, truck wheel wander can influence rutting. The increase in wheel wander can increase the amount and distance of lateral movement in the pavement. Excessive wheel wander has the potential to create wider and possibly deeper ruts in an HMA pavement.

Rutting can also manifest because of a poor pavement subgrade. Two of the causes of a weak subgrade are moisture and poor compaction during construction. A weakened subgrade is susceptible to higher stresses attributable to traffic loading; thus, there is an increased probability of rutting in the pavement.

Prior to Superpave, one of the major pavement distresses was rutting; therefore, it is logical to include an available empirical performance test to ensure that rutting will not occur. The asphalt pavement analyzer (APA) patterned after the Georgia loaded-wheel tester (GLWT) can be used to check rutting resistance of an asphalt mixture. It is an upgraded version of the GLWT and is being used by many state agencies to check for rutting susceptibility during mix design and production. Twenty-one agencies that use the device were represented at an APA Users Group meeting in 2000 (R.C. Williams, D. Hill, and J. Barak, unpublished data). The APA applies repetitive linear loads to compacted beam or cylindrical specimens through pressurized hoses and wheels at a specified test temperature. Although the APA has been used in research studies and mix approval, there is no universally accepted test procedure.

NCHRP Project 9-17 has conducted an evaluation of the APA that recommended a test method and criteria, but as indicated in the final report, those criteria will have to be adjusted by the states based on experience with their mixes, traffic, and climatic conditions.[1] Minnesota is currently engaged in a study to develop an APA rut test procedure for evaluating mixes in Minnesota.[2] The study will use several representative Minnesota DOT mixes to investigate the effect of mix and component properties on rutting, establish failure criteria, and develop a relationship between APA rut depth and dynamic modulus.

The Virginia Transportation Research Council (VTRC) developed an early rut test procedure with criteria that has been used in Virginia to check certain mixes for rutting resistance.[3] Criteria were based on testing of pre-Superpave mixes that had performed satisfactorily; therefore, the level of laboratory rutting that produced failure in the field was not identified. There was some indication from comparison of the WesTrack rutting and samples from the track that were tested in the APA that the criteria were reasonable. In addition, the current rut test has seldom indicated rutting susceptibility, which could mean that the rut test criteria are too conservative or mixes are generally designed on the extremely dry side of optimum asphalt. Therefore, there is a need to establish the laboratory rutting value at which rutting occurs in the field.

A previous study[4] indicated that current Superpave mixes can tolerate additional asphalt to enhance durability but rutting resistance should be checked. A rutting performance test will allow mix designs to be optimized to include the appropriate amount of asphalt binder. Tentative procedures that are based on input from many users are being prepared in an AASHTO and ASTM format, which will be adopted through the normal balloting procedures. The draft procedures are not anticipated to change significantly through the balloting process except possibly for wheel load and hose pressure, which is discussed later.

A reason to use the AASHTO procedure is that it uses cylindrical specimens prepared in the gyratory compactor as opposed to the current procedure that uses beam specimens, which are more difficult to make. By using cylindrical specimens, more VDOT laboratories could use the test. VDOT also desires to follow national standards when possible, and VDOT's current procedure has several features that differ significantly from the proposed procedures. Therefore, there is a need to investigate the AASHTO method for use by VDOT and establish appropriate failure criteria. Although a tentative procedure similar to the AASHTO procedure and criteria were developed under NCHRP Project 9-17, it was recommended that the method be adapted to local state conditions.[1]

The 2005 APA Users Group meeting indicated that of the 41 states that responded to a survey by the South Carolina DOT, 12 states have a loaded-wheel tester specification (9-APA, 2-Hamburg, and 1-APA or Hamburg). Nineteen states use the APA for research.

METHODS

General

Virginia has a laboratory rut test procedure and acceptance criteria using the APA with beam specimens. In order to use cylindrical specimens for acceptance, a correlation needed to be made between test results performed using beam specimens with the VDOT procedure and cylindrical specimens using the recommended AASHTO procedure. In 2004, surface mixes were collected for testing using the Virginia beam tests and test conditions being recommended for the cylindrical specimens at that time. Analysis of the data revealed a narrow range of rut depths for the cylindrical specimens indicating possibly that the testing conditions needed to be modified to achieve a wider range of rut depths and a better correlation. After some discussion, the project advisory panel recommended that additional mixes be sampled during 2005, the cylindrical specimens be compacted to 8 percent instead of 4 percent air voids, and possibly a small amount of asphalt binder be added to some of the samples to achieve greater rut depths. Therefore, two sets of data are presented that represent tests performed under different conditions for samples taken during 2004 and 2005.

Rut depth was originally measured manually by hand with the older model APA, but both VDOT APA test devices have been upgraded to record rut depth automatically. Since the criteria developed for VDOT in an earlier study were developed from manual measurements, the relation to automated measurements is necessary if the automated measurements are to be used in the future for mix approval. This study provided data to allow a correlation between the manual and automated rut depths.

Another objective of this investigation was to identify some mixes that had rutted under traffic in order to verify the failure criteria presently being used in Virginia. These criteria were developed by testing mixes that were being produced with acceptable performance and applying a variability allowance. Field engineers were contacted, and existing field survey data were examined. If rutted pavements could be located , laboratory rut tests would be performed on the materials used in the pavements.

Materials

All mixes tested were sampled from field projects and are listed in Table 1. The samples were taken from eight of the VDOT's nine districts in 2004 and six districts in 2005 representing a wide range of aggregates, asphalt binders, and mix designs. All 19 mixes tested in 2004 were 9.5 mm nominal size; of the 10 mixes tested in 2005, 7 were 9.5 mm nominal size and 3 were 12.5 mm nominal size. All mixes tested in 2004 were *A* mixes; 5 mixes tested in 2005 were *A* mixes and 5 were *D* mixes. *A* mixes were designed with 65 gyrations and had PG 64-22 binder, and *D* mixes were designed with 65 gyrations and had PG 70-22 binder.

All mixes were tested without modification; however, tests were also performed on the mixes sampled during 2005 after the addition of 1 percent of asphalt binder. The binder was added in the laboratory during sample preparation prior to compaction, and care was taken to help ensure the binder was uniformly distributed.

Table 1. Mixes Sampled

Year	Mix Type	Number of Mixes
2004	SM 9.5A	19
2005	SM 9.5A	4
	SM 9.5D	3
	SM 12.5A	1
	SM 12.5D	2

Tests

Rut Test: Beams

Virginia Test Method 110, Method of Test for Determining Rutting Susceptibility Using the Asphalt Pavement Analyzer, was used to test the beam specimens (Figure 1). The APA tests three beams at one time under a controlled temperature for 8,000 cycles. The load is applied to the beam through a pressurized hose in contact with a concave steel wheel. The test conditions are listed in Table 2. The tests performed with the GLWT and early versions of the APA required that rutting measurements be taken by hand. Subsequently, the developers of the APA

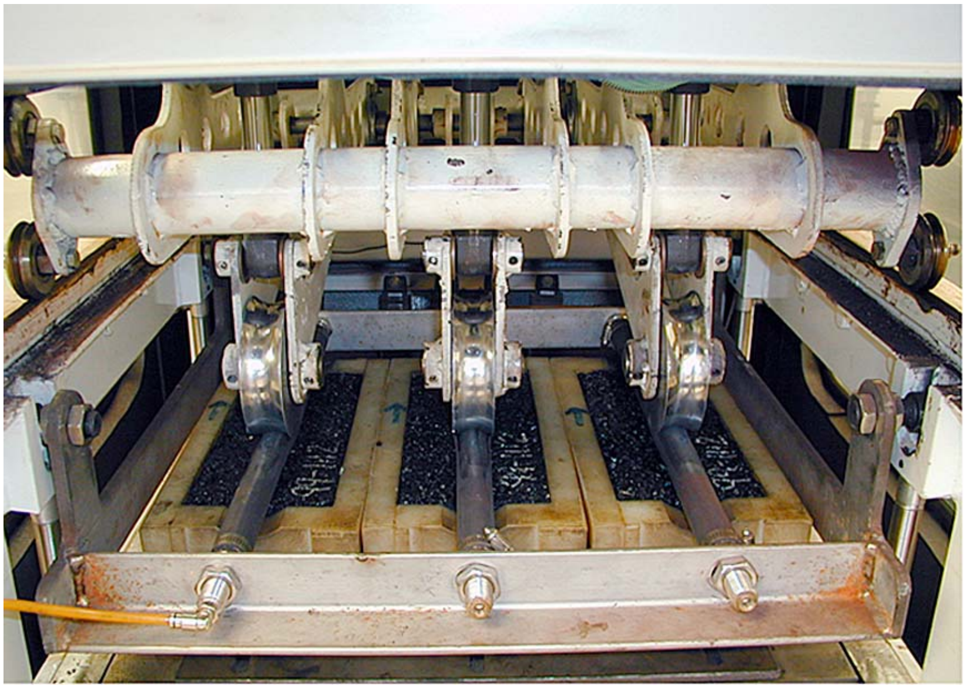

Figure 1. APA Performing Rut Tests

Table 2. Testing Conditions

Test Parameter	Beams	Cylinders	
	2004 and 2005	**2004**	**2005**
Test temperature, C (°F)	49 (120)	64 (147)	64 (147)
Hose pressure, kPa (psi)	827 (120)	827 (120)	827 (120)
Wheel load, N (lb-f)	534 (120)	534 (120)	534 (120)
Air void content, %	8	4	8
Specimen size, mm (in)	75 x 125 x 300 (3 x 5 x 12)	75 x 150 diameter (3 x 6 diameter)	75 x 150 diameter (3 x 6 diameter)

have made available a device upgrade that allows automatic recording of the rutting. The APA used in this experiment used the upgrade to measure rutting automatically, but hand measurements were also conducted. Hand measurements were made at five locations along the length of the beam.

Rut Test: Cylinders

The tentative version of the AASHTO method using cylinders recommended 689 kPa (100 psi) and 445 N (100 lb-f), respectively, for the hose pressure and wheel load. However, since the pressure and load used in the development of the AASHTO method through NCHRP Project 9-17 used the pressure and wheel load listed in Table 2, those parameters were used in the experiment. It was also believed that these conditions presented a better chance of obtaining a reasonable range of rut depths. The use of 4 percent voids offered a future possibility of using gyratory specimens that are routinely used to determine volumetric properties for quality control/quality assurance. Subsequently, tests were also performed on specimens at 8 percent voids when the tests at 4 percent voids did not yield much rutting. Rutting was measured both automatically and by hand.

RESULTS

Mixes Collected During 2004

Correlations that were developed for various combinations of specimen type and type of measurement (hand and automatic) are shown in Table 3. Although the hand measurements were recorded at five longitudinal locations along the beam, the correlations also were developed using only the three points near the center of the beam since these points were used in the development of Virginia's current rutting criteria.

The correlation of beam rutting to cylinder rutting was poor using hand measurements at three or five points and also using automatic measurements. Examination of the plot in Figure 2 revealed a narrow range of rutting for the cylinders of 1 to 3 mm, which undoubtedly contributed to the poor correlation. The test results for the beams indicated a wider range of rutting of approximately 2 to 10 mm. When the poor correlations and narrow range of rutting for the cylindrical specimens were discovered, advice was sought from members of the project panel, and the panel recommended that some tests be redone using higher air voids for the cylindrical specimens.

Table 3. Correlations for Data Combinations (2004)

Description	Equation	R^2 Value
5 point		
Beam (hand) vs. cylinder (hand)	y = 0.1701x + 1.6496	0.299
Beam (auto) vs. cylinder (auto)	y = 0.132x + 1.5454	0.2484
Beam (hand) vs. beam (auto)	y = 0.9569x + 0.0521	0.9684
Cylinder (hand) vs. cylinder (auto)	y = 0.7834x + 0.2324	0.8957
3 Point		
Beam (hand) vs. cylinder (hand)	y = 0.1584x + 1.688	0.2955
Beam (auto) vs. cylinder (auto)	y = 0.132x + 1.5454	0.2484
Beam (hand) vs. beam (auto)	y = 0.9005x + 0.23	0.9776
Cylinder (hand) vs. cylinder (auto)	y = 0.7834x + 0.2324	0.8957

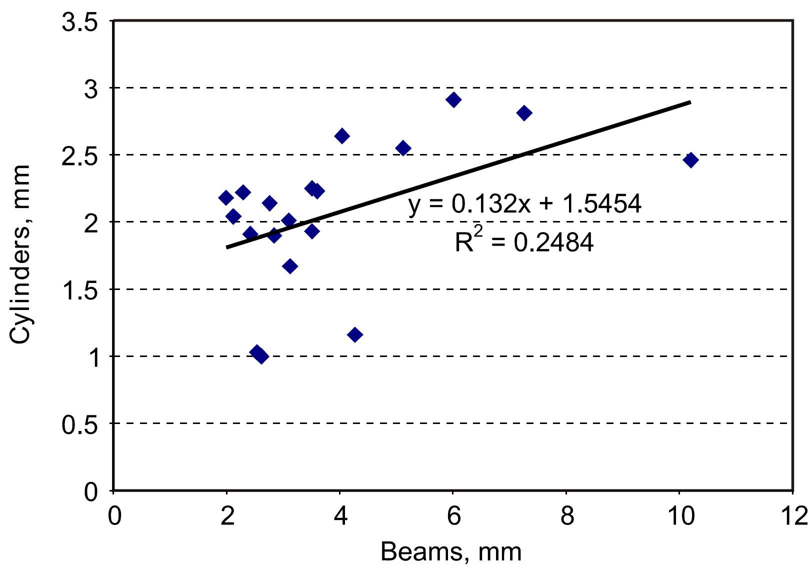

Figure 2. Rutting of Beams vs. Cylinders Using Automation for 2004 Mixes

The correlations for the hand versus automated rutting measurements were very good for both beams and cylinders, although R^2 values were higher for the beams. Better correlations for the beams between hand and automated measurements indicate that the variability was less for test results for beams than for the test results for cylinders. The variables that might have caused the differential variability between methods were specimen geometry, confinement within the mold, and length of measurement. Figure 3 illustrates that the relationship between hand and automated measurements was approximately 1:1; however, the automated values were slightly less. These results are logical since the automated method averaged the points along the full length of the beam and the hand measurements were made at the three points near the center of the beam, which may tend to have the highest rut depths along the length of the beam.

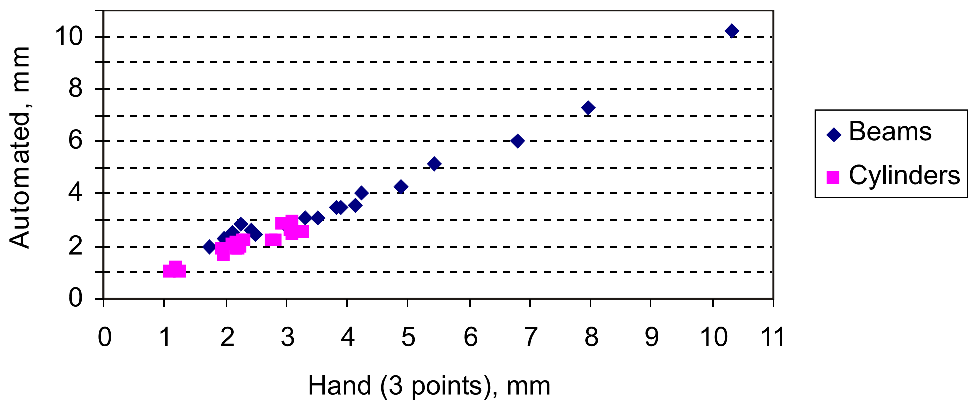

Figure 3. Hand vs. Automated Rut Measurements for 2004 Mixes

Mixes Collected During 2005

As discussed, the researchers decided to sample and test additional mixes when the correlations between rut depths of the beams and cylinders were found to be very poor for the mixes collected during 2004. Ten mixes were sampled as indicated in Table 1. The target air void content of cylinders was increased from the 4 percent used in earlier tests to 8 percent. Beam rut tests were performed on all of the mixes, but tests on cylindrical specimens could be performed on only six of the mixes because of an insufficient quantity of material.

Examination of Table 4 shows much better correlation between test results for beams and cylinders than was obtained for mixes sampled in 2004, even though only six mixes were analyzed. Hand measurements gave a slightly better correlation, although the difference might not have been significant. Figure 4 shows that the rutting range for the tests for cylinders was approximately 2 to 5 mm compared to a range of 1 to 3 mm obtained with the mixes tested earlier with 4 percent air voids. The increase in air voids seemed to give better differentiation in rutting. The rut depth of beams was progressively larger than the rut depth of cylinders as the total rut depth increased above 3. As anticipated, the addition of 1 percent of asphalt increased the rut depth considerably for both the cylinders and beams (Figure 5). It is evident that most of the mixes would not tolerate as much as 1 percent additional asphalt.

Table 4. Correlations for Data Combinations (2005)

Description	Equation	R^2 Value
5 point		
Beam (hand) vs. cylinder (hand)	y = 0.3589x + 2.8845	0.8382
Beam (auto) vs. cylinder (auto)	y = 0.3521x + 1.9901	0.7106
Beam (hand) vs. beam (auto)	y = 0.8048x + 1.1974	0.9829
Cylinder (hand) vs. cylinder (auto)	y = 0.4933x + 4.283	0.7667
3 Point		
Beam (hand) vs. cylinder (hand)	y = 0.3533x + 3.0202	0.8088
Beam (auto) vs. cylinder (auto)	y = 0.3544x + 1.9737	0.7081
Beam (hand) vs. beam (auto)	y = 0.7799x + 1.5613	0.9796
Cylinder (hand) vs. cylinder (auto)	y = 0.4355x + 4.7019	0.7837

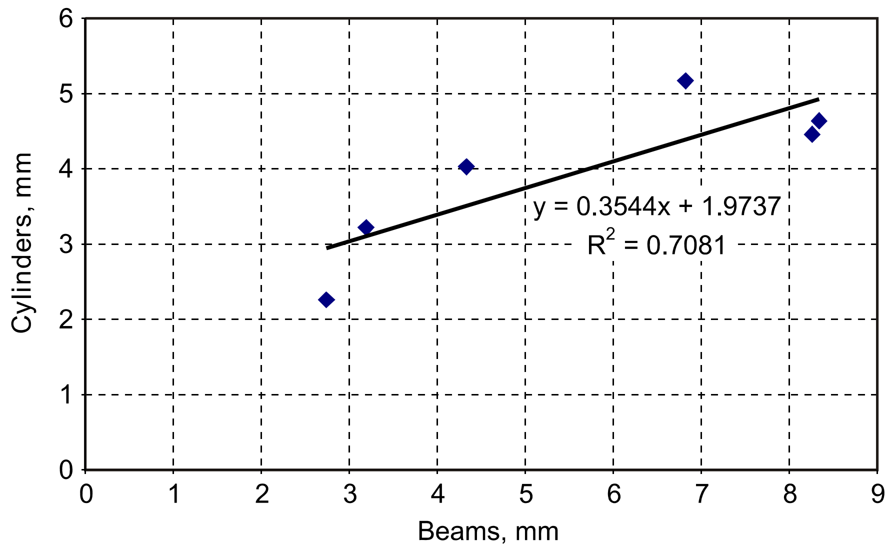

Figure 4. Beams (3 point) vs. Cylinders (Automatic) Rut Measurements for 2005 Mixes

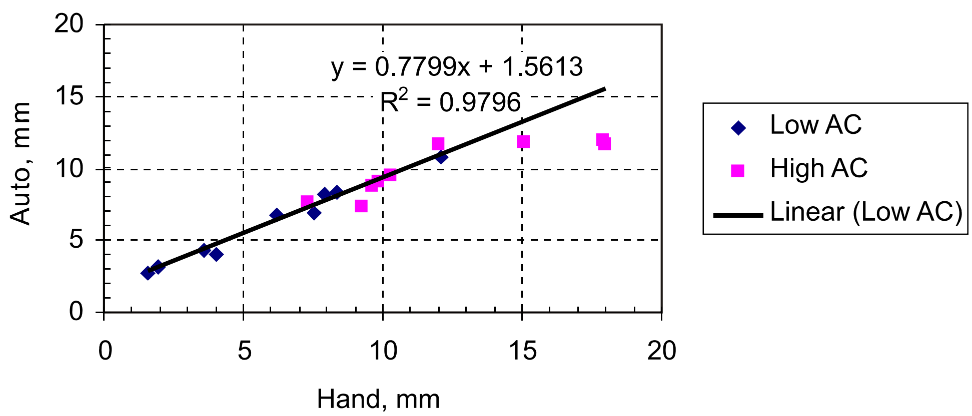

Figure 5. Hand vs. Automated Rut Measurements for 2005 Mixes

The correlations of hand vs. automated measurements were very good for both beams and cylinders, although the R^2 values were higher for the beams. The relationship was approximately 1:1 (Figure 5); however, several points at high rut depths for the hand measurements did not show corresponding high values for the automated measurements. Perhaps the short rut path for the 150-mm-diameter cylindrical specimens does not allow the potential rut depth to develop as fully as it does in the 300-mm-long beam specimens.

Identification and Testing of Rutted Pavement

An attempt was made to locate pavement sections that exhibited moderate to severe rutting. District personnel that were knowledgeable about the pavement condition in their district were contacted, and the database containing routine pavement quality results was examined. Only one incident of rutting was reported. The mix contained excessive asphalt, and the rutting involved a short length of pavement near an intersection where the traffic was difficult to quantify. Although some pavement samples were taken initially, the difficulty in considering the effects of traffic made the usefulness of the information doubtful. The statewide database of primary and interstate routes was also examined for significant levels of rutting with negative results. Therefore, efforts were not successful to link field rutting to laboratory testing.

DISCUSSION

When air voids of the cylinders was increased from 4 to 8 percent, there was a reasonable correlation between rut depths measured with beams compared to rut depths measured with cylinders. Testing of cylinders could be used to predict rutting susceptibility. However, even though the simpler cylindrical testing would be possible, beam testing is still preferable because of its lower variability.

Excellent correlations were developed between measurements taken by hand at the three points near the beam’s center and automated measurements. Since the two APAs used by VDOT were upgraded to use automated measurements, using the automated measurements for research and routine approval/forensic testing would be preferable. The correlations developed in this study were used to convert the acceptance criteria currently in effect for VDOT (see Table 5). The conversions from 2004 mix data are possibly more accurate because more mixes were used in the correlation than from the 2005 mixes. As explained previously, it is logical that the automated measurements should be slightly less than measurements done by hand, which mirrors the converted criteria from testing of the 2004 mixes.

Table 5. Conversion of Acceptance Criteria from Correlations

Current 3-point Beam	Automated: 2004 Mix Correlation	Automated: 2005 Mix Correlation
3.5	3.4	4.3
5.5	5.2	5.8
7.0	6.5	7.0
2004 correlation: Automated = 0.9005 (3-point beam) + 0.23		
2005 correlation: Automated = 0.7799 (3-point beam) + 1.56		

CONCLUSIONS

- Correlations between rut test results using beams and cylindrical specimens for the mixes tested at 4 percent air voids were poor.
- Correlations between rut test results using beams and cylindrical specimens for mixes tested using 8 percent air voids were fair.
- Test results for cylindrical specimens were more variable than test results for beam specimens.
- An excellent correlation was obtained between manual rut depth measurements and automated measurements, allowing the automated system to be used for approval and research purposes in the future.
- Lack of statewide field rutting prevented determination of lab rutting values that coincide with field rutting.

RECOMMENDATIONS

1. VTRC and the VDOT Materials Laboratory should retain testing of beam specimens for approval/evaluation of rutting with the APA.
2. VTRC and the VDOT Materials Laboratory should use the automated system for rut depth measurement on the APA.
3. If rutting appears in pavements, VTRC should collect mix data with the APA and retain them in a database to help identify laboratory criteria for failure in the future.

COSTS AND BENEFITS ASSESEMENT

If the results of the study had been positive, the simplified testing would have made implementing more rut testing at local VDOT laboratories possible. Local rut testing would have allowed more risk to be taken in an attempt to incorporate design changes in asphalt mixes to increase durability, which would have likely affected the cost-benefit analysis of mixes. Since the results indicated that beam specimens that are more difficult to fabricate were preferable to cylindrical specimens, a change was not realized.

A positive result of the study was that a correlation was developed that allows the automated testing method to be used, which will help free up laboratory time for other testing. Both VDOT labs that have the APA equipment have automated measurement capability.

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APPENDIX A
Rut Depth Results for 2004 Mixes

Mix ID	Beam (hand), mm*	Cylinder (hand), mm	Beam (automatic), mm	Cylinder (automatic), mm
04-1073	2.48	1.95	2.42	1.91
04-1074	4.13	2.28	3.60	2.23
04-1078	3.52	2.25	3.10	2.01
04-1079	3.33	1.98	3.12	1.67
04-1080	4.88	1.19	4.27	1.16
04-1081	3.01	2.18	2.76	2.14
04-1082	1.98	2.33	2.29	2.22
04-1085	6.81	3.12	6.01	2.91
04-1086	2.27	2.20	2.84	1.90
04-1090	3.83	2.84	3.51	2.25
04-1091	1.73	2.76	1.99	2.18
04-1092	4.24	3.09	4.04	2.64
04-1093	2.17	2.11	2.12	2.04
04-1096	3.89	2.22	3.51	1.93
04-1098	10.31	3.10	10.20	2.46
04-1099	5.44	3.28	5.12	2.55
04-1100	2.44	1.28	2.61	1.00
04-1118	7.97	2.94	7.26	2.81
04-1123	2.13	1.10	2.54	1.03
Average	4.03	2.33	3.86	2.05

*Hand measurements made at three points near center of beam length.

APPENDIX B
Rut Depth Results for 2005 Mixes

Mix ID	No Additional AC		1% Additional AC			
	Beam (hand), mm	Beam (automatic), mm	Beam (hand), mm	Beam (automatic), mm	Cylinder (hand), mm	Cylinder (automatic), mm
05-1035	1.60	2.74	9.28	7.38	3.05	2.26
05-1036	1.93	3.19	15.04	11.85	3.91	3.22
05-1057	6.19	6.82	9.87	9.08	6.00	5.17
05-1064	8.33	8.34	17.94	11.99	5.87	4.64
05-1065	7.88	8.26	12.04	11.65	5.26	4.46
05-1067	3.56	4.33	9.66	8.76	4.45	4.03
05-1041	1.93	3.19	15.04	11.85	----	----
05-1047	7.54	6.94	10.31	9.47	----	----
05-1051	12.09	10.72	17.98	11.62	----	----