2005

Evaluation of Superpave mixtures in West Virginia using the asphalt pavement analyzer

Gabriel E. Patino
West Virginia University

Follow this and additional works at: <https://researchrepository.wvu.edu/etd>

Recommended Citation

Patino, Gabriel E., "Evaluation of Superpave mixtures in West Virginia using the asphalt pavement analyzer" (2005). *Graduate Theses, Dissertations, and Problem Reports*. 1613.
<https://researchrepository.wvu.edu/etd/1613>

This Thesis is protected by copyright and/or related rights. It has been brought to you by the The Research Repository @ WVU with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you must obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/ or on the work itself. This Thesis has been accepted for inclusion in WVU Graduate Theses, Dissertations, and Problem Reports collection by an authorized administrator of The Research Repository @ WVU. For more information, please contact researchrepository@mail.wvu.edu.

**EVALUATION OF SUPERPAVE MIXTURES IN
WEST VIRGINIA USING THE ASPHALT PAVEMENT ANALYZER**

By

Gabriel E. Patino

**Thesis submitted to the
College of Engineering and Mineral Resources
At West Virginia University
in partial fulfillment of the requirements
for the degree of:**

Master of Science

In

Civil Engineering

John P. Zaniewski, Ph.D., PE Chair

David R. Martinelli, Ph.D.

Ronald W. Eck, Ph.D., PE

Department of Civil and Environmental Engineering

Morgantown, West Virginia

2005

**Keywords: Asphalt Pavement Analyzer, Pavement Condition Survey, Rutting,
Superpave.**

ABSTRACT

EVALUATION OF SUPERPAVE MIXTURES IN WEST VIRGINIA USING THE ASPHALT PAVEMENT ANALYZER

Gabriel E. Patino

The Superpave mix design method is widely implemented in the United States. Fundamental tests have been developed to assess a pavement's distress; however, those tests are time-consuming and require special equipment. Simpler tests, such as wheel tracking devices, have been developed. The most common is the Asphalt Pavement Analyzer, APA, a loaded wheel tester method to evaluate rutting, moisture susceptibility, and fatigue cracking.

This research focused on establishing whether there are relationships between the APA rutting potential and field performance. The APA was used to measure the rutting potential of Superpave mixes constructed throughout the state. Then the WVDOH provided rutting data from their pavement condition database. Comparison between the laboratory rutting potential and the field results was established. The APA test results indicate the Superpave mixes used in the state are not rut susceptible. The field data verifies that pavements constructed with Superpave mixes are not rutting.

ACKNOWLEDGMENTS

I would like to express my gratitude to Dr. John P. Zaniwski, chair of this project, for his guidance throughout the research development and thesis writing process. Without his invaluable support and constructive criticisms, this work would not have been completed. I would also like to express my gratefulness to Dr. David R. Martinelli, member of my committee, for all his encouragement, guidance, and time during my entire academic formation at the Civil and Environmental Engineering Department in West Virginia University. Likewise, I extend my thankfulness to Dr. Ronald W. Eck, member of my committee, for all his guidance and precious time. Additionally, I would like to thank Dr. George Seidel for all his assistance with the statistical analysis.

Special thanks to Andy Kincell from the Asphalt Technology Laboratory at WVU, Stuart Grove from the Division of Materials of the WVDOT, Mr. Norm Roush, Deputy Commissioner WVDOT for providing the ARAN database, to the Division of Highways of the WVDOT, sponsor of this research, and all the material supply companies that contributed materials to this effort.

Finally, I would like to show my gratitude to my dad, Gabriel Roberto, and my grand parents, Gabriel de J (RIP) and Teresa, for their unconditional love and support throughout my life and college career. Likewise, I would also like to express my appreciation to my Mom, Gladys Amanda, to my Brother, Jaime Orlando, and; in general, to my whole family in Colombia and in the US, for all their love and support during my life.

TABLE OF CONTENTS

ABSTRACT.....	ii
ACKNOWLEDGMENTS	iii
TABLE OF CONTENTS.....	iv
LIST OF TABLES.....	vii
LIST OF FIGURES	ix
CHAPTER 1 INTRODUCTION	1
1.1 Introduction.....	1
1.2 Problem Statement.....	2
1.3 Objectives	3
1.4 Research Approach	3
1.5 Scope and Limitations.....	3
1.6 Thesis Overview	4
CHAPTER 2 LITERATURE REVIEW	5
2.1 Introduction.....	5
2.2 Rutting.....	6
2.3 Asphalt Pavement Analyzer.....	6
2.4 Evaluation of Rutting Potential Using the APA	10
2.4.1 Temperature Effect Model.....	10
2.4.2 Comparison of APA to WesTrack	12
2.4.3 VDOT Development of APA Limits for Mix Evaluation.....	13
2.4.4 TDOT Application of APA for Mixture Screening	15
2.4.5 FDOT Evaluation of APA Testing Parameters.....	17
2.4.6 NCAT Application of APA to Evaluate Mix Design Parameters.....	22
2.4.7 NCAT Recommendations for Rutting Potential Evaluation	27

2.4.8 SCDOT Parametric Study of Mix Design Parameters	29
2.4.9 ORITE Evaluation of Loaded Wheel Tests	32
2.4.10 NCAT Comparison of Simulative and Fundamental Tests.....	36
2.4.11 NCAT Evaluation of Aggregate Gradations.....	39
2.4.12 FDOT Evaluation of Effect of Binder on Rutting Potential.....	42
2.4.13 NCAT Evaluation of APA Test Parameters and Configuration	43
2.5 Summary Rutting–APA Literature Review	53
2.5.1 Summary of APA Test Parameters	53
2.5.2 Summary of APA Evaluation of Mix Parameters.....	57
2.6 Automatic Road Analyzer in West Virginia	59
CHAPTER 3 RESEARCH METHODOLOGY	63
3.1 Introduction.....	63
3.2 Phase I Laboratory Data Collection and Analysis	63
3.3 Phase II Field Data Collection and Analysis	64
CHAPTER 4 RESULTS AND ANALYSIS	69
4.1 Introduction.....	69
4.2 Analysis of the Laboratory Data	69
4.2.1 Analysis of Rutting Potential versus Air Voids	69
4.2.2 Analysis of Rutting Potential versus NMAS	75
4.2.3 Analysis of Rutting Potential vs Binder Type	77
4.3 Comparison with the Literature	78
4.4 Analysis of the Field Data-ARAN.....	86
4.5 Comparison between APA Rutting Potential and ARAN	86
CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS	91
5.1 Conclusions.....	91
5.2 Recommendations.....	92

REFERENCES	93
APPENDIX 1 Laboratory Data	100
APPENDIX 2 Field Data	108
APPENDIX 3 Statistical Analysis	115

LIST OF TABLES

Table 2.1 Original Superpave Gradation Requirements	5
Table 2.2 GDOT Mix Specifications.....	11
Table 2.3 GLWT Rutting Potential Data Used for Development of Temperature Effect Model	11
Table 2.4 FHWA-VTRC-NDOT Performance Ranking of the Field and APA	13
Table 2.5 VTRC Results of Binder Experiment.....	15
Table 2.6 UT-TDOT Test Results	16
Table 2.7 FDOT Field Rut Results.....	18
Table 2.8 FDOT APA Rutting Potential for Cylindrical Samples.....	18
Table 2.9 FDOT APA Rutting Potential for Beam Samples	19
Table 2.10 FDOT Variability of APA Rutting Potential for Cylindrical Samples	20
Table 2.11 FDOT Variability of APA Rutting Potential for Beam Samples.....	20
Table 2.12 NCAT-ALDOT APA Rutting Potential	22
Table 2.13 NCAT-ALDOT APA Rutting Potential Mean and Standard Deviation.....	24
Table 2.14 NCAT-ALDOT RSCH Shear Strength Results.....	25
Table 2.15 NCAT-ALDOT RSCSR Shear Strength Results.....	25
Table 2.16 NCAT-ALDOT APA Rutting Potential and Field Ruts.....	27
Table 2.17 NCAT Performed Test Results.....	30
Table 2.18 NCAT Tentative Criteria for Simulative Test	30
Table 2.19 SCDOT Mix Characteristics & APA Rutting Potential.....	31
Table 2.20 SCDOT APA Tentative Criteria.....	32
Table 2.21 ORITE in Cooperation with ODOT APA Rutting Potential	34
Table 2.22 ORITE-APLF Rutting Results.....	34
Table 2.23 NCAT Test Results.....	37
Table 2.24 NCAT Tentative Criteria	40
Table 2.25 NCAT Test Results.....	41
Table 2.26 FDOT APA Rutting Potential at 8000 cycles.....	42
Table 2.27 NCAT-NCHRP APA Rutting Potential of WesTrack Mixes	44

Table 2.28 NCAT-NCHRP Field Rut Results of WesTrack	45
Table 2.29 NCAT- NCHRP APA Rutting Potential of MnRoad Mixes	45
Table 2.30 NCAT-NCHRP Field Rut Results from MnRoad	45
Table 2.31 NCAT-NCHRP APA Rutting Potential of FHWA ALF Mixes	46
Table 2.32 NCAT-NCHRP Field Rut Results from FHWA ALF	46
Table 2.33 Tentative APA Criteria for Manual Rut Measurements after 10,000 Cycles	52
Table 2.34 Tentative APA Criteria for Manual Rut Measurements after 8,000 Cycles	52
Table 2.35 Summary of APA Test Procedure Parameters.....	56
Table 2.36 Summary of Mix Design Parameters.....	58
Table 3.1 Projects Included in Phase II	67
Table 4.1 West Virginia Superpave Rutting Database	70
Table 4.2 Statistical Analysis of the Rutting Potential vs. % Air Voids.....	75
Table 4.3 Statistical Analysis of the Rutting Potential vs. NMAAS	77
Table 4.4 Statistical Analysis of the Rutting Potential vs. Binder Types	78
Table 4.5 Summary of 9.5 mm Mixes from Literature Review Adjusted for Temperature	80
Table 4.6 Maximum, Minimum and Average Values for the 9.5 Mixes	81
Table 4.7 Summary of 12.5 mm Mixes from Literature Review Adjusted for Temperature	81
Table 4.8 Maximum, Minimum, and Average Values for the 12.5 Mixes	82
Table 4.9 Summary of 19 mm Mixes from Literature Review Adjusted for Temperature	83
Table 4.10 Summary of 19 mm Mixes from Literature Review Unadjusted.....	84
Table 4.11 Maximum, Minimum, and Average Values for the 19 mm Mixes Adjusted for Temperature...	84
Table 4.12 Maximum, Minimum, and Average Values for 19 mm Mixes with AC-30 and PG 70-22.....	85
Table 4.13 Comparison between APA Rutting Potential and the Field Ruts from ARAN	89

LIST OF FIGURES

Figure 2.1 Asphalt Pavement Analyzer	7
Figure 2.2 Schematic of the APA Loading Mechanism	9
Figure 2.3 APA Rutting Potential Manual Measurement	9
Figure 2.4 FDOT APA and GLWT Rutting Potential	21
Figure 2.5 FDOT APA Rutting Potential Beam and Cylindrical Samples	21
Figure 2.6 APA Rutting Potential vs. RSCH Test Results 12.5 mm PG 64-22	26
Figure 2.7 APA Rutting Potential vs. RSCH Test Results 19.5 mm PG 64-22	26
Figure 2.8 APA Rutting Potential vs. RSCSR Test Results 12.5 mm PG 64-22	26
Figure 2.9 APA Rutting Potential vs. RSCSR Test Results 19.5 mm PG 64-22	27
Figure 2.10 Results of APA Test on Plant Mixes & Comparison with ORITE-APLF Test Results	35
Figure 2.11 Correlations between APA, RSCH, and RLCC	38
Figure 2.12 NCAT Graphic of Tentative Criteria	40
Figure 2.13 NCAT-NCHRP Effects of Air Voids on APA Rutting Potential	48
Figure 2.14 NCAT-NCHRP Effects of Test Temperature on APA Rutting Potential	48
Figure 2.15 NCAT-NCHRP Effects of Hose Diameter on APA Rutting Potential	49
Figure 2.16 NCAT-NCHRP Effects of Sample Type on APA Rutting Potential	49
Figure 2.17 NCAT-NCHRP Selected Combination 4PGSC	51
Figure 2.18 NCAT-NCHRP Selected Combination 5PGSB	51
Figure 2.19 NCAT-NCHRP APA Ruts versus Field Ruts NDOT	54
Figure 2.20 NCAT-NCHRP APA Ruts versus Field Ruts NCAT	54
Figure 2.21 Comparisons between Laboratory (4PGSC) and Field Ruts Phase II and III	55
Figure 2.22 Comparisons between Laboratory (5PGSB) and Field Ruts Phase II and III	55
Figure 2.23 Automatic Road Analyzer	60
Figure 3.1 APA Data Sheet	65
Figure 3.2 Field Data Collection and Analysis	66
Figure 4.1 Laboratory Data and Their Averages	72
Figure 4.2 Rutting Potential versus % Air Voids for the 9.5 mm Mixes	73

Figure 4.3 Rutting Potential versus % Air Voids for the 12.5 mm PG 76-22 Mixes.....	73
Figure 4.4 Rutting Potential versus % Air Voids for the 19 mm Mixes.....	74
Figure 4.5 Rutting Potential versus % Air Voids for the 37.5 mm Mixes.....	74
Figure 4.6 Rutting Potential versus NMAS for all Mixes	76
Figure 4.7 Rutting Potential versus Binder Type	77
Figure 4.8 Comparisons between the 9.5 mm Mixes	81
Figure 4.9 Comparisons between the 12.5 mm Mixes	82
Figure 4.10 Comparisons between the 19 mm Projects Adjusted for Temperature	84
Figure 4.11 Comparisons between the 19 mm Mixes with AC-30 and PG 70-22.....	85
Figure 4.12 Field Ruts of the West Virginia Projects per Year	87
Figure 4.13 Comparison between the APA Rutting Potential and the Field Ruts from ARAN	88

CHAPTER 1 INTRODUCTION

1.1 Introduction

In the early 1980s, increases in traffic, higher tire pressures, and heavier axle loads in the United States contributed to the need for the development of an improved mix design for various traffic volumes, loads, and environmental conditions (Roberts, et al., 1996). In the late 1980s, the Congress of the United States funded the Strategic Highway Research Program (SHRP) with the aim of achieving improved pavement performance (Roberts, et al., 1996). One of the areas of the study was dedicated to asphalt binder specifications and mixture design methods.

In 1993, the Strategic Highway Research Program was completed. A new mix design procedure was introduced along with a new performance grading system for asphalt binders (PG), and consensus properties for aggregates (Roberts, et al., 1996). The system is known as the Superior Performing Asphalt Pavement System (Superpave), and has been adopted by most states in the United States and provinces in Canada (Bouldin and Dongre, 2002; Zang, et al., 2002; and Kandhal and Cooley, 2003).

Federal Agencies, State Departments of Transportation (SDOTs), universities, and private industry have conducted several studies to identify alternatives that prevent distress, and achieve pavements with more traffic load resistance and durability at lower costs. Different fundamental tests have been developed to analyze the pavements distress; however, those tests are time consuming and require special equipment. Moreover, the fundamental tests were not planned for quality control or quality acceptance purposes. Therefore, the public and the private sectors have been working on the development of simpler and quicker tests for use during hot mix asphalt (HMA) design and production, as well as pavement construction (Kandhal and Cooley, 2003).

Originally, Superpave included methods to evaluate the rutting potential of the HMA. However, due to the cost and complexity of the test equipment, this method has not been widely accepted. Alternatively, many States, which have implemented the Superpave design in their highways, are using loaded wheel testers to evaluate rutting potential. Numerous simulators have been designed to test the susceptibility of the HMA not only for rutting, but also for fatigue cracking and moisture susceptibility, including:

the French Rutting Tester, FRT, the Hamburg Loaded Wheel Tester , HLWT, from Germany, and the Asphalt Pavement Analyzer, APA, the most recent version of the Georgia Loaded Wheel Tester, GLWT, from America. Of these, the APA has been widely used by different DOTs and universities in the nation, and has become the most accepted simulative test (Minnesota DOT, 2003).

The Asphalt Pavement Analyzer is considered a simple method to evaluate rutting, fatigue cracking and moisture susceptibility of mixtures; although, the APA test results does not reflect any fundamental property of the mixtures tested (Kandhal and Cooley, 2003). The relationship between field performance and APA test results involves specific factors or parameters such as aggregate properties, binder grade, mix design type, construction quality, traffic level, and traffic speed.

This thesis presents the results of a laboratory evaluation of the APA rutting potential of Superpave mixes constructed throughout West Virginia. As projects were constructed by different state contactors, samples were collected and delivered to the Asphalt Technology Laboratory of West Virginia University where they were tested with the APA. Samples were collected from 8 districts of the West Virginia Division of Highways, WVDOH, from 29 projects, with a total of 46 different mixes being evaluated. The WVDOH supplied data on the field performance of the projects. Project performance data were harvested from the division's pavement performance database. These data are collected by a contractor using the Automatic Road Analyzer (ARAN) system, for collecting pavement condition data. Roughness and rutting data were used for the analysis.

1.2 Problem Statement

Since the Superpave mix design system was developed under the Strategic Highway Research Program, many state highway agencies (SHAs) have implemented the volumetric mixture design method (Kandhal and Mallick, 1999; and Zhang, et al., 2002). The WVDOH has implemented the Superpave mixtures on the National Highways System projects since 1997 (Zaniewski and Diazgranados-Diaz, 2004). However, Superpave was based on volumetric properties and there were neither strength nor stability test to verify the mix designs (Zhang, et al., 2002). For this reason, simulative tests have been employed as supplement tests by different SHAs to assess the rutting

potential of asphalt mixtures. The problem for all researchers has been to establish whether there are relationships between the rutting potential, from the simulative tests, and the actual field performance.

1.3 Objectives

The objectives of this research project were:

- Test the rutting potential of the Superpave mix samples from the different Superpave projects of the West Virginia highway network using the Asphalt Pavement Analyzer in the Asphalt Technology Laboratory at West Virginia University.
- Generate a laboratory database based on Asphalt Pavement Analyzer tests.
- Assemble data from the West Virginia pavement performance database on the pavement sections with Superpave mixes.
- Compare the laboratory database with the field database.

1.4 Research Approach

The project was divided in two phases. Phase I was focused on the laboratory data collection. Phase II was focused on the field data collection. The Phase I was the result of testing and evaluation of Superpave hot mix samples at the Asphalt Technology Laboratory at West Virginia University using the Asphalt Pavement Analyzer. Phase II involved assembling data from the West Virginia pavement condition database. The databases from both phases were compared to determine if relationships exist between the field and the laboratory data.

1.5 Scope and Limitations

The research report herein focuses on the evaluation of the rutting potential measurements using the APA, and the field rut measurements from the Automated Road Analyzer (ARAN). Comparison was performed between the laboratory and field results to establish whether there are relationships between them, and subsequently, evaluate for APA criteria under the West Virginia requirements.

The samples tested during this program were collected from projects constructed throughout West Virginia from 1999 to 2003. These samples represent actual materials used in West Virginia during the study period. Therefore, the samples included in the research are an artifact of the construction program. As a result, it was not possible to perform an experimental design to investigate the different factors and levels which influence the rutting potential of asphalt concrete. The lack of a design experiment compromises the degree of confidence that can be associated with the conclusions from this research.

1.6 Thesis Overview

The research work was organized in five chapters and three appendices. Chapter 1 was the introduction of the report. Chapter 2 presents the literature review including a review of the Asphalt Pavement Analyzer and a review of pavement condition surveys. Chapter 3 presents the research methodology for the phase one and phase two of the project. Chapter 4 presents the results and analysis, and finally Chapter 5 presents the conclusions and recommendations. Appendices 1 and 2 present the laboratory database and field database, respectively. Appendix 3 presents the statistical results.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter presents a summary of the subjects covered in this research including rutting, the Asphalt Pavement Analyzer, and the pavement condition survey with the Automatic Road Analyzer (ARAN).

Much of the literature concerning the evaluation of the Asphalt Pavement Analyzer was performed as the Superpave mix design method was initially being implemented. This mix design method is based on volumetric evaluation of the relationships between binder, aggregate and air content. When Superpave was introduced, there was a concern that certain aggregate gradations would produce tender mixes that would be difficult for the contractor to compact. To minimize the issue with tender mixes, the researchers instituted the concept of a restricted zone in the aggregate gradations. Although the restricted zone has subsequently been removed from the gradation requirements, it was referred to in many of the projects reviewed herein. Table 2.1 shows the gradation requirements for Superpave mixes with the original restricted zone requirement (Harman et al., 2002). Aggregate gradations that pass below the restricted zone are considered coarse gradations while those that pass above the restricted zone are considered fine gradations.

Table 2.1 Original Superpave Gradation Requirements

Standard Sieve (mm)	Percent Passing Criteria (Control Points)				
	Nominal Maximum Sieve Size				
	9.5 mm	12.5 mm	19 mm	25 mm	37.5 mm
50.0					100
37.5				100	90-100
25.0			100	90-100	
19.0		100	90-100		
12.0	100	90-100			
9.50	90-100				
2.36	32-67	28-58	23-49	19-45	15-41
0.075	2.0-10.0	2.0-10.0	2.0-8.0	2.0-7.0	0.0- 6.0
Sieve	Recommended Restricted Zone				
4.75				39.5	34.7
2.36	47.2	39.1	34.6	26.8-30.8	23.3-27.3
1.18	31.6-37.6	25.6-31.6	22.3-28.3	18.1-24.1	15.5-21.5
0.60	23.5-27.5	19.1-23.1	16.7-20.7	13.6-17.6	11.7-15.7
0.30	18.7	15.5	13.7	11.4	10.0

Source: Harman, et al. 2002.

2.2 Rutting

Rutting, or permanent deformation, reduces pavement service life resulting in premature maintenance, and raising the operational cost of the highways (Jackson and Baldwin, 2000). Rutting is usually developed gradually with increasing numbers of load applications, which produce an accumulation of unrecoverable strain in the HMA. Rutting appears as permanent deformation depressions in the wheel paths (Skok, et al., 2003). Permanent deformation can develop in the pavements from different causes, including (Skok, et al., 2003, Brown, et al., 2001):

1. Repeated application of high stresses over the subgrade.
2. Inadequate pavement structures, as result of thin pavement layers and unbound materials underneath the HMA.
3. Inadequate or low shear strength allowing shear failure or lateral deformation of the HMA, and
4. Consolidation or compaction of the HMA under traffic.

The first two items are related to the traffic and pavement structure. The influence of the asphalt concrete on these mechanisms is limited to the effect of the stiffness on the structural capacity of the pavement. The last two items are directly related to the ability of the asphalt concrete to resist permanent deformation. Behavior associated with these mechanisms is related to the characteristics of the asphalt concrete that can be evaluated with the Asphalt Pavement Analyzer.

2.3 Asphalt Pavement Analyzer

The Georgia Department of Transportation (GDOT) sponsored the development of the Georgia Loaded Wheel Tester (GLWT) to evaluate the rutting potential of asphalt concrete mixes (Collins, et al., 1995). Implementation of this device required the development of specific test procedures and criteria for screening unsuitable mixes. The initial GDOT-GDT-115, Method of Test for Determining Rutting Susceptibility Using the Loaded Wheel Tester (Collins, et al., 1995), procedure indicated asphalt concrete had excessive rutting potential when the rut depths measured with the GLWT were greater

than 7.5 mm. The testing protocol specified 8,000 loading cycles at 40°C (104°F), with a wheel load of 448 N (100 lbf), and hose pressure 690 kPa (100 psi).

The Asphalt Pavement Analyzer (APA), Figure 2.1 (Kandhal and Cooley, 2002b), was developed by Pavement Technology Inc. as a commercial version of the GLWT. The APA is the result of research work of the Federal Highway Administration (FHWA) and GDOT to enhance the existing device and incorporate new features, including the ability to evaluate HMA for rutting, fatigue cracking, and moisture susceptibility (Kandhal and Cooley, 2003).

Figure 2.1 Asphalt Pavement Analyzer

The APA was designed as a tool to screen asphalt concrete mix designs with respect to rutting potential in an efficient and cost-effective manner (Skok, et al., 2003). Different state and local transportation agencies use the APA as a supplementary test to their mix design procedures. For instance, Georgia, Maryland, and Utah have incorporated pass or fail criteria for all their mixes as part of performance-based specification (Shami, et al., 1997; Skok, et al., 2003). Ohio implemented a loaded wheel test requirement for screening Superpave mixes with fine aggregates that do not satisfy the fine aggregate angularity requirements of Superpave (Item 442, ODOT

Specifications, 2002). Several states have researched the application of the APA, but implementation into the mix design requirements is lacking due to their inability to establish suitable criteria for mix screening purposes (Sargand and Kim, 2001). States, such as: Alabama, Arkansas, Florida, Illinois, Michigan, Mississippi, Nevada, North Carolina, Oregon, Oklahoma, South Carolina, South Dakota, Tennessee, and Texas, were actively pursuing evaluation of the APA as recently as 2003 (Skok, et al., 2003). The Virginia Department of Transportation Road and Bridge Specification Manual (2002) allows use of the APA to evaluate the rutting potential of mixes at the discretion of the engineer.

The APA was developed to evaluate the performance of mixes under simulated loading traffic conditions. The loading mechanism is illustrated in Figure 2.2 (Pavement Technology web site, 2005). A vertical load is transmitted from a loading wheel to the surface of the sample through a pneumatic hose. The load wheel applies repeated loads by tracking along the pneumatic hose. As shown in Figure 2.2, the temperature cabinet contains three loading mechanisms. The ability to automatically record and store results to a computer, as shown on Figure 2.2, is an upgrade feature that is not available on the APA in the WVU Asphalt Technology Laboratory.

The repetitive loading produces permanent deformation in the samples. Rutting potential is quantified by measuring the rut-depth of the samples. The rut readings are measured using either an automated data acquisition system or manually. The automated data acquisition system takes the rut depths measurements and displays them in a numeric and/or graphic format. A total of five measurements can be taken per single pass. The manual measurements are taken using a Digimatic caliper and a metal guide, which is placed on top of the sample mold (Skok, et al., 2003). Figure 2.3 (Pavement Technology web site, 2005) presents the APA manually measurement procedure.

The APA is available with three types of molds, beam rut test mold, cylindrical rut test mold, and the beam fatigue test mold. The beam specimens are 125mm wide by 300 mm long by 75 mm tall; and the cylindrical specimens are 150 mm of diameter by 75 mm tall. Commonly, the beam and cylindrical specimens are compacted using the Asphalt Vibratory Compactor (AVC) and the Superpave Gyratory Compactor (SGC), respectively.

Figure 2.2 Schematic of the APA Loading Mechanism

Figure 2.3 APA Rutting Potential Manual Measurement

When the APA was released to the market, the testing protocol called for testing at 50°C (122°F), rather than the 40°C (104°F) specified for the GLWT testing (Collins, et al., 1997). The load, tube pressure and number of repetition specifications did not change. The criteria for determining when a mix displayed excessive rutting potential were reduced to 5 mm.

2.4 Evaluation of Rutting Potential Using the APA

2.4.1 Temperature Effect Model

One of the most important testing parameters influencing rutting potential is the temperature of the mix during testing. One of the first published research reports on the application of the APA evaluated the effect of temperature and proposed a model that can be used to adjust the test results for different temperatures (Shami, et al., 1997). The initial testing protocol for using the GLWT specified a test temperature of 40°C (104°F), when the APA was introduced the test temperature was raised to 50°C (122°F) (Collins, et al., 1997).

Laboratory testing was developed to evaluate rutting potential of seven Superpave mixes. To provide data for the development of the temperature effect model, tests were conducted at 40°C (104°F), 50°C (122°F), and 60°C (140°F). Rutting potential readings were taken at 1,000, 4,000, and 8,000 load repetitions. The wheel load was 448 N (100 lbf), and the hose pressure was 690 kPa (100 psi). Beam samples were compacted using the Asphalt Vibratory Compactor to 4±1% of air voids. The Superpave mixes were 12.5 mm and 19 mm with AC-30 binder. Table 2.2 presents the mix specifications. Table 2.3 presents the GLWT rutting potential.

Regression analysis of the data in Table 2.3 was used to develop the temperature effect model given in Equation 2.1. The model essentially allows the conversion between reference conditions of rutting potential, temperature and number of repetitions to an alternate set of conditions if two of the three variables are known, i.e. rutting potential can be estimated for non-standard temperature or number of repetitions.

$$\frac{R}{R_0} = \left(\frac{T}{T_0} \right)^{2.625} \left(\frac{N}{N_0} \right)^{0.276} \quad (2.1)$$

Table 2.2 GDOT Mix Specifications

Mix Type	Aggregate Source	NMAS	Binder Type	% Asphalt Cement	% Air Voids
Mix 1	Lithia	12.5	AC-30	5.1	4.6
Mix 2	Dalton	12.5	AC-30	5.2	4.5
Mix 3	Palmer	19	AC-30	4.6	4.6
Mix 4	Buford	19	AC-30	4.6	5.0
Mix 5	Buford	12.5	AC-30	5.7	5.0
Mix 6	Buford	19	AC-30	5.8	4.0
Mix 7	Buford	12.5	AC-30	5.8	3.0

Table 2.3 GLWT Rutting Potential Data Used for Development of Temperature Effect Model

Samples Results at 8000 Cycles Voids			Samples Results at 8000 Cycles Binder AC-30, Interval 4±1% Air Voids			
Mix Type	Temp	Rut GLWT (mm)	Mix Type	NMAS	Temp	Rut GLWT (mm)
Mix 1	40	1.84	Mix 3	19	40	1.73
Mix 1		1.96	Mix 3	19		1.64
Mix 1		1.77	Mix 3	19		1.85
Mix 1		1.84	Mix 3	19		1.81
Mix 1	50	4.79	Mix 3	19	50	2.39
Mix 1		3.92	Mix 3	19		2.85
Mix 1		4.81	Mix 3	19		3.01
Mix 1		4.28	Mix 3	19		3.02
Mix 1	60	6.30	Mix 3	19	60	4.04
Mix 1		6.35	Mix 3	19		4.33
Mix 1		5.28	Mix 3	19		4.25
Mix 1		6.17	Mix 3	19		3.30
Mix 2	40	2.85	Mix 4	19	40	2.41
Mix 2		2.71	Mix 4	19		1.38
Mix 2		3.35	Mix 4	19	60	6.46
Mix 2		2.76	Mix 4	19		4.81
Mix 2	50	4.36	Mix 5	12.5	40	2.94
Mix 2		4.21	Mix 5	12.5		2.50
Mix 2		4.14	Mix 5	12.5	60	8.99
Mix 2		4.45	Mix 5	12.5		7.71
Mix 2	60	7.57	Mix 6	19	40	1.80
Mix 2			Mix 6	19		1.64
Mix 2			Mix 6	19	60	5.33
Mix 2			Mix 6	19		5.69
			Mix 7	12.5	40	0.97
			Mix 7	12.5		1.25
			Mix 7	12.5	60	3.48
			Mix 7	12.5		3.27

Where:

R = Predicted Ruth Depth.

R_0 = Reference rut depth obtained from the LWT test at the reference conditions T_0 , N_0 .

T , N = Temperature and load cycles the rut depth is sought.

T_0 , N_0 = Reference temperature and load cycles for R_0 .

The authors concluded that the TEM can be used to evaluate rutting potential of the asphalt mixtures using the GLWT at different range of temperatures, and at different number of loading cycles. The TEM allow the users to establish rut depth acceptance criteria for asphalt mixture at temperature more closely associated with the field pavement temperature. Moreover, the testing time, for the rutting test, can be reduce by lowering the number of loading cycles, an advantage for quicker evaluation in the field (Shami, et al., 1997).

2.4.2 Comparison of APA to WesTrack

The FHWA, the Virginia Transportation Research Council (VTRC), and the Nevada Department of Transportation (NDOT), cooperated to assess the ability to evaluate rutting potential using three simulative testers: the APA, the Hamburg Wheel Tracking Device (HWTd), and the French Rutting Tester (FRT) (Williams and Prowell, 1999). Samples of ten sections of the WesTrack's oval were tested to evaluate the ability of the equipment to identify the rutting potential of mixes relative to their performance on the test track. The authors did not specify the mix design type, or the nominal maximum aggregate size. Eight of the mixes contained PG 64-18 binder and the other two had a modified PG 64-22 binder.

The laboratory testing was conducted at two facilities. The testing of samples in the HWTd and the FRT were performed at the Turner-Fairbank Highway Research Center by the FHWA. The FRT test was carried out at 60°C (140°F) under dry conditions, the wheel load was 5000 N (1124 lbf), the hose pressure was 600 kPa (87 psi), and rut measurements were taken at 300, 1,000, 3,000, 10,000, and 30,000 cycles. The HWTd test was carried out at 50°C (122°F) under wet conditions, the wheel load was 685 N, and rut measurements were taken every 100 cycles. The APA tests were performed at the VTRC. Beam samples were compacted using the Asphalt Vibratory

Compactor to 7% air voids. The APA testing was carried out at 60°C (140°F) under dry conditions, the wheel load was 533 N (120 lbf), the hose pressure was 830 kPa (120 psi), and rut measurements were taken at 500, 2,000, 4,000, and 8,000 cycles. The rutting potential results of the three devices were compared with field rut measurements of the WesTrack sections. All the sections correlated satisfactorily. Table 2.4 presents the performance ranking of the mixes based on WesTrack field measurements and the APA. Eight of the ten mixes were ranked the same between the two data sets. The largest discrepancy in ranking was Section 38 which ranked third based on the WesTrack results and seventh by the APA. The authors published the field ruts of the WesTrack section; unfortunately, they did not publish the rut results for the loaded wheel testers (Williams and Prowell, 1999).

Table 2.4 FHWA-VTRC-NDOT Performance Ranking of the Field and APA

Rank	West Track	APA
1	51	51
2	43	43
3	38	39
4	39	35
5	35	54
6	54	55
7	37	38
8	55	37
9	56	56
10	36	36

2.4.3 VDOT Development of APA Limits for Mix Evaluation

Maupin (1998) reported on the use of the GLWT and APA to evaluate the rutting potential of Superpave mixes. Prowell (1999) used the APA to expand on Maupin's research and develop tentative criteria for rutting potential measured by the APA. Prowell reported that Maupin's testing was focused on evaluating whether the GLWT could distinguish between different performances graded binders in Superpave mixes. Laboratory testing was carried out of three 12.5 mm Superpave mixes, with gradations above, through, and below the restricted zone, identified as Blends 1, 2, and 3, respectively, and PG 64-22 binder. Three replicated beams were prepared for each blend at optimum +0.5% asphalt content. The asphalt content was increased to increase the sensitivity of the GLWT to binder grade. Beam samples were compacted to 7% air voids

employing a rolling wheel kneading compactor. The blends were tested using the GLWT and rut readings were taken at 8,000 cycles. The GLWT test temperature was 38°C (100°F), the wheel load was 445 N (100 lbf), and the hose was inflated to 689 kPa (100 psi). The results are shown in the Task 1 column of Table 2.5.

Based on the test results and statistical analysis, Maupin (1998) chose Blend 3, the coarse gradation (below the restricted zone) for the binder grade experiment. The blend with the highest rutting potential was selected to represent the most critical rutting potential. Three replicate specimens were prepared with five grades of binders: PG 58-22, PG 64-22, PG 70-22, PG 76-22 and PG 82-22. The PG 76-22 binders were produced using three methods, air blowing AB, multigrade chemical gelling, and Styrene-Butadiene polymer. PG 82-22 was produced with Styrene-Butadiene polymer. Following the GDOT recommended procedure for mixes containing polymer modified asphalt, the specimens were tested in the GLWT at a temperature of 49°C (120°F), with a wheel load of 533 N (120 lbf), and the hose inflated to 830 kPa (120 psi). Rut readings were taken at 8,000 cycles, as shown in the Task 2 column of Table 2.5. Maupin (1998) concluded that the GLWT was sensitive to the binder grade and asphalt content. However, it was noted that the GLWT had difficulty maintaining temperature and the reciprocating carriage had significant wear.

Maupin (1998) decided to repeat the evaluation of the effect of binder type using an APA in place of the GLWT. The APA tests were performed at 49°C (120°F), with a wheel load of 533 N (120 lbf), and the hose inflated to 830 kPa (120 psi). Rut readings were taken at 8,000 cycles. Beam samples were prepared with the Asphalt Vibratory Compactor. The 12.5 mm granite aggregate evaluated during this task was slightly finer gradation than the Blend 3 used in the previous work. However, the gradation still passed below the restricted zone. The tests during Task 3 were performed at an asphalt content of 5 percent, the design binder content for this aggregate blend. Three replicate specimens were prepared for each binder grade: PG 58-22, PG 64-22, PG 70-22, and PG 76-22 modified Styrene-Butadiene polymer. The rut results are shown in the Task 3 column of Table 2.5. Maupin concluded the APA was also sensitive to the binder grade as the measured rutting potential decreased as the stiffness of the binder, as indicated by the upper temperature rating of the binder, increased.

Prowell (1999) used the APA to research 187 mixes representing 13 different 50 blow Marshall mixes. The mixes were 12.5 mm with PG 64-22, PG 70-22, and PG 76-22 modified Styrene-Butadiene polymer. Beam samples were compacted in the Asphalt Vibratory Compactor. The target air void content was 7% for all mixes. The APA test were performed at 49°C (120°F), with a wheel load of 533 N (120 lbf), and the hose inflated to 830 kPa (120 psi). Tentative criteria for three types of mixes were proposed based on the 95 % confidence limit of a normal distribution. These criteria were included in the 2002 specifications of the VDOT; however, in the 2003 revision to the specification specific limits on allowable rutting potential for different mix types was replaced with the statement:

Based on rut testing performed by the Department and/or field performance of the job mix, the Engineer reserves the right to require adjustments to the job mix formula.

Table 2.5 VTRC Results of Binder Experiment

Superpave Mixes Laboratory Tests						
Task 1 Choose the Blend			Task 2 Binder Experiment		Task 3 Binder Experiment	
12.5 mm, PG 64-22, 7% Air void			12.5 mm, 6.2% AC, 7% Air void		12.5 mm, 5.0% AC, 7% Air void	
Type of Mix	% Asphalt Content	GLWT Ruts at 8000 Cycles	Type of Mix	GLWT Ruts at 8000 Cycles	Type of Mix	APA Ruts at 8000 Cycles
Blend 1	5.5	4.14	PG 58-28	6.70	PG 58-28	4.99
Blend 2	5.5	4.60	PG 64-22	5.60	PG 64-22	3.90
Blend 3*	6.2	5.57	PG 70-22	4.50	PG 70-22	2.80
			PG 76-22 (Multigrade)	3.20	PG 76-22 (SB)	1.20
			PG 76-22 (AB)	2.30		
			PG 76-22 (SB)	1.05		
			PG 82-22 (SB)	1.10		

*Chosen

Test Experiment described by Prowell, 1999, of Maupin work, 1998.

2.4.4 TDOT Application of APA for Mixture Screening

Jackson and Baldwin (2000) evaluated the rutting potential of Marshall and Superpave mixes used by the Tennessee Department of Transportation (TDOT). The APA was used to evaluate the rutting potential of mixes with respect to different aggregates and binder types. Factors evaluated included binder type, binder content, dust content, dust to asphalt ratio and gradation to determine whether the APA could identify their influence on rutting potential. HMA samples of 19 mm NMAA aggregate were

collected from 34 projects. All samples were compacted to $7\pm 1\%$ air voids using the Superpave Gyratory Compactor. Conventional TDOT mixes were designed by the 75-blow Marshall design, whereas the new TDOT mixes were designed following the Superpave volumetric mix design criteria. The binders for the Marshall mixes were AC-20, polymer modified AC-20, PG 64-22, and polymer modified PG 76-22. Binders for the Superpave mixes were PG 64-22 and polymer modified PG 76-22. The APA tests were performed at 50°C (122°F), and ruts reading were taken at 500, 1,000, 4,000, and 8,000 cycles. The wheel load was 445 N (100 lbf), and the hose pressure was 690 kPa (100 psi). Table 2.6 presents the test results.

Table 2.6 UT-TDOT Test Results

19 mm Mixes, 7% Air Voids							
MIX ID	Mix Design	Binder Type	Binder Content (%)	Dust Content (%)	Dust/Asphalt Ratio (%)	Gradation TRZ*	Rut (mm) 8000 cycles
10MB	Marshall	AC- 20	4.2	4.6	1.1	n	3.55
8MS	Marshall	AC- 20	7.6	5.2	0.7	y	8.93
2MB	Marshall	AC- 20	5.7	4.8	0.8	n	2.88
3MS	Marshall	AC-20	6.0	3.0	0.5	n	3.89
4MB	Marshall	AC-20	4.6	4.9	1.1	n	1.53
5MB	Marshall	AC-20	4.6	5.8	1.3	n	3.05
1MB	Marshall	AC-20PM	5.1	5.4	1.1	y	3.21
1MS	Marshall	AC-20PM	6.6	6.0	0.9	y	2.64
10MS	Marshall	PG64-22	7.2	4.2	0.6	y	8.14
11MS	Marshall	PG64-22	6.6	3.5	0.5	y	10.55
12MS	Marshall	PG64-22	7.1	5.4	0.8	y	5.47
3MB	Marshall	PG64-22	4.0	5.0	1.3	n	1.30
6MB	Marshall	PG64-22	5.5	5.4	1.0	n	3.73
5MS	Marshall	PG64-22	5.7	4.3	0.8	y	7.52
6MS	Marshall	PG64-22	5.7	5.2	0.9	n	4.55
7MB	Marshall	PG64-22	5.6	4.9	0.9	n	4.15
7MS	Marshall	PG64-22	7.3	5.4	0.7	y	5.89
8MB	Marshall	PG64-22	4.9	4.1	0.8	y	3.93
9MB	Marshall	PG64-22	4.5	3.9	0.9	y	5.00
9MS	Marshall	PG64-22	5.9	3.7	0.6	y	9.92
2MS	Marshall	PG76-22	6.6	3.9	0.6	n	2.04
4MS	Marshall	PG76-22	6.1	4.9	0.8	n	3.44
2SB	Superpave	PG64-22	5.3	3.0	0.6	n	2.52
3SB	Superpave	PG64-22	4.7	4.4	0.9	n	4.24
3SS	Superpave	PG64-22	6.2	6.1	1.0	y	3.76
4SS	Superpave	PG64-22	5.0	3.2	0.6	n	4.17
5SS	Superpave	PG64-22	5.4	4.8	0.9	y	6.48
6SS	Superpave	PG64-22	5.3	4.6	0.9	n	3.09
1SBF	Superpave	PG76-22	4.2	5.2	1.2	y	2.53
1SBNF	Superpave	PG76-22	4.7	5.2	1.1	y	2.04
1SSF	Superpave	PG76-22	6.0	5.4	0.9	n	1.68
1SSNF	Superpave	PG76-22	6.1	5.4	0.9	n	1.96
2SS	Superpave	PG76-22	6.3	4.7	0.7	n	2.06
7SS	Superpave	PG76-22	6.2	6.3	1.0	n	2.42

*TRZ Through restricted zone

Regression equations of the rutting potential with the air voids, binder content, dust content, and dust to asphalt ratio were analyzed. It was concluded that the effects of these variables on rutting potential were not significant. However, comparing mix performance to the GDOT criteria of 5 mm rutting potential at 50°C (122°F) showed that all the mixes that failed had AC-20 or PG 64-22 binders. Some of the mixes with unmodified binders passed the criteria along with all the mixes with modified binders. The Superpave mixes performed better than the Marshall mixes. The researchers concluded that the APA was sensitive to the binder types and mix designs.

2.4.5 FDOT Evaluation of APA Testing Parameters

Choubane, et al., (2000) evaluated the suitability of the APA to assess the rutting potential of Florida mixes. Comparisons were established between the field performance of the mixes and the APA results. The researchers also compared the testing variability between beam and cylindrical samples. Finally, the authors compared the APA rutting potential from this study and the GLWT rutting potential from previous research of the same sections by West, et al., (1991).

The study included mixes, with known field rut measurements, from three different sections of the Florida interstate pavement system constructed in the early 1980's, all with different rutting potential. The first section, Mix B, exhibited good performance under heavy traffic; the second section, Mix C, rutted severely and was removed after four years of service; and the last section, Mix D, had light to moderate signs of rutting. Table 2.7 presents the field rut measurements of the three sections. All the mixes were 12.5 mm Marshall design with AC-20 binder. Core samples were obtained from the sections to establish the in-place gradations and asphalt contents.

Laboratory samples were prepared to rigorously match the characteristics of the mix placed in the field with respect to gradation and asphalt content. Nine beams and eighteen cylinders per mixture were compacted employing the Asphalt Vibratory Compactor and Superpave Gyratory Compactor, respectively. All samples were compacted to 7% air voids. The test temperature of the APA was 41°C (105°F), the wheel load was 540 N (122 lbf) and the 690 kPa (100 psi). These parameters matched those used by West, et al., (1991) research with the GLWT. Rut measurements were collected at 0, 1,000, 4,000, and 8,000 loading cycles. Table 2.8 shows the APA rutting

potential for the cylindrical samples. Table 2.9 shows the APA rutting potential for the beam samples. The APA successfully ranked the three field mixes.

Table 2.7 FDOT Field Rut Results

Florida DOT Field Rut Depths (mm)							
Year	MIX B	MIX C	MIX D	Year	MIX B	MIX C	MIX D
1981	X	3.2	X	1988	6.4	XX	6.4
1982	0.0	6.4	0.0	1989	6.4	XX	6.4
1983	1.6	9.5	2.1	1990	6.4	XX	6.4
1984	1.6	14.3	2.1	1991	6.4	XX	6.4
1985	1.6	15.9	2.1	1992	6.4	XX	7.9
1986	3.2	XX	6.4	1993	6.4	XX	7.9
1987	6.4	XX	6.4	1994	6.4	XX	7.9

Source: Choubane, et al. (2000).

X = Under Construction

XX = Removed and Replaced

Table 2.8 FDOT APA Rutting Potential for Cylindrical Samples.

12.5 Marshall Mixes with AC-20 Binder											
Test #	Number Cycles	Mix Type	Sample Location Within APA Testing Set up						Average		
			Left		Center		Right		Samples @ Front	Samples @ Back	Both Front & Back
			Front	Back	Front	Back	Front	Back			
Test 1 18 samples	1000	Mix B	4.6	4.6	3.6	3.8	5.4	4.8	4.5	4.4	4.5
	1000	Mix C	5.7	6.7	5.8	5.7	6.7	7.0	6.1	6.5	6.4
	1000	Mix D	5.2	5.0	4.5	4.5	4.8	5.1	4.9	4.8	4.9
	4000	Mix B	6.7	7.2	5.8	6.1	8.0	7.4	6.8	6.9	6.9
	4000	Mix C	10.6	12.3	10.6	9.6	12.0	12.4	11.1	11.4	11.2
	4000	Mix D	8.1	7.5	6.5	7.3	7.8	8.2	7.5	7.7	7.6
	8000	Mix B	8.3	8.8	7.2	7.7	9.7	8.9	8.4	8.5	8.4
	8000	Mix C	15.0	15.9	14.8	12.9	16.7	16.5	15.5	15.1	5.3
	8000	Mix D	9.8	9.2	8.0	9.2	9.9	10.6	9.2	9.7	9.5
Test 2 18 samples	1000	Mix B	4.1	4.2	3.5	4.0	3.2	3.8	3.6	4.0	3.8
	1000	Mix C	6.2	5.7	6.1	5.8	6.6	5.4	6.3	5.6	6.0
	1000	Mix D	6.1	6.7	4.9	5.5	6.3	6.3	5.7	6.2	5.9
	4000	Mix B	6.7	6.9	5.5	6.9	6.7	6.4	6.3	6.7	6.5
	4000	Mix C	11.4	10.2	10.4	9.7	11.4	10.0	11.0	10.0	4.0
	4000	Mix D	8.7	9.3	7.0	7.7	9.0	8.4	8.2	8.4	8.3
	8000	Mix B	8.1	8.4	6.8	7.9	8.3	7.7	7.7	8.0	7.9
	8000	Mix C	15.6	13.9	14.2	13.4	16.0	13.8	15.3	13.7	14.5
	8000	Mix D	10.1	10.8	8.3	8.8	10.4	9.7	9.6	9.8	9.7
Test 3 18 samples	1000	Mix B	4.5	5.4	4.4	4.4	5.1	5.8	4.7	5.2	4.9
	1000	Mix C	9.4	9.4	9.6	8.8	10.4	9.9	9.8	9.4	9.6
	1000	Mix D	5.2	5.8	4.5	5.4	4.7	5.4	4.8	5.5	5.2
	4000	Mix B	6.8	7.7	6.7	6.4	8.0	8.2	7.2	7.4	7.3
	4000	Mix C	15.1	14.5	15.5	13.9	15.8	15.0	15.5	14.5	15.0
	4000	Mix D	8.3	8.6	6.8	8.2	7.5	8.6	7.5	8.5	8.0
	8000	Mix B	8.1	9.2	8.0	7.7	9.4	9.6	8.5	8.8	8.6
	8000	Mix C	18.3	17.2	19.1	16.9	19.0	18.9	18.8	17.7	18.2
	8000	Mix D	9.9	10.7	8.2	9.8	9.2	10.8	9.1	10.4	9.8

Table 2.9 FDOT APA Rutting Potential for Beam Samples

12.5 Marshall Mixes with AC-20 Binder						
Test #	Number Cycles	Mix Type	Sample Location Within APA Testing Set up			
			Left	Center	Right	Average
Test 1 9 samples	1000	Mix B	2.4	2.7	2.7	2.6
	1000	Mix C	8.3	7.0	8.4	7.9
	1000	Mix D	4.2	4.1	5.3	4.5
	4000	Mix B	4.9	5.3	5.7	5.3
	4000	Mix C	14.2	11.6	14.1	13.3
	4000	Mix D	7.0	6.1	8.2	7.1
	8000	Mix B	6.3	9.0	7.7	7.7
	8000	Mix C	19.4	15.4	18.5	17.8
	8000	Mix D	9.1	7.5	10.1	8.9
Test 2 9 samples	1000	Mix B	3.2	3.2	3.1	3.1
	1000	Mix C	7.6	8.1	7.8	7.9
	1000	Mix D	4.0	4.6	3.6	4.1
	4000	Mix B	5.2	5.3	5.5	5.4
	4000	Mix C	12.6	13.6	14.1	13.4
	4000	Mix D	7.2	6.9	6.1	6.7
	8000	Mix B	6.3	6.4	6.9	6.5
	8000	Mix C	17.7	18.1	19.9	18.2
	8000	Mix D	9.7	8.6	7.7	8.7
Test 3 9 samples	1000	Mix B	3.7	3.9	3.2	3.6
	1000	Mix C	8.9	8.8	8.0	8.6
	1000	Mix D	4.5	4.2	4.7	4.5
	4000	Mix B	5.8	5.9	5.1	5.6
	4000	Mix C	15.0	14.1	12.9	14.0
	4000	Mix D	7.2	6.3	7.0	6.8
	8000	Mix B	7.2	7.1	6.7	7.0
	8000	Mix C	20.1	18.3	16.9	18.4
	8000	Mix D	9.4	7.8	8.5	8.6

The authors studied the APA testing repeatability between the three possible loading positions within each test and between the three performed tests, to establish the testing variability between beam and cylindrical specimens. Tables 2.10 and 2.11 present the variability results for cylindrical and beam specimens, respectively. These tables present significant variability between the three testing locations and between the three tests completed, both for cylindrical (front and back within each position), and beam samples. Choubane, et al., (2000) concluded that the variability appeared to be mix dependent and increased with the loading cycles.

Additionally, paired-difference experiments were performed to establish the significance level of the differences among the respective average measurements of the tests and among the three testing locations within each test. Choubane, et al., (2000)

concluded that the APA testing variability might be different from test to test and, within each test, from location to location. Choubane, et al., (2000) also stated that “It may be hypothesized that the APA testing setup is not completely effective in keeping the air pressure within the three pneumatic cylinders uniform throughout the loading duration”. Hence, the testing variability could have been caused by possible pressure fluctuations within the cylinders during testing.

Table 2.10 FDOT Variability of APA Rutting Potential for Cylindrical Samples

Variability Between APA Rut Depth Measurements (mm) - Cylindrical Samples										
Cycles	Mix Type	Test 1			Test 2			Test 3		
		Front	Back	Both	Front	Back	Both	Front	Back	Both
1000	Mix B	1.8	0.9	1.8	0.9	0.4	1.0	0.8	1.5	1.5
	Mix C	0.9	1.3	1.3	0.4	0.5	1.2	1.0	1.1	1.6
	Mix D	0.8	0.6	0.8	1.4	1.3	1.8	0.7	0.4	1.3
4000	Mix B	2.3	1.3	2.3	1.2	0.5	1.3	1.3	1.8	1.8
	Mix C	1.4	2.8	2.8	1.1	0.5	1.7	0.6	1.1	1.9
	Mix D	1.6	0.9	1.7	2.0	1.6	2.3	1.4	0.4	1.8
8000	Mix B	2.5	1.3	2.5	1.5	0.7	1.6	1.4	1.9	1.8
	Mix C	1.9	3.6	3.9	1.9	0.5	2.7	0.9	1.9	2.2
	Mix D	2.0	1.5	2.7	2.0	2.0	2.5	1.7	1.0	2.6
Cycles	Mix Type	Variability								
		Between Test						Between Test and Locations		
		Left		Center		Right				
		Front	Back	Front	Back	Front	Back	Front	Back	Both
1000	Mix B	0.5	1.2	0.9	0.5	2.1	2.0	2.1	2.0	2.6
	Mix C	3.7	3.7	3.8	3.1	3.9	4.5	4.7	4.5	5.1
	Mix D	0.8	1.7	0.4	1.0	1.5	1.2	1.8	2.2	2.2
4000	Mix B	0.1	0.9	1.2	0.7	1.3	1.8	2.5	2.1	2.6
	Mix C	4.5	4.2	5.2	4.3	4.3	5.1	5.4	5.4	6.2
	Mix D	0.6	1.8	0.5	0.9	1.5	0.4	2.5	1.9	2.8
8000	Mix B	0.2	0.8	1.2	0.3	1.5	1.8	2.9	1.9	2.9
	Mix C	3.3	3.3	5.0	4.0	2.9	5.1	5.0	6.0	6.3
	Mix D	1.6	1.6	0.4	1.0	1.2	1.0	2.4	2.0	2.8

Table 2.11 FDOT Variability of APA Rutting Potential for Beam Samples

Variability Between APA Rut Depth Measurements (mm) - Beam Samples								
Cycles	Mix Type	Test 1	Test 2	Test 3	Left	Center	Right	Test and Location
1000	Mix B	0.3	0.1	0.7	1.3	1.2	0.5	1.5
	Mix C	1.4	0.5	0.9	1.3	1.8	0.6	1.9
	Mix D	1.2	1.0	0.4	0.5	0.5	1.6	1.6
4000	Mix B	0.9	0.4	0.8	1.0	0.6	0.7	1.0
	Mix C	2.6	1.5	2.1	2.4	2.5	1.2	3.4
	Mix D	2.1	1.0	0.9	0.3	0.8	2.1	2.1
8000	Mix B	2.7	0.6	0.5	0.9	2.6	0.9	2.7
	Mix C	4.0	3.3	3.3	3.5	2.9	3.1	4.7
	Mix D	2.7	1.9	1.7	0.5	1.2	2.4	2.7

The APA results correlated with the GLWT results, despite the fact the APA's ruts measurements were almost twice the GLWT's ruts measurements. Figure 2.4 (Choubane, et al., 2000) shows the APA, and the GLWT rutting potential. The results were consistent for both types of specimens. Figure 2.5 (Choubane, et al., 2000) shows the APA rutting potential of the different sections with the two different types of specimens. Finally, the authors recommended the development of additional APA testing using a wider range of mixes to determine more significant conclusions (Choubane, et al., 2000).

Figure 2.4 FDOT APA and GLWT Rutting Potential

Figure 2.5 FDOT APA Rutting Potential Beam and Cylindrical Samples

2.4.6 NCAT Application of APA to Evaluate Mix Design Parameters

Research sponsored by the Alabama Department of Transportation (ALDOT) at National Center for Asphalt Technology (NCAT) of Auburn University studied the suitability of the APA to evaluate the rutting potential of HMA with different aggregate gradations and asphalt binders (Kandhal and Mallick, 2000). In this study, 36 Superpave mixes were assessed based on the following combination of factors and levels:

<u>Factor</u>	<u>Levels</u>
Binder type	PG 64-22, PG 58-22
Aggregate	Granite, Limestone, Gravel
Nominal maximum aggregate size	12.5, 19
Gradation	Above, through and below restricted zone

Specimens were compacted in the Superpave Gyratory Compactor to target of 4% air voids. The test temperature was 64°C (147°F), the load wheel was 445 N (100 lbf), and the hose pressure was 690 kPa (100 psi). Rut measurements were conducted at 0, 1,000, 4,000, and 8,000 load cycles. Table 2.12 shows the APA rutting potential at 8,000 load cycles.

Table 2.12 NCAT-ALDOT APA Rutting Potential

Mix	Gradation	NMAS	PG	Ruts (mm) 8000 Cycles	Mix	Gradation	NMAS	PG	Ruts (mm) 8000 Cycles
Granite 1	ARZ	12.5	58-22	6.59	Granite 1	ARZ	12.5	64-22	4.48
Granite 2	TRZ	12.5	58-22	3.81	Granite 2	TRZ	12.5	64-22	4.30
Granite 3	BRZ	12.5	58-22	6.01	Granite 3	BRZ	12.5	64-22	5.35
Limestone 1	ARZ	12.5	58-22	4.53	Limestone 1	ARZ	12.5	64-22	3.77
Limestone 2	TRZ	12.5	58-22	5.47	Limestone 2	TRZ	12.5	64-22	3.90
Limestone 3	BRZ	12.5	58-22	7.16	Limestone 3	BRZ	12.5	64-22	6.23
Gravel 1	ARZ	12.5	58-22	7.95	Gravel 1	ARZ	12.5	64-22	6.46
Gravel 2	TRZ	12.5	58-22	6.03	Gravel 2	TRZ	12.5	64-22	5.77
Gravel 3	BRZ	12.5	58-22	5.24	Gravel 3	BRZ	12.5	64-22	5.64
Granite 1	ARZ	19	58-22	3.40	Granite 1	ARZ	19	64-22	3.48
Granite 2	TRZ	19	58-22	2.80	Granite 2	TRZ	19	64-22	1.62
Granite 3	BRZ	19	58-22	2.85	Granite 3	BRZ	19	64-22	3.43
Limestone 1	ARZ	19	58-22	4.00	Limestone 1	ARZ	19	64-22	4.07
Limestone 2	TRZ	19	58-22	5.04	Limestone 2	TRZ	19	64-22	3.98
Limestone 3	BRZ	19	58-22	9.49	Limestone 3	BRZ	19	64-22	5.62
Gravel 1	ARZ	19	58-22	6.41	Gravel 1	ARZ	19	64-22	5.19
Gravel 2	TRZ	19	58-22	5.23	Gravel 2	TRZ	19	64-22	4.35
Gravel 3	BRZ	19	58-22	4.65	Gravel 3	BRZ	19	64-22	4.53

The authors performed an analysis of variance and the Duncan multiple range test to identify significant correlations between the factors and levels. Table 2.13 presents the mean and standard deviation of the APA rutting potential for the mixes. The analysis of variance indicated significant effect of aggregate type, binder type, gradation, coarse type and an interaction of aggregate and gradation. Analyzing all the data, the authors concluded:

- In general, the mixes with gravel and limestone presented higher rutting potential than the granite.
- The granite and limestone mixes with gradations below the restricted zone in general presented the highest rutting potential; conversely, the gradation through the restricted presented the lowest rutting potential. The gradations above the restricted zone presented intermediate rutting potential.
- The gravel mixes with gradations above the restricted zone in general presented the highest rutting potential; on the contrary, the gradation below the restricted presented the lowest rutting potential. The gradations through the restricted zone presented intermediate rutting potential.
- The effect of gradation on granite and limestone 12.5 mm and 19 mm mixes with PG 64-22 was significant, with below restricted zone gradation presenting higher rutting compared to above and through restricted zone gradations.
- The effect of gradation on granite 12.5 mm mixes with PG 58-22 was significant, with below-restricted-zone gradation presenting higher rutting compared to above-restricted-zone and through-restricted-zone gradations. The granite 19 mm mixes with PG 58-22 did not showed significant effects.
- The effect of gradations on gravel 12.5 mm and 19 mm with PG 64-22 was not significant. Mixes with gradations above-restricted-zone and through-restricted-zone presented higher rutting potential than the ones with gradation below-restricted-zone.
- The effect of gradations on gravel 12.5 and 19 mixes with PG 58-22 was significant. The mixes with gradation below the restricted zone present the highest rutting potential; conversely, the mixes with gradation above the restricted

zone present the lowest rutting potential. The mixes with gradation through the restricted zone presented the intermediate rutting potential.

Table 2.13 NCAT-ALDOT APA Rutting Potential Mean and Standard Deviation

Superpave Mixes with PG 58-22 Binder						Superpave Mixes with PG 64-22 Binder					
MIX	Gradation	NMAS	Rut Depth		Rank*	MIX	Gradation	NMAS	Rut Depth (mm)		Rank*
			Mean	Standard Deviation					Mean	Standard Deviation	
Granite 1	ARZ	12.5	4.48	0.737	AB	Granite 1	ARZ	12.5	6.59	1.191	A
Granite 2	TRZ	12.5	4.30	0.825	B	Granite 2	TRZ	12.5	3.81	0.442	B
Granite 3	BRZ	12.5	5.35	0.561	A	Granite 3	BRZ	12.5	6.01	0.622	A
Limestone 1	ARZ	12.5	3.77	0.608	B	Limestone 1	ARZ	12.5	4.53	0.737	B
Limestone 2	TRZ	12.5	3.90	0.452	B	Limestone 2	TRZ	12.5	5.47	1.148	B
Limestone 3	BRZ	12.5	6.23	1.036	A	Limestone 3	BRZ	12.5	7.16	0.949	A
Gravel 1	ARZ	12.5	6.46	0.656	A	Gravel 1	ARZ	12.5	7.95	0.539	A
Gravel 2	TRZ	12.5	5.77	0.342	AB	Gravel 2	TRZ	12.5	6.04	0.477	B
Gravel 3	BRZ	12.5	5.64	0.776	B	Gravel 3	BRZ	12.5	5.24	0.708	B
Granite 1	ARZ	19	3.48	1.205	A	Granite 1	ARZ	19	3.40	0.446	A
Granite 2	TRZ	19	1.62	0.348	B	Granite 2	TRZ	19	2.80	0.283	A
Granite 3	BRZ	19	3.43	0.567	A	Granite 3	BRZ	19	2.85	0.707	A
Limestone 1	ARZ	19	4.07	0.294	B	Limestone 1	ARZ	19	4.00	0.186	B
Limestone 2	TRZ	19	3.98	0.287	B	Limestone 2	TRZ	19	5.04	0.581	B
Limestone 3	BRZ	19	5.62	1.531	A	Limestone 3	BRZ	19	9.49	2.021	A
Gravel 1	ARZ	19	5.19	1.034	A	Gravel 1	ARZ	19	6.41	1.005	A
Gravel 2	TRZ	19	4.35	0.678	A	Gravel 2	TRZ	19	5.23	0.621	B
Gravel 3	BRZ	19	4.53	0.492	A	Gravel 3	BRZ	19	4.65	0.375	B

* A has more rutting than B; Significant level 5%.

Kandhal and Mallick (2000) performed paired t tests to compare the rutting potential of mixes with PG 64-22 and the PG 58-22 binder. The results showed significant differences between the rutting potential of mixes with PG 64-22 and PG 58-22. The mixes with PG 58-22 binder presented higher rutting potential than the mixes with PG 64-22 binder. The authors concluded that the APA was sensitive to the binder type.

The researchers tested the PG 64-22 mixes in the Superpave Shear Tester, SST, to establish a comparison between the APA rutting potential and fundamental test results. The SST is a fundamental test used to determine the rutting potential of HMA. The SST has two tests, the Repeated Shear at Constant Height (RSCH), which give an estimate of the rut depth; and Repeated Shear at Constant Stress Ratio (RSCSR), which identify the mixes susceptible to rutting at low air voids. Tables 2.14 and 2.15 present the RSCH shear strength results, and the RSCSR shear strength results, respectively.

Table 2.14 NCAT-ALDOT RSCH Shear Strength Results

RSCH Peak Shear Strain			
NMAS 12.5		NMAS 19	
Mix	Strain Average	Mix	Strain Average
Granite 1	0.02236	Granite 1	0.01362
Granite 2	0.02201	Granite 2	0.01951
Granite 3	0.02454	Granite 3	0.01881
Limestone 1	0.03631	Limestone 1	0.32145
Limestone 2	0.01932	Limestone 2	0.03925
Limestone 3	0.05110	Limestone 3	0.06270
Gravel 1	0.07194	Gravel 1	0.06613
Gravel 2	0.05049	Gravel 2	0.03779
Gravel 3	0.06553	Gravel 3	0.05424

Source: Kandhal and Mallick (2000).

Table 2.15 NCAT-ALDOT RSCSR Shear Strength Results

RSCSR Peak Shear Strain			
NMAS 12.5		NMAS 19	
Mix	Strain Average	Mix	Strain Average
Granite 1	0.03347	Granite 1	0.02091
Granite 2	0.03417	Granite 2	0.02092
Granite 3	0.02686	Granite 3	0.01721
Limestone 1	0.03397	Limestone 1	0.03617
Limestone 2	0.04249	Limestone 2	0.03514
Limestone 3	0.06156	Limestone 3	0.06229
Gravel 1	0.08948	Gravel 1	0.03489
Gravel 2	0.06063	Gravel 2	0.01287
Gravel 3	0.08457	Gravel 3	0.05496

Source: Kandhal and Mallick (2000).

Plots of the APA rutting potential versus the RSCH, and RSCSR were developed. Figure 2.6 (Kandhal and Mallick, 2000) shows the APA rutting potential versus the RSCH shear strength results for 12.5 mm Superpave mixes with PG 64-22 binder. Figure 2.7 (Kandhal and Mallick, 2000) presents the APA rutting potential versus the RSCH shear strength results for 19.5 mm Superpave mixes with PG 64-22 binder. Figure 2.8 (Kandhal and Mallick, 2000) shows the APA rutting potential versus the RSCH shear strength results for 12.5 mm Superpave mixes with PG 64-22 binder. Figure 2.9 (Kandhal and Mallick, 2000) presents the APA rutting potential versus the RSCSR shear strength results for 19.5 mm Superpave mixes with PG 64-22 binder.

Source: Kandhal and Mallick (2000).

Figure 2.6 APA Rutting Potential vs. RSCH Test Results 12.5 mm PG 64-22

Source: Kandhal and Mallick (2000).

Figure 2.7 APA Rutting Potential vs. RSCH Test Results 19.5 mm PG 64-22

Source: Kandhal and Mallick (2000).

Figure 2.8 APA Rutting Potential vs. RSCSR Test Results 12.5 mm PG 64-22

Source: Kandhal and Mallick (2000).

Figure 2.9 APA Rutting Potential vs. RSCSR Test Results 19.5 mm PG 64-22

Based on the fair correlations, ($R^2=0.62$ and $R^2=0.69$), between the APA and RSCH tests, the authors concluded that both test characterized the mixes in the same way. On the contrary, the APA and RSCSR tests correlations, ($R^2=0.55$ and $R^2=0.44$), were poor, and the authors concluded that both test characterized the mixes differently.

Finally, the authors compared the APA rutting potential with known field rut measurements from Interstate 85. The field mixes were characterized as good (no rutting), fair (6 mm rutting), and poor (12 mm or more rutting). However, the results of the comparison between the APA results and field performance were inclusive. Table 2.16 shows the poorest performing pavement in the field had lower APA rutting potential than the fair section. The authors attributed this difference to the difference in age and traffic exposure between the two sections.

Table 2.16 NCAT–ALDOT APA Rutting Potential and Field Ruts

Mix Type	NMAS	Air Void %	APA Ruts (mm) at 8000cycles	Field Ruts (mm)
A (Good)	19.5	4	1.330	0.00
B (Fair)	19.5	4	5.790	6.00
C (Poor)	19.5	4	4.500	12.50

Source: Kandhal and Mallick (2000).

2.4.7 NCAT Recommendations for Rutting Potential Evaluation

Another NCAT study reviewed the information relevant to the test methods for evaluating rutting, fatigue cracking, low-temperature cracking, moisture susceptibility, and friction properties of the pavements (Brown, et al., 2001). Special emphasis was place on permanent deformation. The literature review included fundamental tests,

empirical test, and simulative tests. Variables such as the test time, test method and criteria, equipment cost, available criteria, and the availability of data to support use, were assessed for all the tests methods. Based on the literature the test methods considered in this study were:

1. Fundamental Tests:

- 1) Uniaxial and triaxial tests: unconfined (uniaxial) and confined (triaxial) cylindrical specimens in creep, repeated loading, and strength tests.
- 2) Additional shear tests - shear loading tests:
 - (1) Superpave Shear Tester - Shear Dynamic Modulus.
 - (2) Quasi-Direct Shear (Field Shear Test).
 - (3) Superpave Shear Tester - Repeated Shear at Constant Height.
 - (4) Direct Shear Test.
- 3) Diametral tests: cylindrical specimens in creep or repeated loading test, strength test.

2. Empirical Tests:

- 1) Marshall Test.
- 2) Hveem Test.
- 3) Corps of Engineering Gyratory Testing Machine.
- 4) Lateral Pressure Indicator.

3. Simulative Tests:

- 1) Asphalt Pavement Analyzer (new generation of Georgia Loaded Wheel Tester).
- 2) Hamburg Wheel-Tracking Device
- 3) French Rutting Tester (LCPC Wheel Tracker)
- 4) Purdue University Laboratory Wheel Tracking Device
- 5) Model Mobile Load Simulator
- 6) Dry Wheel Tracker (Wessex Engineering)
- 7) Rotary Loaded Wheel Tester (Rutmeter)

Based on the literature review the tests identified in Table 2.17 were selected for further evaluation. Four mix designs of "relatively known" rutting rates were selected for the evaluation of the test methods. Two coarse and two fine aggregate blends were used in the mix designs. The Superpave mixes had 12.5 mm NMAS aggregate, with binder

PG 64-22. Table 2.17 lists the test results. Specimens for APA evaluation were compacted in the Superpave Gyratory Compactor with 4% target air voids. The APA test was carried out at 64°C (147°F), the load wheel was 445 N (100 lbf), and the hose pressure was 690 kPa (100 psi). The APA rutting potential was measured at 8,000 cycles. The authors concluded that the tests that appeared to provide reasonable results were the APA, Rutmeter, confined repeated load, dynamic modulus, and lateral pressure indicator.

Even though the Hamburg Wheel Tracking Device and the French Rutting Tester were not evaluated during the laboratory work, the authors included them in the recommendations based on the work of other researchers. The HWTD was included based on Aschenbrener's research (1995); and the WesTrack Forensic Team's research, (1998). The FRT was included based on research by Bonnot (1986); Brousseau (1992); Aschenbrener (1992, 1994); Corte, et al., (1994); WesTrack Forensic Team (1998, 2001). The simulative tests recommended were the APA, as first option, the HWTD, as second option, and the FRT, as third option.

The authors concluded the study by proposing tentative criteria for the three simulative tests. The criteria, based on limited field results, were recommended in general for high traffic areas. Testing with local materials and mixes was recommended before the adoption.

For APA tests, the authors recommended compacting samples to 4 % air voids in the Superpave Gyratory Compactor. They recommended using the high temperature for the selected PG grade and a load wheel of 445 N (100 lbf), and a hose pressure of 690 kPa (100 psi). Table 2.18 presents the tentative parameters and criteria (Brown, et al., 2001).

2.4.8 SCDOT Parametric Study of Mix Design Parameters

Research by the South Carolina Department of Transportation (SCDOT) used the APA to assess the rutting potential of the state mixes (Hawkins, 2001). Variables such as the type of mix design and the dust to asphalt ratio were evaluated and compared. Three aggregate sources were used for the mix designs: Vulcan Blacksburg (marble/schist), Vulcan Liberty (granite), and Tarmac Palmetto (granite). Nine mix designs were chosen

Table 2.17 NCAT Performed Test Results

Performed Test	Parameters	Mix Designs			
		Granite 5.3% ¹ AC	Granite 6.3% ² AC	Gravel 4.3% ³ AC	Gravel 5.3% ⁴ AC
Marshall	Stability (lbf)	6107	6070	6770	6213
	Flow (001 in)	25.0	24.0	18.9	18.3
Hveem	Stability Value	48.1	49.3	48.5	44.6
APA	Rut Depth @ 8000 Cycles (mm)	5.75	4.38	7.82	11.24
Rut Meter	Rut Depth @ 8000 Cycles (mm)	5.478	9.618	21.311	20.963
IDT ⁵	Strength (kPa)	130.2	121.3	100.7	111.4
Diametral Repeated Load ⁶	Perm. Deform. (mm)	2.0	0.8	1.6	1.3
Unconfined Creep ⁷	Permanent Strain %	0.3	0.3	0.5	0.5
Confined Creep ⁸	Permanent Strain %	1.1	1	Failed	Failed
Unconfined Repeated Load ⁹	Permanent Strain %	0.6	0.8	1.4	1.4
Confined Repeated Load-1 ¹⁰	Permanent Strain %	2.3	2.5	26.8	Failed
Confined Repeated Load-2 ¹¹	Permanent Strain %	1.9	2.3	1.3	>18
Dynamic Modulus @40C ¹²	16 Hz (psi x 10 ³)	179.6	130.1	168.2	146.8
	4 Hz (psi x 10 ³)	146.6	100.6	122.9	94.8
	1 Hz (psi x 10 ³)	107	69.2	81.2	64.7
Lateral Pressure Indicator	Horizontal/Vertical (%)	13	16	21.5	24.1
Gyratory Testing	GSI	1.042	1.077	1.041	1.187
Expected Rut Resistance ¹³		Highest	Intermediate	Intermediate	Lowest

Source: Brown, et al. (2001).

Notes:

¹ Granite aggregates, at 4 % air voids, optimum asphalt content, 5.3%.

² Granite aggregates, at 4 % air voids, optimum asphalt content plus 1%, 6.3%.

³ Gravel aggregates, at 4 % air voids, optimum asphalt content plus 1%, 5.3%.

⁴ Gravel aggregates, at 4 % air voids, optimum asphalt content, 4.3%.

⁵ IDT test were conducted according to guidance recommended by Christensen, et al., 2000.

^{6,7,8,9} Test configuration Based on references, necessary changes have been made to obtain reasonable results for the mixes.

⁶ Specimens were 100 mm diameter x 100 mm high, test temperature 40°C.

⁷ Specimens were 100 mm diameter x 100 mm high, test temperature 40°C.

⁸ Specimens were 100 mm diameter x 100 mm high, test temperature 54°C.

⁹ Specimens were 100 mm diameter x 100 mm high, test temperature 40°C.

¹⁰ Specimens were 100 mm diameter x 100 mm high, test temperature 54°C.

¹¹ Specimens were 100 mm diameter x 63.5 mm high, test temperature 60°C.

¹² Specimens with 1:1 diameter to height ratio were used.

¹³ This information was obtained from general knowledge and experience.

Table 2.18 NCAT Tentative Criteria for Simulative Test

Choice	Simulative Test	Recommended Criteria	Test Temp
1st Choise	APA	8 mm @8000 wheel load cycles	High Temp for selected PG grade
2nd Choise	HWTD	10mm @ wheel passes	50°C
3rd Choise	FRT	10mm @ wheel load Cycles	60°C

from the SCDOT Research and Material Laboratory. The mixes were placed on high volume roads in the past.

Beam specimens were compacted with the Asphalt Vibratory Compactor to target 7%, 8%, and 9% air voids, to investigate if the air void content affects measured rutting potential. Three levels of dust asphalt ratio were evaluated: 0.60, 1.20, and 1.60. The binder types were also analyzed to ascertain whether the addition of polymer-modified binders would reduce the rutting potential. The APA test were performed at 64°C (147°F), with a wheel load of 445 N (100 lbf), and hose pressure of 690 kPa (100 psi). Rut measurements were taken after 8,000 load cycles, using the automatic data collection device. Table 2.19 presents the mixes characteristics and APA rutting potential at 8,000 cycles.

Table 2.19 SCDOT Mix Characteristics & APA Rutting Potential

Mix Characteristics & APA Rutting Potential (mm) at 8000 Cycles						
Aggregate Sources	% Air Voids	PG*	D/A Ratio	Superpave		Marshall 12.5 mm Rut Avg.
				19 mm Rut Avg.	12.5 mm Rut Avg.	
Blacksburg	8	64-22	0.60	4.15	4.72	4.62
Blacksburg	8	64-22	1.20	5.90	5.71	5.43
Blacksburg	8	64-22	1.60	6.89	5.35	5.83
Blacksburg	9	64-22	NA	6.90	6.39	6.97
Blacksburg	7	64-22	NA	4.01	4.01	3.50
Blacksburg	8	64-22	NA	NA	4.42	5.45
Blacksburg	8	76-22	NA	NA	1.90	3.04
Liberty	8	64-22	0.60	11.43	6.93	7.57
Liberty	8	64-22	1.20	11.29	10.00	8.04
Liberty	8	64-22	1.60	13.75	11.50	8.51
Liberty	9	64-22	NA	12.72	10.38	11.48
Liberty	7	64-22	NA	6.77	6.90	4.64
Liberty	7	64-22	NA	NA	8.79	7.31
Liberty	8	76-22	NA	NA	3.90	3.36
Palmetto	8	64-22	0.60	6.64	5.55	6.54
Palmetto	8	64-22	1.20	7.57	5.31	7.99
Palmetto	8	64-22	NA	10.27	6.65	9.96
Palmetto	9	64-22	NA	12.27	12.05	9.72
Palmetto	7	64-22	NA	6.18	4.55	7.07
Palmetto	8	64-22	NA	NA	4.17	8.58
Palmetto	8	76-22	NA	NA	2.15	3.27

Source: Hawkins (2001).

*All PG 76-22 Polymer Modified.

Hawkins (2001) compared the APA rutting potential between Superpave and Marshall mixtures. The following were the observations developed:

- Superpave 12.5 mm mixes were more stable and had less rutting potential than the Superpave 19 mm mixes, perhaps due to the different gradations.
- The author established that either for Superpave or Marshall designs, the specimens with higher dust asphalt ratios had the higher rutting potential.
- The 19 mm specimens with 7% of air voids had lower rutting potential than the specimens with 9% of air voids.
- The mixes with PG 76-22 polymer modified binder had less rutting potential than the mixes with unmodified binders.
- In general, the Superpave mixes had lower rutting potential than the Marshall mixes.

The author stated that using the APA properly during the mix design phase, can identify mixes susceptible to rutting and thereby improve pavement performance. . Hawkins (2001) recommended the use of specimens compacted at 7% air voids instead of 9% air voids; and maintaining the dust asphalt ratio at 0.60 to 1.20. Additionally, the author suggested continued use of the APA test with the configuration used for this study. Maximum APA rut depths were proposed for quality control applications. Table 2.20 presents the SCDOT APA tentative criteria. Finally, the author recommended developing a field performance study to validate the tentative criteria (Hawkins, 2001).

Table 2.20 SCDOT APA Tentative Criteria

NMAS	PG	Maximum Rut (mm) @8000 Cycles
19 mm	64-22	7.00
12.5	64-22	5.00
12.5 mm, 19 mm	76-22	3.00

Source: Hawkins (2001).

2.4.9 ORITE Evaluation of Loaded Wheel Tests

Research performed at the Ohio Research Institute for Transportation and the Environment (ORITE) for the Ohio Department of Transportation (ODOT), studied the effect of aggregate characteristics, gradations, and asphalt binders using several test

methods for evaluating rutting, fatigue cracking, and moisture susceptibility (Sargand and Kim, 2001). All mixes were designed using the Superpave method. The study included both fundamental and simulative laboratory tests:

- Triaxial repeated load test.
- Uniaxial static creep test.
- Indirect tensile resilient modulus test.
- Flexural beam fatigue test.
- Indirect tensile strength test.
- Moisture susceptibility test.
- Asphalt Pavement Analyzer.

In the second phase of the study, a subset of the mixes studied during the laboratory phase was evaluated in the ORITE accelerated pavement load facility (ORITE, 2004)

Coarse, intermediate, and fine gradations of 12.5 mm NMAS aggregate were evaluated for mixes made with crushed limestone. Additionally, laboratory and test track were performed on asphalt concrete with gravel aggregates. The binders evaluated were: polymer modified PG 70-22 Styrene-Butadiene-Rubber (SBR), polymer modified PG 70-22 Styrene-Butadiene-Styrene (SBS), and as a control unmodified PG 70-22.

Cylindrical specimens for the APA test were compacted using the Superpave Gyratory Compactor to target $7 \pm 0.5\%$ air voids. The APA tests were carried out at 60°C (140°F), with a wheel load of 511.5 N (115 lbf), and hose pressure of 690 kPa (100 psi) under dry and wet conditions, for rutting and moisture susceptibility, respectively. Rut measurements were conducted at 5, 500, 1,000, and 8,000 load cycles.

The APA results, not only for rutting potential, but also for moisture susceptibility, passed the ODOT specification of maximum 5 mm rut depth. Table 2.21 presents the APA rutting potential under dry conditions at 8,000 cycles. An analyses of variance on all APA dry data showed that binder type was statistically significant. Mixes with SBS modified binder rutted less than mixes with SBR modified binder and unmodified binder. Gradation type was not significant at a 5% significance level. Mixes

with crushed limestone demonstrated significantly less rutting potential less than mixes with gravel aggregates.

The results from the triaxial repeated load test and the uniaxial static creep test correlate with the results from the APA. The authors stated that the results agreed with the results obtained by Kandhal and Mallick (2000).

Table 2.21 ORITE in Cooperation with ODOT APA Rutting Potential

APA Rut Results Under Dry Condition Mixes 12.5 mm with PG 70-22, 7% air voids			
Aggregate	Gradation	Asphalt Type	Rut (mm) At 8000 Cycles
Limestone	Coarse	Unmodify	0.86
		SBS	0.72
		SBR	1.12
	Intermediate	Unmodify	0.99
		SBS	0.68
		SBR	0.95
	Fine	Unmodify	0.81
		SBS	0.54
		SBR	0.81
Gravel	NA	Unmodify	6.11
		SBS	4.73
		SBR	4.86

Source: Sargand and Kim (2001).

Three 12.5 mm crushed limestone mixes were evaluated at the ORITE APLF facility. Pad 1 consisted of a coarse aggregate gradation with PG 70-22 modified with SBS. Pad 2 had the same gradation with PG 70-22 unmodified binder. Pad 3 consisted of fine gradation with PG 70-22 unmodified binder. Test temperatures were 40°C (104°F) to 50°C (122°F). The rut results from the APLF are shown in the Table 2.22.

Table 2.22 ORITE-APLF Rutting Results

Test Condition	Pad	Gradation	NMAAS	PG	Rut Depth (mm) @ Number of Wheel Pass					
					0	1000	1500	3000	4000	6000
Speed: 3.2km/hr Test Temp: 40°C	1	Coarse	12.5	70-22 SBS	0.00	x	4.07	x	5.66	6.77
	2	Coarse	12.5	70-22 Unmodify	0.00	x	3.27	x	4.87	5.54
	3	Fine	12.5	70-22 Unmodify	0.00	4.61	5.89	6.79	x	8.77
Speed: 8.0km/hr Test Temp: 40°C	1	Coarse	12.5	70-22 SBS	0.00	2.17	2.87	4.29		
	2	Coarse	12.5	70-22 Unmodify	0.00	2.14	2.88	4.21		
Speed: 8.0km/hr Test Temp: 50°C	1	Coarse	12.5	70-22 SBS	0.00	1.49	2.43	4.77		
	2	Coarse	12.5	70-22 Unmodify	0.00	1.82	1.82	4.80		
	3	Fine	12.5	70-22 Unmodify	0.00	2.95	2.95	5.34		

Source: Sargand and Kim (2001).

Supplementary APA rutting tests were performed to compare with the ORITE-APLF results. The APA test setting was performed at 60°C (140°F), with a wheel load of 511.5 N (115 lbf), and hose pressure of 690 kPa (100 psi) under dry conditions. Six specimens of each mix were compacted in the Superpave Gyratory Compactor at 7±1% air voids. Figure 2.10 (Sargand and Kim, 2001) presents comparison of the APA rutting potential with the APLF test results.

Source: Sargand and Kim (2001).

Figure 2.10 Results of APA Test on Plant Mixes & Comparison with ORITE-APLF Test Results

For the two tests conditions, 3.2 km/hr at 40°C (104°F) and 8.0 km/hr at 50°C (122°F), pad 1 with the coarse gradation and SBS modified PG 70-22 exhibited the lowest rut depths. Conversely, pad 3, with the fine gradation and unmodified binder, exhibited the highest rut depths. The results from APA tests performed on samples of the material used to construct the pads, correlate well with the results from the APLF test at 3.2 km/hr (2mph) and 40°C (104°F). The authors attributed this observation to the fact that the APA wheel speed is closer to 3.2 km/hr than 8.0 km/hr (5mph). They concluded that the APA was a reliable tool for testing (Sargand and Kim, 2001).

2.4.10 NCAT Comparison of Simulative and Fundamental Tests

Research by NCAT compared the Repeated Shear at Constant Height and the Repeated Load Confined Creep test, to the Asphalt Pavement Analyzer, to recommend critical rut depths (Zhang, et al., 2002). For the testing, two coarse aggregates, granite and crushed gravel, were selected. Seven fine aggregates, which ranged from very rounded, FAA=38.6, to very angular FAA=50.1, were selected. The fine aggregates are described as:

- FA-2, Natural quartz sand with some chert, FAA=42.6
- FA-3, Uncrushed, natural quartz sand with some chert, FAA=42.6
- FA-4, Mined sandstone, cone crusher, FAA=49.7
- FA-6, Mined limestone, crushed by impact crusher, FAA=46.9
- FA-7, Mined granite, cone crusher, FAA=48.9
- FA-9, Mined diabase, impact crusher, FAA=50.1
- FA-10, Natural sand, FAA=38.6

Five 9.5 mm NMAAS aggregate gradations were used for the study: one above the restricted zone, ARZ; one below the restricted zone, BRZ; one through the restricted zone, TRZ; one humped through the restricted zone, HRZ; and one that crosses through the restricted zone, CRZ. The HRZ gradation was similar to the TRZ gradation and represents the gradation of natural sands. The CRZ gradation represents gradations that present stability problems.

Forty-one Superpave design mixtures with PG 64-22 binder were tested. Specimens were compacted in the Superpave Gyratory Compactor to target $6.0 \pm 0.5\%$ air voids. The APA test was carried out following the method GDOT-GDT-115 (Collins, et al., 1997). However, a test temperature of 64°C (147°F) was used, because this temperature corresponds to the high temperature of the standard performance grade for most projects in the southeast. The wheel load was 445 N (100 lbf) and the hose pressure was 690 kPa (100 psi). Rut measurements were taken at 8,000 load cycles manually, and for 17 mixes the rut depths were recorded using the automated data acquisition system. Table 2.23 presents the tests results.

Table 2.23 NCAT Test Results

9.5 mm Superpave Mixes with PG 64-22, 6±0.5% Air Voids						
Gradation	Aggregates		Opt. Asphalt	APA Ruts (mm)	RSCH	RLCC
	Fine Agg - #	Coarse Agg.	Content %	at 8000 Cyles	Strain (%)	Strain (%)
TRZ	FA-2	Granite	5.7	15.15	6.47	17.90
BRZ	FA-3	Granite	5.4	18.57	3.92	**
CRZ	FA-3	Granite	5.6	17.39	8.01	**
TRZ	FA-4	Granite	5.7	8.45	1.18	11.13
BRZ	FA-6	Granite	5.8	7.33	2.89	7.35
CRZ	FA-6	Granite	5.9	7.25	2.54	6.63
TRZ	FA-7	Granite	6.0	10.25	2.71	8.81
HRZ	FA-10	Granite	4.5	16.01	5.41	37.04
TRZ	FA-4	Granite	5.8	8.13	1.64	7.70
BRZ	FA-4	Granite	5.9	8.31	1.71	7.07
CRZ	FA-4	Granite	6.1	8.95	1.97	10.75
TRZ	FA-7	Granite	5.5	8.15	1.41	6.36
BRZ	FA-7	Granite	5.8	8.65	1.82	6.43
CRZ	FA-7	Granite	6.0	9.64	1.61	10.37
TRZ	FA-9	Granite	5.5	9.08	1.58	4.60
BRZ	FA-9	Granite	5.8	8.32	1.71	3.27
HRZ	FA-10	Granite	3.6	10.51	2.64	24.80
HRZ	FA-10	Granite	4.2	5.54	1.16	22.20
HRZ	FA-10	Gravel	4.0	10.94	1.25	25.11
BRZ	FA-6	Granite	5.3	4.82	1.11	3.19
ARZ	FA-6	Granite	5.3	4.55	1.13	1.40
TRZ	FA-6	Granite	5.0	4.31	0.94	1.80
CRZ	FA-6	Granite	5.7	5.54	1.30	2.88
BRZ	FA-7	Granite	6.0	4.62	1.59	3.75
TRZ	FA-7	Granite	5.7	4.97	0.96	3.82
BRZ	FA-7	Gravel	5.4	7.64	1.20	11.17
CRZ	FA-7	Gravel	5.6	7.76	1.44	12.62
BRZ	FA-4	Granite	6.0	7.84	1.33	8.79
ARZ	FA-4	Granite	6.1	7.28	1.30	5.57
TRZ	FA-4	Granite	5.8	7.06	1.36	3.93
CRZ	FA-4	Granite	6.2	7.53	1.57	7.07
BRZ	FA-4	Gravel	5.6	8.77	1.30	12.08
ARZ	FA-4	Gravel	5.7	7.83	1.25	11.97
TRZ	FA-4	Gravel	5.3	6.46	1.25	5.44
CRZ	FA-4	Gravel	5.6	7.86	1.88	8.40
ARZ	FA-9	Granite	5.7	5.12	0.92	0.83
TRZ	FA-9	Granite	5.6	4.64	0.85	4.70
BRZ	FA-9	Gravel	6.0	7.1	2.09	6.36
ARZ	FA-9	Gravel	5.5	5.37	1.94	2.62
TRZ	FA-9	Gravel	5.3	5.76	1.40	13.70
CRZ	FA-9	Gravel	5.7	5.49	1.12	7.29

Source: Zhang, et al. (2002).

** Test specimens failed prior to 3,600 load repetitions.

Source: Zhang, et al. (2002).

Figure 2.11 Correlations between APA, RSCH, and RLCC

The results from the fundamental test, RSCH and RLCC, correlated well with the rut result from the APA. Figure 2.11 (Zhang, et al., 2002) presents the relationships between the APA rut depth and the RSCH shear strain, and the APA rut depth and the RLCC permanent strain. For both relations, the slopes of the regressions lines were positive, which means that increases in plastic or permanent deformation strain corresponds with higher APA rutting potential (Zhang, et al., 2002).

Tentative rut depth criteria for the APA were proposed by the authors based on the results of this study and the work developed by Gabrielson (1992); and Bukowski and Harman (1997). Zhang, et al. (2002) stated that research by Gabrielson suggested that permanent strain values within the RLCC test of 10 to 13 percent are acceptable. Moreover, Zhang, et al. (2002) stated that research by Bukowski and Harman suggested that plastic shear strain within the RSCH test of 2 to 3 percent are acceptable, mixes

above 3 percent are considered poor performing and mixes below 2 percent are very rut resistant.

The authors, based upon the relationship between the APA and the RLCC (Gabrielson's strain values), established critical rutting potential range of 8.0 mm to 9.5 mm for the APA, as presented in the Figure 2.11. Furthermore, the authors, based upon the relationship between the APA and the RSCH (Bukoswki and Harman's strain values), established another critical rutting potential range of 8.2 mm to 11.0 mm for the APA, as presented in the Figure 2.11. Overlapping both rutting potential ranges, the final critical range for the APA would be 8.2 mm to 9.5 mm. Consequently, the authors recommend a maximum/critical rut depth value of 8.2 mm, when the test is developed at the high temperature of the standard PG grade. In this case, the standard PG grade was the PG 64-22, which means that the 8.2 mm critical rut depth is valid when the APA test is performed at 64°C (147°F).

Rutting potential criteria of 8.2 mm seem high when compared to the 5 mm criteria used by Georgia, Maryland, and Utah (Shami, et al., 1997). However, 5 mm criteria were established for a test temperature of 50°C. Using the temperature effect model (Shami, et al., 1997) to adjust 5 mm rut depth criterion to 64°C (147°F) after 8,000 load cycles, the authors found that the corresponding rut depth value was 9.56 mm. This value matches the upper limit of 9.5 mm. Figure 2.12 graphically presents the criteria (Zhang, et al., 2002). Table 2.24 shows the tentative criteria. The authors concluded that the APA test was suitable and could be used to assess the rutting potential until a fundamental test is developed (Zhang, et al., 2002; and Kandhal and Cooley, 2002b).

2.4.11 NCAT Evaluation of Aggregate Gradations

Another NCAT study evaluated the rutting potential of coarse and fine graded Superpave mixtures to determine if the restrictions on gradations are justified (Kandhal and Cooley, 2002a). Eight 9.5 mm, and six 19 mm Superpave design mixtures with binder PG 64-22 were evaluated. The mixes had two coarse aggregates, crushed granite and crushed gravel; and four fine aggregates, sandstone, limestone, granite, and diabase. The fine aggregates had different surface texture, particle shape and mineralogical composition. A coarse gradation below the restricted zone, BRZ, and fine gradation above the restricted zone, ARZ, were used for the aggregate combinations.

Source: Zhang, et al. (2002).

Figure 2.12 NCAT Graphic of Tentative Criteria

Table 2.24 NCAT Tentative Criteria

Relationship	Fundamental Tests	Simulative Tests	Tentative Criteria
RSCH-APA $R^2 = 0.684$	RSCH Plastic Shear Strain %	<8.245 - Good	<8.2 - Good >9.5 - Poor
	<2.0 - Good >3.0 - Poor	>10.979 - Poor	
RLCC-APA $R^2 = 0.526$	RLCC Permanent Strain	Corresponding APA Rut Depth	
	<10.0 - Good >13.0 - Poor	<8.068 - Good >9.486 - Poor	
Georgia's Criterion (Temperature Effect Model)	APA @ 50°C 5 mm	APA @ 64°C 9.559 mm	>9.6 - Poor

Source: Zhang, et al. (2002).

The mixes were evaluated with the Superpave Shear Tester (Repeated Shear at Constant Height), the Repeated Load Confined Creep test, and the Asphalt Pavement Analyzer. The authors did not perform the RSCH and RLCC tests on the 19 mm Superpave mixes, because the Zhang, et al. (2002) study showed that the three tests provided similar results. The APA test was performed at 64°C (147°F), with a wheel load of 445 N (100 lbf), and hose pressure of 690 kPa (100 psi). Cylindrical samples were compacted in the Superpave Gyratory Compactor to target 6.0±0.5% air voids. Rut measurements were conducted at 8,000 load cycles. Table 2.25 presents the tests results.

The 9.5 mm granite-coarse-and-limestone-fine aggregate combination mixes rutted less than the 19 mm crushed-gravel-and-granite-fine aggregate combination mixes. The APA rutting potential results passed a 9.5 mm rut depth criteria at 64°C (147°F). The results of the three rutting susceptibility tests, RSCH, RLCC, and APA, indicated that no significant differences in rutting potential occur between the coarse and the fine gradations. The authors concluded that the mix designers should not limited the Superpave mixes on the coarse or fine side of the restricted zone, because mixes with either gradation can perform well. Finally, the APA test was recommended to evaluate the rutting potential of any mixture (Kandhal and Cooley, 2002a).

Table 2.25 NCAT Test Results

Superpave Mixes, 6±0.5% Air Voids									
Mix ID	Aggregate		Gradation	Opt. Asphalt Content, %	NMAS	PG	APA Ruts (mm) 8000 Cycles	RSCH % Strain	RLCC % Strain
NCAT #	Coarse	Fine							
NCAT 1	Granite	Limestone	BRZ	5.3	9.5	64-22	4.82	1.105	3.190
NCAT2	Granite	Limestone	ARZ	5.3	9.5	64-22	4.55	1.126	1.400
NCAT3	Granite	Sandstone	BRZ	6.0	9.5	64-22	7.84	1.309	8.790
NCAT4	Granite	Sandstone	ARZ	6.1	9.5	64-22	7.28	1.301	5.570
NCAT5	Crushed Gravel	Sandstone	BRZ	5.6	9.5	64-22	8.77	1.295	12.080
NCAT6	Crushed Gravel	Sandstone	ARZ	5.7	9.5	64-22	7.83	1.251	11.970
NCAT7	Crushed Gravel	Diabase	BRZ	6.0	9.5	64-22	7.1	2.087	6.360
NCAT8	Crushed Gravel	Diabase	ARZ	5.5	9.5	64-22	5.37	1.942	2.620
NCAT9	Crushed Gravel	Granite	ARZ	4.6	19	64-22	9.22	x	x
NCAT10	Crushed Gravel	Granite	BRZ	5.0	19	64-22	7.88	x	x
NCAT11	Crushed Gravel	Sandstone	ARZ	4.8	19	64-22	8.75	x	x
NCAT12	Crushed Gravel	Sandstone	BRZ	5.0	19	64-22	8.19	x	x
NCAT13	Granite	Diabase	ARZ	4.6	19	64-22	5.88	x	x
NCAT14	Granite	Diabase	BRZ	4.7	19	64-22	7.63	x	x

Source: Kandhal and Cooley (2002a).

2.4.12 FDOT Evaluation of Effect of Binder on Rutting Potential

Moseley, et al. (2003) studied the effect of different binder types on rutting potential using the Asphalt Pavement Analyzer. Fourteen 9.5 mm, and 12.5 mm Superpave design mixes with binders PG 76-22, PG 67-22, PG 67-22 with five percent Asphalt Rubber Binder (ARB-5, for dense-graded friction coarses), and PG 67-22 with twelve percent Asphalt Rubber Binder (ARB-12, for open-graded friction coarses) were tested. The PG 76-22 is a modified binder. All 9.5 mixes were fine graded. Both fine and coarse graded 12.5 mm mixes were studied. Cylindrical specimens were compacted using the Superpave Gyratory Compactor at $7\pm0.5\%$, and $7\pm1.0\%$ air voids content, for unmodified and rubber modified binders, respectively. The APA tests were conducted at 64°C (147°F), with a wheel load of 445 N (100 lbf), and hose pressure of 690 kPa (100 psi). Rutting potential was measured at 8,000 load cycles (Page, 2004). Table 2.26 shows the APA rutting potential.

The results of the test showed that the most rutting resistant binder was the PG 76-22, followed by the PG 67-22 ARB-12, PG 67-22 ARB-5, and the neat PG 67-22. The coarse 12.5 mm gradation had the lowest rutting potential, followed by the 12.5 mm fine, and the 9.5 mm fine. The authors concluded that the APA was sensitive to the different types of binders and gradations (Moseley, et al., 2003).

Table 2.26 FDOT APA Rutting Potential at 8000 cycles

Mix Type	% AC	PG	NMAS	APA Rut (mm)
Fine	8.4	76-22	9.5	2.40
Fine	7.9	76-22	12.5	2.20
Coarse	7.9	76-22	12.5	1.20
Fine	8.7	67-22 ARB 5	9.5	4.10
Fine	8.2	67-22 ARB 5	12.5	3.80
Coarse	8.2	67-22 ARB 5	12.5	2.40
Fine	8.7	67-22	9.5	5.90
Fine	8.2	67-22	12.5	3.90
Coarse	8.2	67-22	12.5	2.90
Fine	8.7	67-22 ARB 12	9.5	4.40
Fine	8.2	67-22 ARB 12	12.5	3.00
Coarse	8.2	67-22 ARB 12	12.5	1.70
Fine	8.7	67-22 ARB 12	12.5	3.10
Coarse	8.7	67-22 ARB 12	12.5	1.90

Source: Moseley, et al. (2003).

2.4.13 NCAT Evaluation of APA Test Parameters and Configuration

Research sponsored by the National Cooperative Highway Research Program (NCHRP) at NCAT evaluated the suitability of the Asphalt Pavement Analyzer test method to assess the rutting potential, and its use in field Quality Control/Quality Acceptance (QC/QA) operations (Kandhal and Cooley, 2003). The research was performed in three phases. In Phase I, the authors review previous studies of the APA and other loaded wheel testers. Based on the literature reviewed, the investigators designed a comprehensive testing program for laboratory testing, using mixes of known field rutting performance that represent different materials and climatic conditions of the United States.

Phase II involved the development of the laboratory and field testing. Ten mixes of known field rutting performance were tested at three different laboratories and test track facilities:

- WesTrack (Nevada)
- Minnesota Road Research Project (MnRoad)
- FHWA Accelerated Loading Facility (ALF) at Turner-Fairbank Highway Research Center (Virginia)

The WesTrack mixes were three 19 mm Superpave design with PG 64-22 binder; two mixes were fine-graded and one was coarse graded. The MnRoad mixes were three 12.5 mm mixes, one Superpave design and the other two Marshall designs. The Superpave mixture had AC-20 binder, which should perform similar to PG 64-22; and the Marshall mixtures had a 120/150 penetration graded asphalt binder, which should perform similar to PG 58-28. The FHWA-ALF mixes included three 19 mm, and one 37.5 mm Superpave design. Three types of binder were used; AC-10, AC-20, and a Styrene- Butadiene-Styrene, SBS, modify binder. The FHWA evaluated these binders using the Performance Grading method and determined the AC-10 and AC-20 met the requirements for PG 58-28 and PG 64-22, respectively. The modified binder met the performance grade requirements for a PG 82-22.

For each type of mix, beam and cylindrical specimens were compacted employing the Asphalt Vibratory Compactor and the Superpave Gyratory Compactor, respectively.

Beam samples were compacted to target air void contents: $5\pm0.5\%$ and $7\pm0.5\%$.

Cylindrical specimens were compacted to target air void contents: $4\pm0.5\%$ and $7\pm0.5\%$.

The mixes were tested in the APA at two temperatures, the high standard performance grade temperature for the location, and the high standard performance grade temperature for the location plus 6°C . The high standard performance grade temperature was 64°C (147°F) for WesTrack and 58°C (136°F) for the MnRoad and FHWA-ALF sections.

Two types of hoses were used in the APA, a standard and a large, with 25 mm and 38 mm of external diameters, respectively. Rut measurements were manually taken at 10,000 load cycles. For the entire study, the wheel load was 533 N (120 lbf), and the hose pressure was 830 kPa (120 psi.). The APA rutting potential was compared with the field ruts of the mixes at the different testing facilities. Tables 2.27 and 2.28 present the APA rutting potential and field ruts of the WesTrack mixes, respectively. Tables 2.29 and 2.30 show the APA rutting potential and field ruts of the MnRoad mixes, respectively. Tables 2.31 and 2.32 present the APA rutting potential and field ruts of the FHWA ALF mixes, respectively.

Table 2.27 NCAT-NCHRP APA Rutting Potential of WesTrack Mixes

19 mm Superpave Mixes with PG 64-22						
Test Temperature	Hose Diameter	Specimen Type	Air Void %	APA Rut Results (mm) at 10000 Cycles		
				Section 15	Section 19	Section 24
PG High	25 mm	Cylinder Beam	7 ± 0.5	10.13	6.12	8.17
			7 ± 0.5	8.52	9.14	8.70
	38 mm	Cylinder Beam	7 ± 0.5	8.30	4.19	4.05
			7 ± 0.5	6.46	7.99	6.39
PG High + 6°C	25 mm	Cylinder Beam	7 ± 0.5	12.78	9.61	10.56
			7 ± 0.5	12.65	11.14	11.69
	38 mm	Cylinder Beam	7 ± 0.5	12.01	7.22	4.57
			7 ± 0.5	9.33	6.21	8.40
PG High	25 mm	Cylinder Beam	5 ± 0.5	6.64	7.76	8.27
			4 ± 0.5	6.08	10.84	13.33
	38 mm	Cylinder Beam	5 ± 0.5	6.36	5.35	7.54
			4 ± 0.5	5.10	5.76	7.08
PG High + 6°C	25 mm	Cylinder Beam	5 ± 0.5	8.81	8.80	9.29
			4 ± 0.5	11.57	13.07	14.88
	38 mm	Cylinder Beam	5 ± 0.5	7.83	6.10	5.47
			4 ± 0.5	5.64	6.87	5.24

Source: Kandhal and Cooley (2003).

Table 2.28 NCAT-NCHRP Field Rut Results of WesTrack

19 mm Binder PG 64-22			
Section #	Design	Field Ruts (mm)	Corresponding ESALs (10 ⁶)
Section 15	Superpave	9.2	5.0
Section 19	Superpave	14.5	5.0
Section 24	Superpave	23	2.7

Source: Kandhal and Cooley, (2003).

Table 2.29 NCAT- NCHRP APA Rutting Potential of MnRoad Mixes

NCAT-NCHRP REPORT 508 APA Ruts Results (mm) of MnRoad Mixes						
Test Temperature	Hose Diameter	Specimen Type	Air Void %	APA Rut Results at 10000 Cycles		
				Cell 16	Cell 20	Cell 21
PG High	25 mm	Cylinder	7±0.5	9.91	17.63	8.08
		Beam	7±0.5	11.20	12.79 a	14.87 b
	38 mm	Cylinder	7±0.5	6.72	12.19	11.52
PG High + 6°C	25 mm	Cylinder	7±0.5	11.18 c	21.42	22.37
		Beam	7±0.5	19.86	24.54	24.37
	38 mm	Cylinder	7±0.5	7.69	13.47	14.67
PG High	25 mm	Cylinder	5±0.5	5.43	17.03	15.96
		Beam	4±0.5	7.77	19.89	20.61
	38 mm	Cylinder	5±0.5	6.72	10.43	8.33
PG High + 6°C	25 mm	Cylinder	5±0.5	14.49	19.44	19.33
		Beam	4±0.5	29.45	25.54	25.14
	38 mm	Cylinder	5±0.5	8.52	9.58	10.92
		Beam	4±0.5	8.97	16.09	15.62

Source: Kandhal and Cooley (2003).

a = Test was terminated at 5454 cycles because the wheels began riding on the samples.

b = Test was terminated at 5722 cycles because the wheels began riding on the samples.

c = Test was terminated at 5410 cycles because the wheels began riding on the samples.

Table 2.30 NCAT-NCHRP Field Rut Results from MnRoad

NMAS 12.5 mm					
Cell #	Design	Binder Used	Binder Perform as	Field Ruts (mm)	Corresponding ESALs (10 ⁶)
Cell 16	Superpave	AC-20	PG 64-22	5.3	3.0
Cell 20	Marshall	120/150 PGAB*	PG 58-28	18.8	2.4
Cell 21	Marshall	120/150 PGAB*	PG 58-28	12.1	3.0

Source: Kandhal and Cooley (2003).

*PGAB, Penetration Graded Asphalt Binder

Table 2.31 NCAT-NCHRP APA Rutting Potential of FHWA ALF Mixes

Test Temperature	Hose Diameter	Specimen Type	Air Void %	APA Rutting Potential (mm) at 10000 Cycles			
				Lane 5	Lane 7	Lane 10	Lane 12
PG High	25 mm	Cylinder	7±0.5	5.17	1.40	4.17	5.61
		Beam	7±0.5	9.53	2.36	5.04	7.43
	38 mm	Cylinder	7±0.5	6.11	2.49	5.68	3.98
		Beam	7±0.5	7.55	2.17	4.62	4.67
PG High + 6°C	25 mm	Cylinder	7±0.5	6.54	2.60	5.02	8.95
		Beam	7±0.5	10.14	3.81	7.35	6.88
	38 mm	Cylinder	7±0.5	6.54	3.51	5.74	6.11
		Beam	7±0.5	10.24	2.51	6.52	6.87
PG High	25 mm	Cylinder	5±0.5	6.47	3.19	4.84	2.38
		Beam	4±0.5	9.02	2.26	7.79	8.07
	38 mm	Cylinder	5±0.5	3.71	1.59	3.68	3.12
		Beam	4±0.5	6.12	2.07	5.04	4.48
PG High + 6°C	25 mm	Cylinder	5±0.5	8.94	2.10	8.27	7.98
		Beam	4±0.5	7.94	3.26	8.54	9.63
	38 mm	Cylinder	5±0.5	8.60	3.15	4.72	4.06
		Beam	4±0.5	10.08	2.80	5.13	6.66

Source: Kandhal and Cooley (2003).

Table 2.32 NCAT-NCHRP Field Rut Results from FHWA ALF

Lane #	Mixture Design	NMAS	Binder Used	Binder Perform as	Field Ruts (mm) [ALF Passes]	Field Ruts (mm) After 10 Million ESAL
Lane 5	Superpave	19	AC-10	PG 58-28	27.4 [4000]	1370
Lane 7	Superpave	19	SBS Modify Binder	PG 82-22	18.1 [200000]	18
Lane 10	Superpave	19	AC-20	PG 64-22	36.3[10000]	520
Lane 12	Superpave	37.5	AC-20	PG 64-22	24.1 [200000]	24

Source: Kandhal and Cooley (2003).

Based on the results of this phase, a recommended testing protocol for the Asphalt Pavement Analyzer was developed. The authors started the analysis by checking the effects of the experimental variables on APA rutting potential. With respect to air voids, test temperature, the hose diameter, and sample type, the following conclusions were drawn during the second phase:

- Air voids: APA rutting potential was compared at the two levels of air void content, Figure 2.13 (Kandhal and Cooley, 2003). The cylindrical and beam compacted at 4% and 5% air voids, respectively, had closer results to the field than the cylindrical and beam specimens compacted at

7% air voids. However, the final conclusion was that "the air voids did not appear to have significant effect" on the rut measurements.

- Test temperature: It was concluded that the test performed at the high standard performance grade temperature for a location correlated better with field rutting performance than the samples tested at the high standard performance grade for a location plus 6°C grade. Furthermore, it was concluded that the higher the APA test temperature, the higher the rut depth in the specimens. Figure 2.14 (Kandhal and Cooley, 2003) presents the effects of test temperatures on APA rutting potential.
- Hose diameter: The standard and the large hose predicted field rutting reasonably the same. The standard hose showed less variability than the large one. Figure 2.15 (Kandhal and Cooley, 2003) presents the effects of hose diameter on APA rutting potential.
- Sample type: It was concluded that the beam and cylindrical provide similar results at low APA rut depths (< 4mm). Although, when mixes of high rutting potential were tested (APA rut depths > 4 mm), the beam samples have higher rut depths than the cylindrical specimens. Figure 2.16 (Kandhal and Cooley, 2003) presents the effects of test sample type on APA rutting potential.
- APA and field rut depths correlated well on an individual project basis for the WesTrack, MnRoad, and FHWA ALF mixes.

Based on the conclusions, two APA testing combinations were selected to develop tentative rutting potential criteria:

- Combination 4PGSC: Cylindrical specimens compacted at 4% air voids, tested at the PG temperature using the standard hose.
- Combination 5PGSB: Beam specimens compacted at 5% air voids, tested at the PG temperature using the standard hose.

Source: Kandhal and Cooley (2003).

Figure 2.13 NCAT-NCHRP Effects of Air Voids on APA Rutting Potential

Source: Kandhal and Cooley (2003).

Figure 2.14 NCAT-NCHRP Effects of Test Temperature on APA Rutting Potential

Source: Kandhal and Cooley (2003).

Figure 2.15 NCAT-NCHRP Effects of Hose Diameter on APA Rutting Potential

Source: Kandhal and Cooley (2003).

Figure 2.16 NCAT-NCHRP Effects of Sample Type on APA Rutting Potential

Tentative criteria were developed from a combination of the MnRoad and WesTrack field and APA data sets. Figures 2.17 and 2.18 (Kandhal and Cooley, 2003) present the 4PGSC and 5PGSB data, respectively. The y-axis is the field ruts, from MnRoad and WesTrack, divided by the square root of the equivalent single axle loads (ESALs). The y-axis data points were defined as the field rut depth divided by the square root of the corresponding traffic. The values used for this calculation are given in Tables 2.27 and 2.29 for the WesTrack and MnRoad sections, respectively. The corresponding APA data are given in Tables 2.28 and 2.30, respectively. A line was constructed based on the data points, but the manner for determining the location and shape of the line was not documented. For development of the APA criteria, a critical field rut of 12.5 mm was assumed to represent the maximum acceptable level of rutting in the field. The assumed critical field rut value was divided by the square root of 2, 3, 5, 10, and 30 million ESALs. The resulting values were projected from the y axis to the line, then projected to the x-axis to select the proposed criteria as given in Table 2.33. The process was repeated using Figure 2.18 to establish the criteria for the 5PGSB combination. The criteria seemed logical because, as the traffic level increases, the required rut resistance also increases.

These criteria are based on 10,000 load repetitions used for the research. However, the researchers recommended test protocol specifies 8,000 repetitions with the rut depths measured manually. Through a series of transformations, the researchers developed the criteria in Table 2.34 to accommodate this need.

At the completion of the second phase the researchers developed a testing method following the standard AASHTO format, including information on the apparatus, calibration of the components, preparation of samples, etc. The operational parameters that were selected were:

- beam samples prepared with the Asphalt Vibratory Compactor to a target of 5 percent air voids or cylindrical samples prepared with the Superpave Gyratory Compactor to 4 percent air voids,
- wheel load was 534 N (120 lbf),
- hose pressure was 830 kPa (120 psi),

Source: Kandhal and Cooley (2003).

Figure 2.17 NCAT-NCHRP Selected Combination 4PGSC

Source: Kandhal and Cooley (2003).

Figure 2.18 NCAT-NCHRP Selected Combination 5PGSB

Table 2.33 Tentative APA Criteria for Manual Rut Measurements after 10,000 Cycles

Traffic Level ESALs (10^6)	Combination	
	4PGSC	5PGSB
2.0	12 mm	15 mm
3.0	10 mm	13 mm
5.0	7 mm	10 mm
10.0	5 mm	7 mm
30.0	3 mm	4 mm

Source: Kandhal and Cooley (2003).

Table 2.34 Tentative APA Criteria for Manual Rut Measurements after 8,000 Cycles

Traffic Level ESALs (10^6)	Combination*	
	4PGSC	5PGSB
2.0	11.0 mm	14.0 mm
3.0	9.5 mm	12.0 mm
5.0	6.5 mm	9.5 mm
10.0	4.5 mm	6.5 mm
30.0	3.0 mm	3.5 mm

Source: Kandhal and Cooley (2003).

*Values have been rounded to the nearest 0.5 mm

- test temperature equal to high temperature of the standard Superpave binder performance grade identified by the specifying agency. The test temperature is not increased when the grade of binder specified for a project is "bumped" to accommodate either slow traffic or high ESALs.
- manual measurement of rutting potential after 8,000 repetitions.

It should be noted that the recommended wheel load force and pressure in the hose were selected based on the results of Williams and Prowell (1999). Experiments were not performed during this research to validate these values. All samples were also tested to 10,000 repetitions with automatic data recording for lower number of repetitions.

Next, an experimental plan was developed to validate the APA test method. In this phase, fourteen mixes with known field performance, which were not included in Phase II, were tested following the recommended APA test procedure. The mixes were reproduced in the laboratory with original materials. Figures 2.19 and 2.20 present the comparison between the APA and data from I-80 in Nevada and the NCAT test track, respectively. There was not a good comparison between the lab and field performance.

Figures 2.21 and 2.22 present the comparison between the laboratory ruts, from cylinder and beam specimens, respectively, versus field ruts, for the second and third phases of the project.

It was concluded that the relationship between the APA rutting potential and the field performance varies from project to project depending on location and traffic characteristics. Therefore, it is not possible to estimate the field performance from APA rutting potential, on a specific project, from relationships developed on other projects with a different environment (Kandhal and Cooley, 2003).

2.5 Summary Rutting–APA Literature Review

The majority of the states have adopted the Superpave design since 2000 (Kandhal and Cooley Jr., 2002b). However, the Superpave volumetric mix design does not have a fundamental-mechanical test to evaluate the permanent deformation of the diverse types of mixtures. Therefore, different agencies are employing simulative test in order to evaluate mixes. The Asphalt Pavement Analyzer is one of the simulative tests most used in the states. Several studies from different federal and state agencies were included in the APA literature review. The following is the summary of the APA literature review.

2.5.1 Summary of APA Test Parameters

Since the APA was developed, it has been used in several research projects. Since this is a relatively new test method, there has been a wide variety of test parameters used as summarized in Table 2.35. Initially, the Georgia Loaded Wheel Tester was used, but it has been replaced by the commercial version, the APA. The Asphalt Vibratory Compactor was developed in conjunction with the GLWT. However, both the GLWT and the APA have the ability to test samples prepared with the Superpave Gyratory Compactor. There does not appear to be a benefit to using either type of sample, other than the convenience advantage of the SGC.

Collins, et al. (1995) recommended compacting samples to $7 \pm 1\%$. This was later revised to $7 \pm 0.5\%$. Research has been performed air contents of 4% to 9%. Kandhal and Cooley (2003) did not find important differences between 4% and 7%. However, Hawkins (2001) found differences between 7% and 9%, based on a limited data set.

Source: Kandhal and Cooley (2003).

Figure 2.19 NCAT-NCHRP APA Ruts versus Field Ruts NDOT

Source: Kandhal and Cooley (2003).

Figure 2.20 NCAT-NCHRP APA Ruts versus Field Ruts NCAT

Source: Kandhal and Cooley (2003).

Figure 2.21 Comparisons between Laboratory (4PGSC) and Field Ruts Phase II and III

Source: Kandhal and Cooley (2003).

Figure 2.22 Comparisons between Laboratory (5PGSB) and Field Ruts Phase II and III

Table 2.35 Summary of APA Test Procedure Parameters

Study	Equipment	Compaction	Air Void %	Wheel Load (lbf)	Hose Pressure (psi)	Temperature °C
Collins, et al. (1995)	GLWT	AVC, SGC	7±1	100	100	40
Shami, et al. (1997)	GLWT	AVC	4±1	100	100	40,50,60
Collins, et al. (1997)	APA	AVC, SGC	7±1	100	100	50
Williams and Prowell (1999)	APA	AVC, SGC	7	120	120	60
Prowell (1999)	APA	AVC	7	120	120	49
Maupin (1998)	GLWT	RWC ¹	7	100	100	38
Maupin (1998)	GLWT	RWC ¹	7	120	120	49
Maupin (1998)	APA	AVC	7	120	120	49
Jackson and Baldwin (2000)	APA	SGC	7±1	100	100	50
Choubane, et al. (2000)	APA	AVC, SGC	7	122	100	41
West, et al. (1991)	GLWT	RWC ¹	6	122	100	41
Kandhal and Mallick (2000)	APA	SGC	4	100	100	64
Brown, et al. (2001)-Recommended Test	APA	SGC	4	100	100	High PG (64) ³
Hawkins (2001)	APA	AVC	8 (7, 9) ⁴	100	100	64
Sargand and Kim (2001)	APA	SGC	7±0.5	115	100	60
Zhang, et al. (2002)	APA	SGC	6±0.5	100	100	64
Kandhal and Cooley (2002a)	APA	SGC	6±0.5	100	100	64
Moseley, et al. (2003)	APA	SGC	7±0.5, 7±1.0	100	100	64
Kandhal and Cooley (2003)	APA	AVC	5±0.5, 7±0.5	120	120 ²	58, 64, 70
	APA	SGC	4±0.5, 7±0.5	120	120 ²	58, 64, 70

¹ Rolling Wheel Compactor² Two hose sizes³ High Temperature for selected PG grade, Brown's research was 64°C⁴ Testing developed using specimens compacted at 8% air voids, and duplicates were made at 7%, and 9% air voids

NCAT recommends a target void content of 4% for cylinder and 5% for beam samples (Kandhal and Cooley, 2003).

Collins, et al. (1995) recommended a load force of 100 lbf, a tube pressure of 100 psi, and 8,000 repetitions. For the most part, these recommendations have been followed. Williams and Prowell (1999) recommended a hose pressure of 120 psi and wheel load of 120 lbf. The most recent NCAT research adopted this recommendation without experimental evaluation (Kandhal and Cooley, 2003). Research has not been performed to develop a correlation between rutting potential measured under these different loading conditions. If the NCAT recommendations are followed in the future, the previous work with the APA will be invalid due to the empirical nature of the test.

Due to the viscous nature of asphalt, test temperature has an important influence on the results produced by the APA. Collins, et al. (1995) recommended a test temperature of 40°C (104°F), for the GLWT. Maupin (1998) experienced difficulties trying to maintain 49°C (120°F) with the GLWT. The APA does not appear to have this

problem. Collins et al. (1997) recommended a test temperature of 50°C (122°F), for the APA. Kandhal and Cooley (2003) reported test results at 70°C (158°F). Their recommendation is to test at the high temperature of the performance grade binder, selected based on environment, without modifications for traffic conditions. Shami, et al. (1997) developed a temperature effect model which may be used to compensate for different test temperatures. However, their research covered the range of 40°C (104°F) to 60°C (140°F). Use of the TEM for 70°C (158°F) would be an extrapolation with potential erroneous results.

2.5.2 Summary of APA Evaluation of Mix Parameters

Different mix parameters have been used to determine APA's criteria, for quality control procedures, and field performance. Table 2.36 presents the summary of mix design parameters. Shami, et al. (1997) developed the temperature effect model using the GLWT to test 12.5 mm and 19 mm Superpave mixes with AC-30 binder. Maupin (1998) performed testing with the GLWT and the APA employing 12.5 mm Superpave mixes to evaluate their sensitivity to different binder types, PG 58-22, PG 64-22, PG 70-22, PG 76-22 modified, and PG 82-22 modified. Prowell (1999) continued Maupin's work and performed the APA test using 12.5 mm Marshall mixes with PG 64-22, PG 70-22, and PG 76-22 modified binders. APA tentative criteria for three VDOT types of mixes were proposed as guidance for the district material engineers.

Jackson and Baldwin (2000) compared the rutting potential of 19 mm Marshall mixes with AC-20, and AC-20 modified binder, with 19 mm Superpave mixes with PG 64-22 and PG 76-22 modified binder. The outcome showed that the Superpave mixes have higher rut resistance. Choubaine, et al. (2000) tested 12.5 mm Marshall mixes with AC-20 binder in the APA. The results were compared with the field performance and the APA successfully ranked the mixes. Additionally, the APA rutting potential was compared with West, et al. (1991) GLWT rutting potential, and the outcome was also consistent.

Kandhal and Mallick (2000) tested 12.5 mm and 19 mm Superpave mixes with PG 58-22 and PG 64-22 binders in the APA. The rutting potential was compared with the Superpave Shear Tester results and fair correlations were established between the tests. Brown, et al. (2001) performed the APA test employing 12.5 mm Superpave mixes

Table 2.36 Summary of Mix Design Parameters

Study	% Air Void	Mix Design	NMAS	Binder Type	Validation/Criteria
Shami, et al. (1997)	4±1	Superpave	12.5	AC-30	Georgia temperature effect model (TEM)
	4±1	Superpave	19	AC-30	
Williams and Prowell (1999)	7	NA	NA	PG 64-18	Westrack Ranking.
	7	NA	NA	PG 64-22	
Prowell (1999)	7	Marshall	12.5	PG 64-22	APA Tentative Criteria.
	7	Marshall	12.5	PG 70-22	
	7	Marshall	12.5	PG 76-22*	Ranking.
Maupin (1998)	7	Superpave	12.5	PG 58-22	
	7	Superpave	12.5	PG 64-22	
	7	Superpave	12.5	PG 70-22	
	7	Superpave	12.5	PG 76-22*	
	7	Superpave	12.5	PG 82-22*	
Jackson and Baldwin (2000)	7±1	Marshall	19	AC-20	Comparison of APA rutting potential between Marshall and Superpave mixes.
	7±1	Marshall	19	AC-20*	
	7±1	Superpave	19	PG 64-22	
	7±1	Superpave	19	PG 76-22*	
Choubane, et al (2000)	7	Marshall	12.5	AC-20	Comparisons between APA and Field; and APA and GLWT. Evaluation of APA test variability.
West, et al. (1991)	6	Marshall	12.5	AC-20	
Kandhal and Mallick (2000)	4	Superpave	12.5	PG 58-22	Analysis of aggregate gradation and binders. Comparisons between APA and SST; and APA and Field.
	4	Superpave	12.5	PG 64-22	
	4	Superpave	19	PG 58-22	
	4	Superpave	19	PG 64-22	
Brown, et al. (2001)	4	Superpave	12.5	PG 64-22	Tentative Configurations for APA, FRT, HWT
Hawkins (2001)	8 (7, 9) ¹	Marshall	12.5	PG 64-22	Evaluations of aggregates, binder type, percent of air voids, and dust/asphalt ratio were performed. Comparison of APA rutting potential between Marshall and Superpave mixes.
	8	Marshall	12.5	PG 76-22*	
	8 (7, 9) ¹	Superpave	12.5	PG 64-22	
	8	Superpave	12.5	PG 76-22*	
	8 (7, 9) ¹	Superpave	19	PG 64-22	
Sargand and Kim (2001)	7±0.5	Superpave	12.5	PG 70-22	Evaluation of Binder type. Comparison between APA and Field.
	7±0.5	Superpave	12.5	PG 70-22*	
	7±0.5	Superpave	12.5	PG 70-22*	
	7±0.5	Superpave	12.5	PG 70-22*	
Zhang, et al. (2002)	6±0.5	Superpave	9.5	PG 64-22	Comparison between the APA and SST. APA tentative criteria were proposed.
Kandhal and Cooley (2002a)	6±0.5	Superpave	9.5	PG 64-22	Evaluation of aggregates gradation.
	6±0.5	Superpave	19	PG 64-22	Comparison between the APA and SST.
Moseley, et al. (2003)	7±0.5, 7±1.0	Superpave	9.5	PG 67-22	Evaluation of Binder type.
	7±0.5, 7±1.0	Superpave	9.5	PG 76-22*	
	7±0.5, 7±1.0	Superpave	12.5	PG 67-22	
	7±0.5, 7±1.0	Superpave	12.5	PG 76-22*	
Kandhal and Cooley (2003)	5±0.5, 7±0.5	Marshall	12.5	AC-20	Evaluation of air voids, tests temperature, hose diameter, sample type. Comparison between APA and Field. Comparison between the APA and the HWT.
	4±0.5, 7±0.5	Marshall	12.5	AC-20	
	5±0.5, 7±0.5	Superpave	12.5	AC-20	
	4±0.5, 7±0.5	Superpave	12.5	AC-20	
	5±0.5, 7±0.5	Superpave	19	AC-10 (PG 58-28)	
	4±0.5, 7±0.5	Superpave	19	AC-10 (PG 58-28)	
	5±0.5, 7±0.5	Superpave	19	AC-20 (PG 64-22)	
	4±0.5, 7±0.5	Superpave	19	AC-20 (PG 64-22)	
	5±0.5, 7±0.5	Superpave	19	PG 64-22	
	4±0.5, 7±0.5	Superpave	19	PG 64-22	
	5±0.5, 7±0.5	Superpave	19	SBS (PG 82-22)*	
	4±0.5, 7±0.5	Superpave	19	SBS (PG 82-22)*	
	5±0.5, 7±0.5	Superpave	37.5	AC-20 (PG 64-22)	
	4±0.5, 7±0.5	Superpave	37.5	AC-20 (PG 64-22)	

* Modified

¹ Testing developed using specimens compacted at 8% air voids, and duplicates were made at 7%, and 9% air voids

with PG 64-22; and testing configurations were proposed for the APA, HWTD and FRT. Hawkins (2001) compared the rutting potential of 12.5 mm Marshall with PG 64-22 and PG 76-22 modified binder; with 12.5 mm and 19 mm Superpave mixes with PG 64-22 and PG 76-22 modified binder. Based on the results, tentative criteria were proposed for the APA.

Sargand and Kim (2001) tested 12.5 mm Superpave mixes with PG 70-22, and PG 70-22 modified binder in the APA under dry and wet conditions. The results from the rutting potential and the moisture susceptibility pass the 5 mm ODOT criteria. Moreover, comparison between the results of the Accelerated Pavement Loading Facility at Ohio University and the APA rutting potential was conducted, and the outcome was consistent. Zhang, et al. (2002) tested 9.5 mm Superpave mixes with PG 64-22. The APA rutting potential was compared with the fundamental outcome from Superpave Shear Tester, and tentative criteria were proposed. Kandhal and Cooley (2002) continued testing 9.5 mm and 19 mm mixes with PG 64-22 binder. Comparison with the Superpave Shear Tester outcome was also performed and the results were consistent.

Finally, Kandhal and Cooley (2003) performed testing using 12.5 mm Marshall mixes with AC-20 binder; 12.5 mm Superpave mixes with AC-20 binder, 19 mm Superpave with AC-10, AC-20, PG 64-22, and SBS modified binder; and 37.5 mm Superpave with AC-20 binder. Comparison of the APA rutting potential and field performance was conducted and the results showed differences.

2.6 Automatic Road Analyzer in West Virginia

The West Virginia Department of Transportation has been using the services of Roadware Group Inc. for pavement condition evaluation. Roadware Group Inc. is a multinational company specialized in infrastructure, pavement management technology, and data collection services. They developed hardware and software for collecting pavement condition data. Several SHAs use the Automatic Road Analyzer to collect the data for their pavement management systems.

The ARAN, Figure 2.23 (Roadware Group Inc, 2004), is a specially equipped vehicle that has the capability of measuring and recording up to 36 characteristics of pavements while traveling at posted speed limits to provide accurate and consistent data

Source: Roadware Group Inc. Web site (2004).

Figure 2.23 Automatic Road Analyzer

in a short period of time. A set of computers connected to sensors, lasers, inertial measurement units, accelerometers, ultrasonic transducers, and digital cameras gather the data. The equipment includes:

- Distance Measuring Instrument (DMI), which measures the ARAN linear distance traveled.
- Global Positioning System (GPS) uses to provide the geographical position and to create maps.

- Laser SDP, longitudinal profile measurement system, which determines the longitudinal profile of the road surface and determines the roughness of the road in terms of International Roughness Index (IRI).
- Laserlux, subsystem of ARAN, which uses a scanning laser to measure the retro-reflectivity of pavement markings.
- Laser XVP, laser transverse profiler, which uses dual scanning lasers to measure the transverse profile and rutting of the road.
- Panoramic right-of-way video, which produce video-logs of the road.
- Position Orientation System for Land Vehicles (POS LV) measure the road cross-fall, the radius and super-elevation of curves and the grade of the road profile.
- Smart Texture device for measuring the mega and macro texture of the pavement using a high speed laser.
- Smart Rutbar, measures transverse road profile to determine the amount and severity of rutting.
- WiseCrax, Automatic Crack Detection System, for pavement distress survey.

The data are analyzed using the Surveyor Program, which derives condition measures from the video images. The ARAN data and associated software are used in different types of applications of PMS, Geographic Information Systems (GIS), safety, and traffic. The only condition measure of interest to this research was the rut measurements. The rut measurements are made using the Smart Rutbar and the Laser XVP located in the front and rear of the vehicle, respectively. The Smart Rutbar uses ultrasonic transducers to measure the transverse profile of a roadway. The Smart Rutbar is composed by the main bar, where 19 sensors were installed, and by two telescoping extensions with 9 sensors each, for a total of 37 sensors to cover a full lane. The sensors perform the measurements to an accuracy of 1.0 mm. The overall accuracy of the rut depth measurement for lane is 1.5 mm, regardless of the vehicle's path, and variable traffic speeds.

The Laser XVP, or Laser Transverse Profiler, uses dual scanning lasers to measure the complete transverse profile of the road with the aim of calculating the depth

of the roadway (rutting). The lateral resolution of the Laser XVP is approximately 1280 points; and the sampling frequency is 20 Hz. The recorded 1280 raw data points are filtered to produce a 40 points transverse profile. The Laser XVP had 1 mm rut accuracy. Both subsystems are compatible with all ARAN subsystems as well as are connected to graphical reporting software (Roadware Group Inc. Web site, 2004).

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

For convenience this project was divided in two phases. Phase I was the laboratory data collection and analysis. WVDOH and associated contractors provided samples of Superpave mixes constructed throughout the state over a period of several years. These samples were tested in the APA for rutting potential. Information on the mix design was provided by the WVDOH. These data were compiled into an Excel spread sheet for analysis. Several relationships between rutting performance and mix parameters could be examined from this database. Phase II was the field data collection and analysis. In this phase, the WVDOH database was reviewed to extract the rut data. Laboratory and field databases were compared to determine the suitability of the APA test to evaluate the rutting potential of the Superpave pavements in West Virginia.

3.2 Phase I Laboratory Data Collection and Analysis

Since 1997, the WVDOH has been placing Superpave mixes on Interstates and high volume roads (Zaniewski and Diazgranados-Diaz, 2004). In 2000, the Asphalt Technology Laboratory at West Virginia University started testing the rutting potential of the Superpave mixes constructed in the State. Appendix 1 presents the laboratory database. Analysis of the laboratory data includes the assessment of mix parameters, along with comparisons with the data reported in the literature review and the field data. Analysis of the laboratory data is reported in Chapter 4.

For the laboratory phase, the samples obtained from the different projects were compacted using the Superpave Gyratory Compactor, type Pine, Model AFGC125X, and tested in an Asphalt Pavement Analyzer manufactured by Pavement Technology Inc., (PTI) Covington, GA, for evaluating rutting potential.

Tests were performed on 46 mixes from 29 different projects. HMA samples were obtained at the time of paving, and transported to the laboratory for testing. The samples were submitted to the laboratory with the mix design and construction data. Samples were collected in five-gallon buckets. Usually six buckets were collected per mix type for each project.

HMA samples were heated for two hours at a temperature of 135°C (275°F). Samples were split for theoretical maximum specific gravity, G_{mm} , (AASHTO T 209-99), and compaction of samples for testing with the APA. G_{mm} was measured for two samples per set of buckets. Cylindrical specimens of 150 mm in diameter by 75 mm tall were compacted in the SGC to a target $7 \pm 1\%$ air voids. The bulk specific gravity (AASHTO T 166) of each compacted sample was measured and the percent air voids was computed. Six samples were compacted for each mix.

The samples were placed in the test chamber for four hours at 60°C (140°F) prior to testing. The six samples from one project were used to populate the six testing positions in the APA. The compacted samples were subjected to 8,000 cycles in the APA. The wheel load and the hose pressure were 445 N (100 lbf) and of 690 kPa (100 psi), respectively. The testing time for a complete rutting evaluation (8,000 cycles) was approximately two hours and fifteen minutes. Rut depth measurements were taken after the test, using a metal guide on top of the sample mold and inserting a dial indicator stem into the slot. The maximum reading after sliding the indicator transversely across the groove was recorded, obtaining the deepest depression of the specimen at the testing position. The data were recorded on a data sheet that is shown in the Figure 3.1 and subsequently, entered into an Excel spreadsheet.

3.3 Phase II Field Data Collection and Analysis

The West Virginia Division of Highways provided rut depth data for each project. Rut depth was measured with the Automated Road Analyzer. Figure 3.2 shows the steps of the process to collect the data. Table 3.1 shows the projects evaluated during the Phase II. Analysis of the field data included the evaluation of the data itself and comparison with the laboratory data. Analysis of the field data is reported in Chapter 4.

ARAN measurements are collected once every two years. Three sets of data (2000, 2002, and 2004) were provided by the WVDOH. Appendix 2 presents the field database averages from the ARAN and the following is the description of the measurements taken:

- International Roughness Index (IRI) Mean, the average IRI over a distance of 0.10 miles.

WVU Asphalt Lab					
GYRO		Asphalt Test Results			
Sample	Type	Project			
Date					
	Wgt Dry	Wgt Wet	G_{mm}		
Tech					
Pill #					
1	Dry	Wet	SSD	G_{mb}	% Air
Weight					
					Gyrations
	Position			Average	
Rut					
Pill #					
2	Dry	Wet	SSD	G_{mb}	% Air
Weight					
					Gyrations
	Position			Average	
Rut					
Pill #					
3	Dry	Wet	SSD	G_{mb}	% Air
Weight					
					Gyrations
	Position			Average	
Rut					
Averages	Calc Wgt	G_{mm}	G_{mb}	% Air	Rut
Notes:				Av. Gyra.	

Figure 3.1 APA Data Sheet

Figure 3.2 Field Data Collection and Analysis

Table 3.1 Projects Included in Phase II

West Virginia Projects						
District	NMAS	PG	Contractor	T-400 #	Project	Interstate - Road
1	9.5	70-22	WV Paving	1322026	U320-64-45.48	I-64
1	9.5	70-22	WV Paving	1322027	S306-64-29.47	I-64
1	19	64-22	WV Paving	1327100	S303-119-9.44	Rt-119
1	19	64-22	WV Paving	1327066	S303-119-9.44	Rt-119
1	37.5	64-22	WV Paving	1343563	U320-119-11.70	Rt-119
2	12.5	76-22	Mountain Enterprise	NA	S350-52-27.47	Rt 52
2	37.5	76-22	Mountain Enterprise	NA	S350-52-27.47	Rt 52
3	9.5	64-22	WV Paving	1327067	S318-77-137.92	I-77
3	9.5	64-22	Carl Kelly	1327041	S318-77-149.00	I-77
3	9.5	70-22	WV Paving	1329055	S354-77-173.24	I-77
3	9.5	70-22	Carl Kelly	1320170	S354-77-176.20	I-77
3	19	70-22	Carl Kelly	1320161	S354-77-176.20	I-77
4	9.5	70-22	Buckeye Asphalt	1349511	S331-68-4.31	I-68
4	9.5	70-22	Buckeye Asphalt	1349508	S331-79-158.31	I-79
4	9.5	70-22	Greer	1319609	S331-79-152.63	I-79
4	9.5	70-22	WV Paving	1320175	S339-68-26.75	I-68
4	9.5	70-22	Buckeye Asphalt	1349508	NH-0068-(102)E	I-68
4	19	70-22	Buckeye Asphalt	1349512	S331-79-158.31	I-79
4	19	70-22	Buckeye Asphalt	1344568	S331-79-154.91	I-79
4	19	70-22	Greer	1318889	S331-79-152.62	I-79
4	19	70-22	WV Paving	1320169	S339-68-26.75	I-68
4	19	70-22	WV Paving	1329058	S339-68-22.91	I-68
4	37.5	64-22	Cascade Asphalt	1326253	U317-79-121.30	I-79
5	9.5	70-22	Valley Quarries	1327044	U302-81-13.65	I-81
5	37.5	70-22	APAC of VA	1322030	S302-81-15.95	I-81
5	37.5	70-22	Valley Quarries	1322035	U302-81-13.65	I-81
5	37.5	70-22	Valley Quarries	1322034	U302-81-13.65	I-81
7	9.5	70-22	J F Allen	1349538	S304-79-71.39	I-79
7	9.5	70-22	Southern WV Asph	1320153	S304-79-64.85	I-79
7	9.5	70-22	Southern WV Asph	1356065	IM0793(190)E	I-79
7	19	70-22	Carl Kelly Paving		IM0792(122)C	I-79
7	19	70-22	J F Allen	1349536	S304-79-71.39	I-79
7	19	64-22	J F Allen	1349537	S304-79-71.39	I-79
7	19	70-22	J F Allen	1327037	S321-79-95.82	I-79
7	19	70-22	Southern WV Asph	1320150	S304-79-64.85	I-79
9	9.5	70-22	Southern WV Asph	1344650	NH-0019(225)E	Rt-19
9	9.5	70-22	Southern WV Asph	1349522	S304-79-54.21	I-79
9	9.5	70-22	Southern WV Asph	1349523	S304-79-54.21	I-79
9	9.5	70-22	Southern WV Asph	1349475	S313-64-155.60	I-64
9	9.5	70-22	Southern WV Asph	1349523	S304-79-42.22	I-79
9	19	70-22	Southern WV Asph	1356039	S304-79-42.22	I-79
9	19	70-22	Southern WV Asph	1349524	S304-79-54.21	I-79
9	19	70-22	Southern WV Asph	1349474	S313-64-155.60	I-64
9	19	70-22	Southern WV Asph	1344648	NH-0019(225)E	Rt-19
10	9.5	70-22	Southern WV Asph	1350490	X328-52-11.16	US460/US52
10	37.5	70-22	Southern WV Asph	1349491	X328-52-11.16	US460/US52

- IRI Standard Deviation,(SD), the standard deviation for that distance.
- IRI Left, the IRI for the left wheel path.
- IRI Right, the IRI for the right wheel path.
- RUT Mean, the average rut depth over a distance for 0.10 miles.
- RUT Maximum, the maximum rut depth recorded over the 0.10 miles distance.
- RUT Standard Deviation (SD), the standard deviation for that distance.

CHAPTER 4 RESULTS AND ANALYSIS

4.1 Introduction

The analysis of the laboratory database included the evaluation of the data itself, as well as comparison with the data reported in the literature review. Comparison between the APA and field data was performed. Table 4.1 presents a summary of the West Virginia database with both the laboratory and field results reported in Appendices 1 and 2, respectively. The laboratory results in this table are the average of samples for each project/mix type combination with air voids in the range of $7\pm 1\%$. Samples with air voids outside this range were excluded from the analysis since they do not meet the testing protocol. Figure 4.1 shows the laboratory data and their averages for the samples which meet the $7\pm 1\%$ air void criteria.

4.2 Analysis of the Laboratory Data

The suitability of the Asphalt Pavement Analyzer was evaluated in this study in order to verify that the APA distinguishes between aggregates and binders. The properties analyzed were:

- Air void of the specimens
- Nominal maximum aggregate size
- Binder type.

It should be noted that for the analysis of rutting potential versus air void, all data runs included in the $7\pm 1\%$ air voids range were employed, instead of their averages, used subsequently, in the analysis of rutting potential versus NMA and binder type.

4.2.1 Analysis of Rutting Potential versus Air Voids

The relationship between APA rutting potential and the air voids of the samples was evaluated. This evaluation determines if the APA rutting potential was influenced by variability of the air voids in the sample. Figures 4.2 through 4.5 present the rutting potential versus air voids for the 9.5, 12.5, 19, and 37.5 mm mixes with trend lines. In all cases, the trend line has a positive slope, i.e. rutting potential increases with air voids.

Table 4.1 West Virginia Superpave Rutting Database

West Virginia Database																	
APA Rutting Potential and Field Ruts (2000, 2002, and 2004)																	
Project ID	District	NMAS	PG	Contractor	Project Number	Date Sampled	Interstate or Route	Project County	Project Mile Post	Project Length Mi	APA Average Rut mm	ARAN Total Mean					
												2000		2002		2004	
												in.	mm.	in.	mm.	in.	mm.
WV-1	1	9.5	70-22	WV Paving	U320-64-45.48	8/00/1999	I-64	Kanawha	45.48	4.50	6.6	0.1	2.5	0.2	5.1	0.2	5.1
WV-2	1	9.5	70-22	WV Paving	S306-64-29.47	10/28/1999	I-64	Putnam	29.47	3.66	4.4	0.1	2.5	0.2	5.1	0.2	5.1
WV-3	1	37.5	64-22	WV Paving	U320-119-11.70	9/10/2001	Rt-119	Kanawha	11.70	2.19	3.9	0.4	10.2	0.1	2.5	0.2	5.1
WV-4	3	9.5	64-22	WV Paving	S318-77-137.92	6/28/2000	I-77	Jackson	137.92	8.05	5.7	0.2	5.1	0.1	2.5	0.2	5.1
WV-5	3	9.5	64-22	Carl Kelly	S318-77-149.00	7/24/2000	I-77	Jackson	149.00	4.00	7.3	0.1	2.5	0.2	5.1	0.2	5.1
WV-6	3	9.5	70-22	WV Paving	S354-77-173.24	8/28/2000	I-77	Wood	173.24	2.93	4.2	0.2	5.1	0.2	5.1	0.2	5.1
WV-7	4	9.5	70-22	Buckeye Asphalt	S331-68-4.31	6/20/2002	I-68	Monongalia	4.31	2.90	5.2	0.0	0.0	0.0	0.0	0.1	2.5
WV-8	4	19	70-22	Buckeye Asphalt	S331-79-154.91	7/24/2001	I-79	Monongalia	154.91	3.40	2.8	0.0	0.0	0.1	2.5	0.1	2.5
WV-9	4	19	70-22	WV Paving	S339-68-22.91	9/7/2000	I-68	Preston	22.91	3.78	3.1	0.0	0.0	0.2	5.1	0.1	2.5
WV-10	4	37.5	64-22	Cascade Asphalt	U317-79-121.30	8/31/2000	I-79	Harrison	121.30	3.70	3.8	0.0	0.0	0.2	5.1	0.1	2.5
WV-11	5	37.5	70-22	APAC of VA	S302-81-15.95	5/9/2000	I-81	Berkeley	15.95	0.05	2.9	0.2	5.1	0.1	2.5	0.1	2.5
WV-12	7	19	70-22	J F Allen	S321-79-95.82	7/25/2000	I-79	Lewis	95.82	2.58	5.4	0.0	0.0	0.1	2.5	0.1	2.5
WV-13	7	9.5	70-22	Southern WV Asph	IM0793(190E)	11/5/2003	I-79	Lewis	98.63	3.69	3.6	0.2	5.1	0.2	5.1	0.2	5.1
WV-14	4	9.5	70-22	Buckeye Asphalt	NH-0068-(102)E	9/5/2003	I-68	Preston	14.35	3.69	4.7	0.2	5.1	0.2	5.1	0.1	2.5
WV-15	7	19	70-22	Carl Kelly Paving	IM0792(122)C	8/5/2000	I-79	Braxton	67.65	4.72	3.8	0.0	0.0	0.1	2.5	0.1	2.5
WV-16a	1	19	64-22	WV Paving	S303-119-9.44	8/3/2000	Rt-119	Boone	9.44	2.92	5.0	0.0	0.0	0.1	2.5	0.1	2.5
WV-16b	1	19	64-22	WV Paving	S303-119-9.44	8/3/2000	Rt-119	Boone	9.44	2.92	4.0	0.0	0.0	0.1	2.5	0.1	2.5
WV-A1	3	9.5	70-22	Carl Kelly	S354-77-176.20	10/23/1999	I-77	Wood	176.2	7.75	6.4	0.1	2.5	0.2	5.1	0.1	2.5
WV-A2	3	19	70-22	Carl Kelly	S354-77-176.20	8/24/1999	I-77	Wood	176.20	7.75	4.5	0.1	2.5	0.2	5.1	0.1	2.5
WV-B1	4	9.5	70-22	Buckeye Asphalt	S331-79-158.31	6/28/2002	I-79	Monongalia	158.31	2.26	5.4	0.0	0.0	0.0	0.0	0.1	2.5
WV-B2	4	19	70-22	Buckeye Asphalt	S331-79-158.31	6/18/2002	I-79	Monongalia	158.31	2.26	5.6	0.0	0.0	0.0	0.0	0.1	2.5
WV-D1	4	9.5	70-22	Greer	S331-79-152.63	7/5/2000	I-79	Monongalia	152.62	2.25	4.0	0.0	0.0	0.2	5.1	0.1	2.5
WV-D2	4	19	70-22	Greer	S331-79-152.62	6/8/2000	I-79	Monongalia	152.62	2.25	6.2	0.0	0.0	0.2	5.1	0.1	2.5
WV-E1	4	9.5	70-22	WV Paving	S339-68-26.75	9/25/1999	I-68	Preston	26.75	3.28	4.9	0.1	2.5	0.1	2.5	0.2	5.1
WV-E2	4	19	70-22	WV Paving	S339-68-26.75	8/20/1999	I-68	Preston	26.75	3.28	4.0	0.1	2.5	0.1	2.5	0.2	5.1
WV-F1	5	9.5	70-22	Valley Quarries	U302-81-13.65	7/31/2000	I-81	Berkeley	13.65	3.37	5.6	0.3	7.6	0.2	5.1	0.1	2.5
WV-F2	5	37.5	70-22	Valley Quarries	U302-81-13.65	7/18/2000	I-81	Berkeley	13.65	3.37	3.9	0.3	7.6	0.2	5.1	0.1	2.5
WV-F2	5	37.5	70-22	Valley Quarries	U302-81-13.65	7/25/2000	I-81	Berkeley	13.65	3.37	6.6	0.3	7.6	0.2	5.1	0.1	2.5
WV-G1	7	9.5	70-22	J F Allen	S304-79-71.39	5/6/2002	I-79	Braxton	71.39	4.16	5.5	0.0	0.0	0.0	0.0	0.1	2.5
WV-G2	7	19	64-22	J F Allen	S304-79-71.39	5/6/2002	I-79	Braxton	71.39	4.16	8.6	0.0	0.0	0.0	0.0	0.1	2.5
WV-G2	7	19	70-22	J F Allen	S304-79-71.39	5/6/2002	I-79	Braxton	71.39	4.16	4.3	0.0	0.0	0.0	0.0	0.1	2.5

Table 4.1 Continued

West Virginia Database																	
APA Rutting Potential and Field Ruts (2000, 2002, and 2004)																	
Project ID	District	NMA5	PG	Contractor	Project Number	Date Sampled	Interstate or Route	Project County	Project Mile Post	Project Length Mi	APA Average Rut mm	ARAN Total Mean					
												2000		2002		2004	
												in.	mm.	in.	mm.	in.	mm.
WV-H1	7	9.5	70-22	Southern WV Asph	S304-79-64.85	8/19/1999	I-79	Braxton	64.85	2.67	3.8	0.2	5.1	0.1	2.5	0.2	5.1
WV-H2	7	19	70-22	Southern WV Asph	S304-79-64.85	8/17/1999	I-79	Braxton	64.85	2.67	4.8	0.2	5.1	0.1	2.5	0.2	5.1
WV-I1	9	9.5	70-22	Southern WV Asph	S304-79-54.21	6/3/2002	I-79	Braxton	54.21	3.61	6.5	0.0	0.0	0.0	0.0	0.1	2.5
WV-I1	9	9.5	70-22	Southern WV Asph	S304-79-54.21	6/18/2002	I-79	Braxton	54.21	3.61	7.9	0.0	0.0	0.0	0.0	0.1	2.5
WV-I2	9	19	70-22	Southern WV Asph	S304-79-54.21	5/1/2002	I-79	Braxton	54.21	3.61	5.5	0.0	0.0	0.0	0.0	0.1	2.5
WV-J1	9	9.5	70-22	Southern WV Asph	S313-64-155.60	4/9/2002	I-64	Greenbrier	155.60	2.51	5.5	0.0	0.0	0.0	0.0	0.1	2.5
WV-J2	9	19	70-22	Southern WV Asph	S313-64-155.60	4/9/2002	I-64	Greenbrier	155.6	2.52	4.9	0.0	0.0	0.0	0.0	0.1	2.5
WV-K1	10	9.5	70-22	Southern WV Asph	X328-52-11.16	6/25/2002	US460/US52	Mercer	11.16	0.58	5.1	0.2	5.1	0.1	2.5	0.1	2.5
WV-K2	10	37.5	70-22	Southern WV Asph	X328-52-11.16	5/23/2002	US460/US52	Mercer	11.16	0.58	4.2	0.2	5.1	0.1	2.5	0.1	2.5
WV-L1	9	9.5	70-22	Southern WV Asph	NH-0019(225)E	11/8/2001	Rt-19	Fayette	10.21	4.09	2.6	0.0	0.0	0.1	2.5	0.2	5.1
WV-L2	9	19	70-22	Southern WV Asph	NH-0019(225)E	11/8/2001	Rt-19	Fayette	10.21	4.09	6.9	0.0	0.0	0.1	2.5	0.2	5.1
WV-M1	9	9.5	70-22	Southern WV Asph	S304-79-42.22	5/1/2003	I-79	Braxton	42.22	5.25	7.5	0.1	2.5	0.1	2.5	0.1	2.5
WV-M2	9	19	70-22	Southern WV Asph	S304-79-42.22	6/26/2003	I-79	Braxton	42.22	5.25	5.0	0.1	2.5	0.1	2.5	0.1	2.5
WV-O1	2	12.5	76-22	Mountain Enterprise	S350-52-27.47	6/6/2003	Rt 52	Wayne	27.47	0.30	1.6	0.1	2.5	0.1	2.5	0.3	7.6
WV-O2	2	37.5	76-22	Mountain Enterprise	S350-52-27.47	6/6/2003	Rt 52	Wayne	27.47	0.30	1.7	0.1	2.5	0.1	2.5	0.3	7.6

Figure 4.1 Laboratory Data and Their Averages

Figure 4.2 Rutting Potential versus % Air Voids for the 9.5 mm Mixes

Figure 4.3 Rutting Potential versus % Air Voids for the 12.5 mm PG 76-22 Mixes

Figure 4.4 Rutting Potential versus % Air Voids for the 19 mm Mixes

Figure 4.5 Rutting Potential versus % Air Voids for the 37.5 mm Mixes

However, the correlation coefficient was low in all cases. The data collected during this research was not structured in a manner that would permit full evaluation of the factors and interactions that affect the rutting potential of asphalt concrete. Therefore, relatively unsophisticated statistical method could have been applied. Nevertheless, with the availability of computer programs for statistical analysis, it was convenient to use analysis of variance (ANOVA) to test the significance of the correlation between rutting potential and air voids. The outputs from these analyses are presented in Appendix 3. Table 4.2 summarized the statistical parameters from both, trend line and ANOVA. Using a 95% confidence level for identifying significance, the only significant relationships between rutting potential and air voids were for the 19 mm PG 64-22 and 37.5 mm PG 70-22 mixes. Even though these slopes were significant, R^2 values were less than 0.4 indicating that the model does a poor job of explaining the variability in the data. Hence, the overall conclusion is that for the data set analyzed, this does not appear to be a consistent and significant relationship between air voids and rutting potential.

Table 4.2 Statistical Analysis of the Rutting Potential vs. % Air Voids

West Virginia Superpave Mixes				
Slope and Correlation Results				
NMAS	Binder	Slope	R^2	Pr > t
9.5 mm	PG 64-22	$y = 1.1507x$	0.0438	0.4960
9.5 mm	PG 70-22	$y = 0.8516x$	0.0339	0.5060
12.5 mm	PG 76-22	$y = 0.8629x$	0.6527	0.1921
19 mm	PG 64-22	$y = 4.3617x$	0.3772	0.0022*
19 mm	PG 70-22	$y = 0.7236x$	0.0355	0.1229
37.5 mm	PG 64-22	$y = 0.0504x$	0.0036	0.9677
37.5 mm	PG 70-22	$y = 1.6976x$	0.3089	0.0068*
37.5 mm	PG 76-22	$y = 2.4545x$	0.2707	0.6963

*Significant

4.2.2 Analysis of Rutting Potential versus NMAS

The relationship between APA rutting potential and the nominal maximum aggregate size was assessed. Four nominal maximum aggregates sizes, 9.5, 12.5, 19, and 37.5 mm were available in the data set.

Figure 4.6 presents APA rutting potential versus NMAS classified by binder type. In this case, two trend lines, PG 64-22 and PG 70-22, have a negative slope, i.e. rutting potential decrease with increments in nominal maximum aggregate size. The flat slope

for the PG 76-22 mixes did not show sensitivity of the rutting potential for the mixes of 12.5 mm and 37.5 mm. It should be noted that all PG 76-22 samples came from one project. On this project, the 12.5 mm mixes were predominantly slag with some limestone and the 37.5 mm mixes were predominantly limestone with some slag. Hence, the relation performance of their two mixes may be attributed to either the aggregate type or the NMAAS (Zaniewski and Nallamotheu, 2003).

Analysis of variance was performed to test the significance of the correlation between rutting potential and NMAAS. The outcome from this analysis is presented in the Appendix 3. Table 4.3 lists the statistical parameters from both, the trend line and ANOVA. Using a 95% confidence level for identifying significant correlations, the ANOVA indicated the correlation between rutting potential and NMAAS was significant for the PG 64-22 mixes. However, the R^2 indicates the model only explains a limited amount of the variability in the PG 64-22 data. The relationship between rutting potential and NMAAS was not significant for PG 70-22 mixes. Consequently, the overall conclusion is that for the data set analyzed, there does not appear to be a consistent and significant relationship between NMAAS and rutting potential.

Figure 4.6 Rutting Potential versus NMAAS for all Mixes

Table 4.3 Statistical Analysis of the Rutting Potential vs. NMA5

West Virginia Superpave Mixes				
Slope and Correlation Results				
NMA5	Binder	Slope	R ²	Pr > t
9.5 mm, 19mm, 37.5 mm	PG 64-22	y = -0.0912x	0.4287	0.0209*
9.5 mm, 19mm, 37.5 mm	PG 70-22	y = -0.0298x	0.0432	0.2068
12.5 mm, 37.5 mm	PG 76-22	y = 0.002x	1	0.9789

*Significant

4.2.3 Analysis of Rutting Potential vs Binder Type

The relationship between APA rutting potential and the binder type was evaluated. The mixes were prepared with three binder types, PG 64-22, PG 70-22, and PG 76-22. Figure 4.7 presents APA rutting potential versus the binder type. There was only one data point for the 12.5 mm mix, so a trend analysis was not possible. In all cases, the trend lines have a negative slope, i.e. rutting potential decrease with increments of binder type. However, the correlation coefficient was low for all cases.

Figure 4.7 Rutting Potential versus Binder Type

Analysis of variance was performed to test the significance of the correlation between the rutting potential and binder type. The outcome from these analyses is presented in Appendix 3. Table 4.4 lists the statistical parameters from both the trend

line and ANOVA. Using a 95% confidence level for identifying significant correlations, the ANOVA indicated there was not significant relationship between the binder type and rutting potential for all the mixes of this study. However, previous studies had established relationship between the rutting potential and the binder type (Maupin, 1998; Jackson and Baldwin, 2000; Kandhal and Mallick, 2000; and Sargand and Kim, 2001).

Table 4.4 Statistical Analysis of the Rutting Potential vs. Binder Types

West Virginia Superpave Mixes				
Slope and Correlation Results				
Binder	NMAS	Slope	R ²	Pr > t
PG 64-22, PG 70-22	9.5	$y = -0.2609x$	0.1351	0.0728
PG 76-22	12.5	NA	NA	NA
PG 64-22, PG 70-22	19	$y = -0.1857x$	0.0975	0.2093
PG 64-22, PG 70-22, PG 76-22	37.5	$y = -0.1325x$	0.1588	0.2816

Maupin (1998) performed a binder experiment using the GLWT and the APA and the test results present evidence to conclude that both devices were sensitive to the binder grade and asphalt content. Jackson and Baldwin (2000) compared the rutting potential of Superpave and Marshall mixes and concluded that the APA was sensitive to the binder types and mix designs. Kandhal and Mallick, (2000) evaluated mix parameters using the APA and concluded that the device was sensitive to the binder types. Sargand and Kim, (2001) assessed mix parameters using several test methods for evaluating rutting, fatigue cracking, and moisture susceptibility and concluded that the APA was sensitive to the binder type. It should be noted that Maupin (1998), Jackson and Baldwin (2000), and Sargand and Kim (2001) developed their test experiments employing unmodified and modified binders.

4.3 Comparison with the Literature

Comparisons were established between the APA rutting potential presented in Table 4.1, and literature as summarized in Section 2.4. Summary of the research data were developed based on the mix parameters, and APA testing parameters. The mix parameters included air void content, NMAS, and binder type. The APA testing parameters in the literature included the test temperature, wheel load, and hose pressure. By using the temperature effect model (Shami, et al., 1997) it was possible to adjust the rutting potential measured at a variety of temperatures to the one used in this research.

No adjustment could be made for the hose pressure and load wheel force. Hence, results obtained for other hose pressures and load wheel force were removed from the data set for the following comparisons.

The temperature effect model reported by Shami, et al. (1997) was employed to adjust the rutting potential of the research that performed the APA tests at temperatures different than 60°C (140°F). The GDOT criteria were adjusted from 50°C (122°F) to 60°C (140°F); this increased the limit from 5 mm to 8 mm.

Table 4.5 presents the measured rutting potential of the 9.5 mm mixes from the literature with the temperature-adjusted rutting potential reported by Zhang, et al. (2002), and by Kandhal and Cooley (2002a). These are Superpave mixes with PG 64-22 binder compacted to $6\pm0.5\%$ air voids. These mixes were compared with the 9.5 mm Superpave with PG 64-22 binder, compacted at $7\pm1\%$ air voids from West Virginia. Table 4.6 and Figure 4.8 present the maximum, minimum, and average values for 9.5 mm mixes. The results indicated the NCAT mixes reported by Kandhal and Cooley (2002a), and the West Virginia mixes pass the adjusted GDOT criteria, 8 mm at 60°C (140°F). However, some exceptions were found in the Zhang's, et al. (2002) research, because eight mixes fail the criteria. The results of this comparison are confounded by the different aggregate types and air void contents used in preparing the mixes, so specific observations of trends cannot be identified.

The 12.5 mm mixes rutting potential from SCDOT (Hawkins, 2001) and FDOT (Moseley, et al., 2003) are summarized in Table 4.7. All mixes had PG 76-22 binder. In both studies, the samples were compacted at 7% air voids. These mixes were compared with the West Virginia 12.5 mm Superpave mixes with PG 76-22 binder, compacted to target $7\pm1\%$ air voids. Table 4.8 and Figure 4.9 present the maximum, minimum, and average values for the SCDOT 12.5 mm mixes. There were only single data points for the FDOT and WV mixes. The results indicated that all mixes pass the adjusted GDOT criteria, 8mm at 60°C (140°F). This finding is reasonable since all mixes were made with polymer modified binders.

Table 4.5 Summary of 9.5 mm Mixes from Literature Review Adjusted for Temperature

Recall ID	Air Voids	NMAS	PG	Original Rut (mm)	Adjusted by TEM Rut to 60°C	Reference
NCAT-Z1	6±0.5%	9.5	PG 64-22	15.15	12.8	Zhang, et al. (2002)
NCAT-Z2	6±0.5%	9.5	PG 64-22	18.57	15.7	Zhang, et al. (2002)
NCAT-Z3	6±0.5%	9.5	PG 64-22	17.39	14.7	Zhang, et al. (2002)
NCAT-Z4	6±0.5%	9.5	PG 64-22	8.45	7.1	Zhang, et al. (2002)
NCAT-Z5	6±0.5%	9.5	PG 64-22	7.33	6.2	Zhang, et al. (2002)
NCAT-Z6	6±0.5%	9.5	PG 64-22	7.25	6.1	Zhang, et al. (2002)
NCAT-Z7	6±0.5%	9.5	PG 64-22	10.25	8.7	Zhang, et al. (2002)
NCAT-Z8	6±0.5%	9.5	PG 64-22	16.01	13.5	Zhang, et al. (2002)
NCAT-Z9	6±0.5%	9.5	PG 64-22	8.13	6.9	Zhang, et al. (2002)
NCAT-Z10	6±0.5%	9.5	PG 64-22	8.31	7.0	Zhang, et al. (2002)
NCAT-Z11	6±0.5%	9.5	PG 64-22	8.95	7.6	Zhang, et al. (2002)
NCAT-Z12	6±0.5%	9.5	PG 64-22	8.15	6.9	Zhang, et al. (2002)
NCAT-Z13	6±0.5%	9.5	PG 64-22	8.65	7.3	Zhang, et al. (2002)
NCAT-Z14	6±0.5%	9.5	PG 64-22	9.64	8.1	Zhang, et al. (2002)
NCAT-Z15	6±0.5%	9.5	PG 64-22	9.08	7.7	Zhang, et al. (2002)
NCAT-Z16	6±0.5%	9.5	PG 64-22	8.32	7.0	Zhang, et al. (2002)
NCAT-Z17	6±0.5%	9.5	PG 64-22	10.51	8.9	Zhang, et al. (2002)
NCAT-Z18	6±0.5%	9.5	PG 64-22	5.54	4.7	Zhang, et al. (2002)
NCAT-Z19	6±0.5%	9.5	PG 64-22	10.94	9.2	Zhang, et al. (2002)
NCAT-Z20	6±0.5%	9.5	PG 64-22	4.82	4.1	Zhang, et al. (2002)
NCAT-Z21	6±0.5%	9.5	PG 64-22	4.55	3.8	Zhang, et al. (2002)
NCAT-Z22	6±0.5%	9.5	PG 64-22	4.31	3.6	Zhang, et al. (2002)
NCAT-Z23	6±0.5%	9.5	PG 64-22	5.54	4.7	Zhang, et al. (2002)
NCAT-Z24	6±0.5%	9.5	PG 64-22	4.62	3.9	Zhang, et al. (2002)
NCAT-Z25	6±0.5%	9.5	PG 64-22	4.97	4.2	Zhang, et al. (2002)
NCAT-Z26	6±0.5%	9.5	PG 64-22	7.64	6.4	Zhang, et al. (2002)
NCAT-Z27	6±0.5%	9.5	PG 64-22	7.76	6.6	Zhang, et al. (2002)
NCAT-Z28	6±0.5%	9.5	PG 64-22	7.84	6.6	Zhang, et al. (2002)
NCAT-Z29	6±0.5%	9.5	PG 64-22	7.28	6.1	Zhang, et al. (2002)
NCAT-Z30	6±0.5%	9.5	PG 64-22	7.06	6.0	Zhang, et al. (2002)
NCAT-Z31	6±0.5%	9.5	PG 64-22	7.53	6.4	Zhang, et al. (2002)
NCAT-Z32	6±0.5%	9.5	PG 64-22	8.77	7.4	Zhang, et al. (2002)
NCAT-Z33	6±0.5%	9.5	PG 64-22	7.83	6.6	Zhang, et al. (2002)
NCAT-Z34	6±0.5%	9.5	PG 64-22	6.46	5.5	Zhang, et al. (2002)
NCAT-Z35	6±0.5%	9.5	PG 64-22	7.86	6.6	Zhang, et al. (2002)
NCAT-Z36	6±0.5%	9.5	PG 64-22	5.12	4.3	Zhang, et al. (2002)
NCAT-Z37	6±0.5%	9.5	PG 64-22	4.64	3.9	Zhang, et al. (2002)
NCAT-Z38	6±0.5%	9.5	PG 64-22	7.10	6.0	Zhang, et al. (2002)
NCAT-Z39	6±0.5%	9.5	PG 64-22	5.37	4.5	Zhang, et al. (2002)
NCAT-Z40	6±0.5%	9.5	PG 64-22	5.76	4.9	Zhang, et al. (2002)
NCAT-Z41	6±0.5%	9.5	PG 64-22	5.49	4.6	Zhang, et al. (2002)
NCAT-KC1	6±0.5%	9.5	PG 64-22	4.82	4.1	Kandhal and Cooley (2002a)
NCAT-KC2	6±0.5%	9.5	PG 64-22	4.55	3.8	Kandhal and Cooley (2002a)
NCAT-KC3	6±0.5%	9.5	PG 64-22	7.84	6.6	Kandhal and Cooley (2002a)
NCAT-KC4	6±0.5%	9.5	PG 64-22	7.28	6.1	Kandhal and Cooley (2002a)
NCAT-KC5	6±0.5%	9.5	PG 64-22	8.77	7.4	Kandhal and Cooley (2002a)
NCAT-KC6	6±0.5%	9.5	PG 64-22	7.83	6.6	Kandhal and Cooley (2002a)
NCAT-KC7	6±0.5%	9.5	PG 64-22	7.10	6.0	Kandhal and Cooley (2002a)
NCAT-KC8	6±0.5%	9.5	PG 64-22	5.37	4.5	Kandhal and Cooley (2002a)

Table 4.6 Maximum, Minimum and Average Values for the 9.5 Mixes

APA Rutting Potential (mm)	Adjusted to 60°C		WV Mixes
	NCAT		
	Zang, et al. (2002)	Kandhal and Cooley (2002a)	
Research ID	1	2	3
Maximum	15.68	7.40	7.27
Minimum	3.92	3.84	5.73
Average	6.90	5.65	6.68

Figure 4.8 Comparisons between the 9.5 mm Mixes

Table 4.7 Summary of 12.5 mm Mixes from Literature Review Adjusted for Temperature

Recall ID	Project ID	Mix Design	Air Voids	NMAS	PG	Original Rut (mm)	Adjusted by TEM Rut to 60°C	Reference
SCDOT-1	Vulcan	Marshall	7%	12.5	PG 76-22	1.90	1.6	Hawkins (2001)
SCDOT-2	Liberty	Marshall	7%	12.5	PG 76-22	3.90	3.3	Hawkins (2001)
SCDOT-3	Palmetto	Marshall	7%	12.5	PG 76-22	2.15	1.8	Hawkins (2001)
FDOT-1	NA	Superpave	7%	12.5	PG 76-22	1.20	1.0	Moseley, et al. (2003)

Table 4.8 Maximum, Minimum, and Average Values for the 12.5 Mixes

APA Rutting Potential (mm)	Adjusted Ruts to 60°C		WV Mixes
	SCDOT (Hawkins, 2001)	FDOT (Moseley, et al., 2003)	
Research ID	1	2	3
Maximum	3.3		
Minimum	1.6		
Average	2.7	1.0	1.6

Figure 4.9 Comparisons between the 12.5 mm Mixes

The 19 mm mixes were grouped according to the binder types. Table 4.9 lists the 19 mm mixes with either a PG 64-22 or AC 20 binder. Mixes with an AC 30 binder are summarized in Table 4.10. These mixes were compared with the 19 mm Superpave with PG 64-22 binder, compacted at $7\pm 1\%$ air voids, from West Virginia. Table 4.11 and Figure 4.10 presents the maximum, minimum, and average values for 19 mm mixes adjusted for temperature. The results indicated that many Marshall and Superpave mixes from the University of Tennessee-TDOT fail the adjusted GDOT criteria. The mixes from NCAT and SCDOT pass the adjusted GDOT criteria. Just one mix of West Virginia did not pass the criteria.

Table 4.9 Summary of 19 mm Mixes from Literature Review Adjusted for Temperature

ID	ID	Design	Voids	NMAS	Type	Original Test		Adjusted by TEM Rut 60°C	Reference
						Temp.	Rut (mm)		
UT-TDOT-1	10MB	Marshall	7%	19	AC- 20	50°C	3.55	5.7	Jackson and Baldwin (2000)
UT-TDOT-2	8MS	Marshall	7%	19	AC- 20	50°C	8.93	14.4	Jackson and Baldwin (2000)
UT-TDOT-3	2MB	Marshall	7%	19	AC20	50°C	2.88	4.6	Jackson and Baldwin (2000)
UT-TDOT-4	3MS	Marshall	7%	19	AC-20	50°C	3.89	6.3	Jackson and Baldwin (2000)
UT-TDOT-5	4MB	Marshall	7%	19	AC-20	50°C	1.53	2.5	Jackson and Baldwin (2000)
UT-TDOT-6	5MB	Marshall	7%	19	AC-20	50°C	3.05	4.9	Jackson and Baldwin (2000)
UT-TDOT-7	10MS	Marshall	7%	19	PG64-22	50°C	8.14	13.1	Jackson and Baldwin (2000)
UT-TDOT-8	11MS	Marshall	7%	19	PG64-22	50°C	10.55	17.0	Jackson and Baldwin (2000)
UT-TDOT-9	12MS	Marshall	7%	19	PG64-22	50°C	5.47	8.8	Jackson and Baldwin (2000)
UT-TDOT-10	3MB	Marshall	7%	19	PG64-22	50°C	1.30	2.1	Jackson and Baldwin (2000)
UT-TDOT-11	6MB	Marshall	7%	19	PG64-22	50°C	3.73	6.0	Jackson and Baldwin (2000)
UT-TDOT-12	5MS	Marshall	7%	19	PG64-22	50°C	7.52	12.1	Jackson and Baldwin (2000)
UT-TDOT-13	6MS	Marshall	7%	19	PG64-22	50°C	4.55	7.3	Jackson and Baldwin (2000)
UT-TDOT-14	7MB	Marshall	7%	19	PG64-22	50°C	4.15	6.7	Jackson and Baldwin (2000)
UT-TDOT-15	7MS	Marshall	7%	19	PG64-22	50°C	5.89	9.5	Jackson and Baldwin (2000)
UT-TDOT-16	8MB	Marshall	7%	19	PG64-22	50°C	3.93	6.3	Jackson and Baldwin (2000)
UT-TDOT-17	9MB	Marshall	7%	19	PG64-22	50°C	5.00	8.1	Jackson and Baldwin (2000)
UT-TDOT-18	9MS	Marshall	7%	19	PG64-22	50°C	9.92	16.0	Jackson and Baldwin (2000)
UT-TDOT-19	2SB	Superpave	7%	19	PG64-22	50°C	2.52	4.1	Jackson and Baldwin (2000)
UT-TDOT-20	3SB	Superpave	7%	19	PG64-22	50°C	4.24	6.8	Jackson and Baldwin (2000)
UT-TDOT-23	3SS	Superpave	7%	19	PG64-22	50°C	3.76	6.1	Jackson and Baldwin (2000)
UT-TDOT-24	4SS	Superpave	7%	19	PG64-22	50°C	4.17	6.7	Jackson and Baldwin (2000)
UT-TDOT-25	5SS	Superpave	7%	19	PG64-22	50°C	6.48	10.5	Jackson and Baldwin (2000)
UT-TDOT-26	6SS	Superpave	7%	19	PG64-22	50°C	3.09	5.0	Jackson and Baldwin (2000)
NCAT-ADOT1	Granite 1	Superpave	4%	19	PG 64-22	64°C	3.48	2.9	Kandhal and Mallick (2000)
NCAT-ADOT2	Granite 2	Superpave	4%	19	PG64-22	64°C	1.62	1.4	Kandhal and Mallick (2000)
NCAT-ADOT3	Granite 3	Superpave	4%	19	PG64-22	64°C	3.43	2.9	Kandhal and Mallick (2000)
NCAT-ADOT4	Limestone 1	Superpave	4%	19	PG64-22	64°C	4.07	3.4	Kandhal and Mallick (2000)
NCAT-ADOT5	Limestone 2	Superpave	4%	19	PG64-22	64°C	3.98	3.4	Kandhal and Mallick (2000)
NCAT-ADOT6	Limestone 3	Superpave	4%	19	PG64-22	64°C	5.62	4.7	Kandhal and Mallick (2000)
NCAT-ADOT7	Gravel 1	Superpave	4%	19	PG64-22	64°C	5.19	4.4	Kandhal and Mallick (2000)
NCAT-ADOT8	Gravel 2	Superpave	4%	19	PG64-22	64°C	4.35	3.7	Kandhal and Mallick (2000)
NCAT-ADOT9	Gravel 3	Superpave	4%	19	PG64-22	64°C	4.53	3.8	Kandhal and Mallick (2000)
SCDOT-4	Vulcan	Superpave	7%	19	PG 64-22	64°C	4.01	3.4	Hawkins (2001)
SCDOT-5	Liberty	Superpave	7%	19	PG 64-22	64°C	6.77	5.7	Hawkins (2001)
SCDOT-6	Palmetto	Superpave	7%	19	PG 64-22	64°C	6.18	5.2	Hawkins (2001)
NCAT-KC9	NA	Superpave	6±0.5%	19	PG 64-22	64°C	9.22	7.8	Kandhal and Cooley (2002a)
NCAT-KC10	NA	Superpave	6±0.5%	19	PG 64-22	64°C	7.88	6.7	Kandhal and Cooley (2002a)
NCAT-KC11	NA	Superpave	6±0.5%	19	PG 64-22	64°C	8.75	7.4	Kandhal and Cooley (2002a)
NCAT-KC12	NA	Superpave	6±0.5%	19	PG 64-22	64°C	8.19	6.9	Kandhal and Cooley (2002a)
NCAT-KC13	NA	Superpave	6±0.5%	19	PG 64-22	64°C	5.88	5.0	Kandhal and Cooley (2002a)
NCAT-KC14	NA	Superpave	6±0.5%	19	PG 64-22	64°C	7.63	6.4	Kandhal and Cooley (2002a)

Table 4.10 Summary of 19 mm Mixes from Literature Review Unadjusted

Recall ID	Project ID	Mix Design	Air Voids	NMAS	Binder	Original Rut (mm)	Reference
GDOT-M31	Mix 3	Superpave	4±1%	19	AC-30	4.04	Shami, et al. (1997)
GDOT-M32	Mix 3	Superpave	4±1%	19	AC-30	4.33	Shami, et al. (1997)
GDOT-M33	Mix 3	Superpave	4±1%	19	AC-30	4.25	Shami, et al. (1997)
GDOT-M34	Mix 3	Superpave	4±1%	19	AC-30	3.30	Shami, et al. (1997)
GDOT-M61	Mix 6	Superpave	4±1%	19	AC-30	5.33	Shami, et al. (1997)
GDOT-M62	Mix 6	Superpave	4±1%	19	AC-30	5.69	Shami, et al. (1997)

Table 4.11 Maximum, Minimum, and Average Values for the 19 mm Mixes Adjusted for Temperature

APA Rutting Potential (mm)	Adjusted Ruts to 60°C					WV Mixes
	UT-TDOT (Jackson and Baldwin, 2000)		NCAT (Kandhal and Mallick, 2000)	SCDOT (Hawkins, 2001)	NCAT (Kandhal and Cooley, 2002a)	
Mix Design	Marshall	Superpave	Superpave	Superpave	Superpave	Superpave
Research ID	1	2	3	4	5	6
Maximum	17.0	10.5	4.7	5.7	7.8	8.6
Minimum	2.1	4.1	1.4	3.4	5.0	4.0
Average	8.1	6.5	3.4	4.8	6.7	5.9

Figure 4.10 Comparisons between the 19 mm Projects Adjusted for Temperature

Table 4.10, lists the 19 mm Superpave mixes with AC-30 binder, compacted at $4\pm 1\%$ air voids, and tested in the GLWT from the GDOT (Shami, et al., 1997). It should be noted that these mixes were the only mixes that did not require adjustments, because the APA tests were performed at 60°C (140°F). These mixes were compared with the 19 mm Superpave with PG 70-22 binder, compacted at $7\pm 1\%$ air voids, and tested in the APA from West Virginia. Table 4.12 and Figure 4.11 present the maximum, minimum, and average values for 19 mm projects with AC-30 and PG 70-22 binders. Even though, the tests were performed in two different simulative tests, the results were consistent. All mixes pass the adjusted GDOT criteria, 8mm at 60°C (140°F). The results indicated that rutting potential of the mixes with AC-30 binder was similar to the WV PG 70-22 mixes.

Table 4.12 Maximum, Minimum, and Average Values for 19 mm Mixes with AC-30 and PG 70-22

APA Rutting Potential (mm)	GDOT (Shami, et al., 1997) AC-30	WV Mixes PG 70-22
Research ID	1	2
Maximum	5.7	7.9
Minimum	3.3	2.6
Average	4.5	4.9

Figure 4.11 Comparisons between the 19 mm Mixes with AC-30 and PG 70-22

The comparisons described above have several limitations with respect to the different types of mixes, aggregates, and testing parameters. Although they demonstrate similar trends in the results of the APA, this observation must be couched with the lack of direct comparative data.

4.4 Analysis of the Field Data-ARAN

The WVDOH provided ARAN rut data for 2000, 2002, and 2004. Figure 4.12 is a summary of the field rut data for each project considered in this study. The number of observations reported on this figure varies depending on the age of the projects. Projects constructed before 2000 have three data points. Projects constructed after 2000 and before 2002 have two data points and projects constructed after 2002 have a single rut observation. ARAN roughness measurements were used to determine if a project was constructed before or after the measurements. The ARAN rut data were collected in 0.1 inch increments, which were converted to millimeters for this analysis. There were some cases where it appears that rutting is decreasing. However, the decreases were always one measurement unit (0.1 inch) and therefore may be attributed to variances in the data collection procedure.

In general, all Superpave sections considered in this research are demonstrating excellent performance with respect to rutting. Only one project has 7.5 mm (0.3 in.) rutting. This is a project constructed on a coal haul route where there is a traffic signal that results in a slow moving/stopped condition. Compared to the rutting performance of this highway section before the replacement of the Marshall mix with a Superpave mix with a modified binder, the performance of the intersection is excellent.

4.5 Comparison between APA Rutting Potential and ARAN

Table 4.13 presents the APA rutting potential and the field ruts of the projects after construction. Figure 4.13 presents the comparison between the APA rutting potential and the field ruts from the ARAN.

The data set was not constructed in a manner that would permit meaningful statistical analysis. The following observations were noted for the data set:

Figure 4.12 Field Ruts of the West Virginia Projects per Year

Figure 4.13 Comparison between the APA Rutting Potential and the Field Ruts from ARAN

Table 4.13 Comparison between APA Rutting Potential and the Field Ruts from ARAN

Project ID	APA Rut (mm)	ARAN (mm) After the Projects Construction			Project ID	APA Rut (mm)	ARAN (mm) After the Projects Construction		
		One Point	Two Points	Three Points			One Point	Two Points	Three Points
WV-1	6.6	2.5	5.1	5.1	WV-E1	4.9	2.5	2.5	5.1
WV-2	4.4	2.5	5.1	5.1	WV-E2	4.0	2.5	2.5	5.1
WV-3	3.9	2.5	5.1		WV-F1	5.6	5.1	2.5	
WV-4	5.7	5.1	2.5	5.1	WV-F2	3.9	5.1	2.5	
WV-5	7.3	2.5	5.1	5.1	WV-F2	6.6	5.1	2.5	
WV-6	4.2	5.1	5.1		WV-G1	5.5	2.5		
WV-7	5.2	2.5			WV-G2	8.6	2.5		
WV-8	2.8	2.5	2.5		WV-G2	4.3	2.5		
WV-9	3.1	5.1	2.5		WV-H1	3.8	5.1	2.5	5.1
WV-10	3.8	5.1	2.5		WV-H2	4.8	5.1	2.5	5.1
WV-11	2.9	2.5	2.5		WV-I1	6.5	2.5		
WV-12	5.4	2.5	2.5		WV-I1	7.9	2.5		
WV-13	3.6	5.1			WV-I2	5.5	2.5		
WV-14	4.7	2.5			WV-J1	5.5	2.5		
WV-15	3.8	2.5	2.5		WV-J2	4.9	2.5		
WV-16a	5.0	2.5	2.5		WV-K1	5.1	2.5	2.5	
WV-16b	4.0	2.5	2.5		WV-K2	4.2	2.5	2.5	
WV-A1	6.4	2.5	5.1	2.5	WV-L1	2.6	2.5	5.1	
WV-A2	4.5	2.5	5.1	2.5	WV-L2	6.9	2.5	5.1	
WV-B1	5.4	2.5			WV-M1	7.5	2.5		
WV-B2	5.6	2.5			WV-M2	5.0	2.5		
WV-D1	4.0	5.1	2.5		WV-O1	1.6	7.6		
WV-D2	6.2	5.1	2.5		WV-O2	1.7	7.6		

- Evaluation of the rutting potential showed one project (WV-G2) failing the GDOT criteria; however, this project did not rut severely in the field.
- Evaluation of the ARAN data showed that WV-O1, the Fort Gay intersection, had the highest rutting level in the field; however this project in the laboratory showed very low rutting potential. This project is on an intersection on a coal haul route. It therefore experiences very heavy traffic that is slow moving and stopped on a regular basis.
- Neither the laboratory data nor the field data showed any project with tendencies for rutting.
- The limited amount of data available for Superpave mixes did not allow the development of APA rutting potential criteria. Development of such criteria would require construction of pavements with high rutting potential to verify that these pavements rut under traffic. Construction of such projects, while desirable for a research project, would be counter productive for the WVDOH. However, it appears that the GDOT criteria is meaningful for West Virginia since the lab data indicated the Superpave

mixes constructed in the state meet the criteria and have good field performance.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The West Virginia Division of Highways sponsored this study to evaluate whether there are relationships between the rutting potential and the field performance of Superpave pavements. The study was performed in two phases. Phase I was the laboratory data collection and analysis. Phase II was the field data collection and analysis. Comparison between the two data sets was performed and the following conclusions were developed.

In Phase I, evaluation of the rutting potential was performed to determine whether the APA differentiates between aggregates and binder. Three properties were analyzed, air voids of the samples, nominal maximum aggregate size, and binder type. Their influence on rutting potential was analyzed, concluding for the data set. Within the limitations of the data it could not be concluded that these factors affect the APA rutting potential.

Additionally, comparison of the APA rutting potential with the literature review was performed. The temperature effect model reported by Shami, et al. (1997) was used to adjust to rutting potential of the different research projects to the West Virginia testing conditions. Based on recommendations in the literature, the adjusted GDOT criteria of 8 mm at 60°C (140°F) for the APA was used to identify mixes with high rutting potential. The results showed that just one West Virginia mix failed the criteria. In general, the results for the West Virginia rutting potential were consistent compared with the research identified in of the literature review.

In Phase II, the West Virginia Department of Highways provided the field rut measurements made by ARAN. Assessment of the ARAN data was necessary to establish the rutting after the construction date of each project. The overall conclusion for the data set analyzed is that none of the projects present severe field rutting.

Finally, comparison of the APA rutting potential with field ruts was performed and the results did not show any project with severe rutting, hence, the results were consistent. However, no relationship was established between the APA rutting potential and the actual field performance due to limited evidence.

5.2 Recommendations

The results of both the APA and the ARAN data demonstrate that the Superpave mixes constructed in West Virginia are rut-resistant. This observation supports the continued use of Superpave mixes for the high traffic volume roads in the state.

The criteria developed by the GDOT when adjusted for temperature, appears to be reasonable, but the data set does not allow the development of state-specific criteria. Based on the data collected to date and the performance of the Superpave sections in the state, it is unlikely that state specific criteria could be developed by continued collection of samples and testing for future Superpave projects. Therefore, it is recommended that the collection and testing of samples be terminated as a routine practice. However, the research has developed a "level of confidence" in the results produced with the APA. Use of the device to study case specific objectives, such as the use of recycled material or a specific project, should be pursued.

REFERENCES

1. Amirkhanian, S. N.; “*Development of a Gyratory Design for Conventional SCDOT Hot Mixed Asphalt Mixture*”. Federal Highway Administration, Department of Transportation South Carolina, Report FHWA-SC-01-05, Columbia, SC, June, 2001.
2. Aschenbrener, T; “*Comparison of Results Obtained From the French Rutting Tester with Pavements of Known Field Performance*”. Colorado Department of Transportation, Report No. CDOT-DTD-R-92-22, October, 1992.
3. Aschenbrener, T.; “*Comparison of Results Obtained from the LCPC Rutting Tester with Pavements of Known Field Performance*”. Transportation Research Record 1454, Transportation Research Board, National Research Council, Washington, D.C., 1994, pp. 66-73.
4. Aschenbrener, T.; “*Evaluation of the Hamburg Wheel Tracking Device to Predict Moisture Damage in Hot Mix Asphalt*”. Transportation Research Record 1492, Transportation Research Board, National Research Council, Washington, D.C., 1995, pp. 103-201.
5. Bonnot, J.; “*Asphalt Aggregate Mixture*”. Transportation Research Record 1096, Transportation Research Board, National Research Council, Washington, D.C., 1986.
6. Bouldin, M. G., and R. Dongre; “*Empirical SHRP Specifications versus Performance Related Models*”. 3rd International Symposium on Binder Rheology and Pavement Performance, TX, 2002.
7. Brousseau, Y.; “*Assessment of the Use of the LCPC Rutting Tester*”. Section des Matériaux de Chaussées. Laboratoire Central des Ponts et Chaussées. Nantes, France, 1992.
8. Brown, E. R., P. S. Kandhal, and J. Zhang; “*Performance Testing for Hot Mix Asphalt*”. Auburn University, National Center for Asphalt Technology, NCAT Report No 01-05A AL, 2001.

9. Bukowski, J. R., and T. Harman; *"Minutes of the Superpave Mixture Report Task Group"*. Meeting of September 1997.
10. Choubane, B., G. C. Page, and J. A. Musselman; *"Suitability of Asphalt Pavement Analyzer for Predicting Rutting"*. Transportation Research Record 1723, Transportation Research Board, National Research Council, Washington, D.C., 2000.
11. Christensen, D.W., R. Bonaquist, and D. P. Jack; *"Evaluation of Triaxial as a Simple Test for Asphalt Concrete Rut Resistance"*. The Pennsylvania Transportation Institute, August 31, 2000.
12. Collins, R., D. E. Watson, and B. Campbell; *"Development and Use of the Georgia Loaded Wheel Tester"*. Transportation Research Record 1492, Transportation Research Board, National Research Council, Washington, D.C., 1995, pp 202-207.
13. Collins, R., A. Johnson, Y. Wu, and J. Lai; *"Evaluation of Moisture Susceptibility of Compacted Asphalt Mixtures by Asphalt Pavement Analyzer"*. Transportation Research Record 1590, Transportation Research Board, National Research Council, Washington, D.C., January, 1997.
14. Corte, J. F., Y. Brosseaud, J. P. Simoncelli, and G. Caroff; *"Investigation of Rutting of Asphalt Surface Layers: Influence of Binder and Axle Loading Configuration"*. Transportation Research Record 1436, Transportation Research Board, National Research Council, Washington, D.C., 1994, pp. 28-37.
15. Cross, S. A., and M. D. Voth; *"Effects of Sample Preconditioning on Asphalt Pavement Analyzer (APA) Wet Rut Depths"*. Paper presented at 80th Annual Transportation Board Meeting, Washington, D.C., 2001.
16. Gabrielson, J. R.; *"Evaluation of Hot Mix Asphalt (HMA) Static Creep and Repeated Load Test"*. PhD Dissertation, Civil Engineering Department, Auburn University, Auburn, AL, December, 1992.
17. Harman, T., J. D'Angelo, and J. Bukowski; *"Superpave Mixture Design Workshop"*. Federal Highway Administration, Washington, DC, 2002.

18. Hawkins, C. W.; *“Investigation of SCDOT Asphalt Mixtures Using the Asphalt Pavement Analyzer – Phase I”*. South Carolina Department of Transportation, Federal Highway Administration, Final Report No FHWA-SC-01-11, Columbia, SC, December, 2001.
19. Jackson, N. M., and C. D. Baldwin; *“Evaluation of the Pavement Analyzer to Predict the Relative Rutting Susceptibility of HMA in Tennessee”*. University Of Tennessee, Knoxville, TN, 1999.
20. Jackson, N. M., and C. D. Baldwin; *“Assessing the Relative Rutting Susceptibility of HMA in the Laboratory with the Asphalt Pavement Analyzer”*. University of Tennessee, Knoxville, TN, January, 2000.
21. Kandhal, P. S., and R B. Mallick; *“Evaluation of Asphalt Pavement Analyzer for HMA Mix Design”*. Auburn University, National Center for Asphalt Technology, NCAT Report No 99-4, June, 1999.
22. Kandhal, P. S., and R. B. Mallick; *“Effects of Mix Gradation on Rutting Potential of Dense-Graded Asphalt Mixtures”*. Transportation Research Record 1767, Transportation Research Board, National Research Council, Washington, D.C., 2000, pp 146-151.
23. Kandhal, P. S., and L. A. Cooley Jr.; *“Coarse versus Fine-Graded Superpave Mixtures: Comparative Evaluation of Resistance to Rutting”*. Auburn University, National Center for Asphalt Technology, NCAT Report No 2002-02, AL, 2002a.
24. Kandhal, P. S., and L. A. Cooley Jr.; *“Evaluation of Permanent Deformation of Asphalt Mixtures Using Loaded Wheel Tester”*. Auburn University, National Center for Asphalt Technology, NCAT Report No 2002-08, AL, October, 2002b.
25. Kandhal, P. S., and L. A. Cooley Jr.; *“Accelerated Laboratory Rutting Test: Evaluation of the Asphalt Pavement Analyzer”*. National Cooperative Highway Research Program, Auburn University, National Center for Asphalt Technology, Transportation Research Board, NCHRP Report 508, Washington, D.C., 2003.
26. Maupin, G. W. Jr.; *“Comparison of Several Asphalt Design Methods”*. Virginia Transportation Research Council, Charlottesville, VA, 1998.

27. Minnesota Department of Transportation; “*2002 Pavement Management Annual Report*”. Office of Material and Road Research, Pavement Management Unit, St. Paul, MN, 2003.
28. Minnesota Department of Transportation, Office of Materials and Road Research. 2004. Web site available at (<http://www.mrr.dot.state.mn.us/pavement/pvmtmgmt/pavemgmt.asp>).
29. Moseley, H. L., G. C. Page, J. A. Musselman, G. A. Sholar, and P. B. Upshaw; “*Laboratory Mixture And Binder Rutting Study*”. Florida Department of Transportation, State Materials Office, Research Report FL/DOT/SMO/03-465, 2003.
30. ORITE Accelerated Pavement Load Facility, Ohio University, 2004. Web site available at (<http://webce.ent.ohiou.edu/orite/APLF.html>).
31. Page, G., Florida DOT phone communication with Gabriel E. Patino, November 2004.
32. Pan, C., and T. D. White; “*Evaluation of Stripping for Asphalt Concrete Mixture Using Accelerated Testing Methods*”. Transportation Research Record 1630, Transportation Research Board, National Research Council, Washington D.C., 1998.
33. Pavement Technology Inc.; “*Asphalt Pavement Analyzer III Users Manual*”. Pavement Technology, Inc., Covington, GA, 1999.
34. Pavement Technology Inc., Web site available at (<http://www.pavementtechnology.com/>), Accessed February 2005.
35. Prowell, B. D.; “*Development of Rutting Criteria for the Asphalt Pavement Analyzer*”. Paper submitted for consideration and publication at the 1999 International Conference on Accelerated Pavement Testing, Paper No. CS6-4, 1999.
36. Roadware Group Inc., Web site available at (<http://www.roadware.com>), Accessed February 2004.

37. Roberts, F. L., P. S. Kandhal, E. R. Brown, D. Y. Lee, and T. W. Kennedy; *"Hot Mix Asphalt Materials, Mixture Design, and Construction"*. NAPA Education Foundation, Second Edition, Lanham, Maryland, 1996.
38. *"Statistical Analysis System (SAS) Procedures Guide"*. Version 6, Third Edition, SAS Institute, Cary, N.C.
39. Sargand, S. M., and S. S. Kim; *"Pavement Performance Testing"*. Ohio Department of Transportation, Ohio Research Institute for Transportation, Civil Engineering Department, Ohio University, Federal Highway Administration, US Department of Transportation, Report No. FHWA/OH-2000/14, Lancaster, OH, December, 2001.
40. Shami, H. I., J. S. Lai, J. A. D'Angelo, and T. P. Harman; *"Development of Temperature-Effect Model for Predicting Rutting of Asphalt Mixtures Using the Georgia Loaded Wheel Tester"*. Transportation Research Record 1590, Transportation Research Board, National Research Council, Washington, D.C., 1997, pp 17-22.
41. Skok, E., E. Johnson, and A. Turk; *"Asphalt Pavement Analyzer (APA) Evaluation"*. University of Minnesota, Minnesota Department of Transportation, Final Report 2003-02, Minneapolis, MN, 2003.
42. Stephens, L. B.; *"Road Surface Management for Local Governments, Six case Studies. Office of Highway Planning"*. Federal Highway Administration, US Department of Transportation, Washington, D.C., 1985.
43. Temple, W., S. Shashikant, H. Paul, and C. Abadie; *"Performance of Louisiana's Chip Seal and Micro-surfacing Programs, 2002"*. Transportation Research Record 1795, Transportation Research Board, National Research Council, Washington D.C., 2002, pp. 3-16.
44. West, R. C., G. C. Page, and K. H. Murphy; *"Evaluation of the Loaded Wheel Tester"*. Research Report FL/DOT/91-391, Florida Department of Transportation, Gainesville, December, 1991.
45. WesTrack Forensic Team; *"Performance of Coarse Graded Mixes at WesTrack – Premature Rutting"*. Final Report, WesTrack, NV, June, 1998.

46. WesTrack Forensic Team Consensus Report; “*Superpave Mixture Design Guide*”. Report No. FHWA-RD-01-052, Federal Highway Administration, Washington, D.C., February 2001.
47. West Virginia University, Asphalt Technology Laboratory. 2004. Web site available at (<http://www2.cemr.wvu.edu/~wwwasph/progress.htm>).
48. West Virginia Department of Transportation, 2004. Web site available at (<http://www.wvdot.com>).
49. Williams, R. C., and B. D. Prowell; “*Comparison of Laboratory Wheel-Tracking Test Results with WesTrack Performance*”. Transportation Research Record 1681, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 121-128.
50. Zaniwski, J. P., and D. Diazgranados-Diaz; “*Evaluation of the 4.75 mm Superpave Mix Criteria for West Virginia*”. Report of the West Virginia Division of Highways, April, 2004.
51. Zaniwski, J. P., and S. H. Nallamothe; “*Evaluation of Binder Graded on Rutting Performance*”. Report of the West Virginia Division of Highways, June, 2003.
52. Zhang, J; L. A. Cooley Jr., and P. S. Kandhal; “*Comparison of the Fundamental and Simulative Test Methods for Evaluating Permanent Deformation of Hot Mix Asphalt*”. Auburn University, National Center for Asphalt Technology, NCAT Report No 2002-07, AL, October, 2002.

SPECIFICATION AND TEST METHODS

AASHTO

- “*Bulk Specific Gravity of Compacted Bituminous Mixture Using Saturated Surface-Dry Specimens*”. AASHTO T 166-00, 2000.
- “*Resistance of Compacted Bituminous Mixture to Moisture Damage*”. AASHTO T 283-99, 1999.
- “*Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures*”. AASHTO T 209-99, 1999.

Ohio Department of Transportation Specifications

- Item 442, Superpave Asphalt Concrete, Ohio Department of Transportation Specifications, 2002 available at
(<http://www.dot.state.oh.us/construction/OCA/Specs/2002CMS/Specbook2002/400%20Flexible%20Pavement/442.htm>)

Virginia Department of Transportation Specifications

- VDOT, 2003, "2002 Road and Bridge Specifications, with revisions beginning with the November 2003 Advertisements, Virginia Department of Transportation, Richmond VA

APPENDIX 1 LABORATORY DATA

West Virginia Laboratory Database											
APA Test at 60°C with wheel load of 100 lbf and hose pressure of 100 psi											
Project ID WV - #	Sample Number	Project Number	NMAAS	Date Sampled	PG	Average					
						Gmb	Air Voids %		Ruts (mm) 8,000 Cycles		Project Ruts 7±1% AV
							General	7±1	General	7±1% AV	
WV-1	67	U320-64-45.48	9.5	8/00/1999	70-22	2.10	13.50		12.270		6.632
WV-1	68	U320-64-45.48	9.5	8/00/1999	70-22	2.25	7.23	7.23	7.950	7.950	
WV-1	69	U320-64-45.48	9.5	8/00/1999	70-22	2.25	7.67	7.67	6.127	6.127	
WV-1	70	U320-64-45.48	9.5	8/00/1999	70-22						
WV-1	71	U320-64-45.48	9.5	8/00/1999	70-22	2.26	6.83	6.83	5.420	5.420	
WV-1	72	U320-64-45.48	9.5	8/00/1999	70-22	2.26	7.13	7.13	6.233	6.233	
WV-1	73	U320-64-45.48	9.5	8/00/1999	70-22	2.22	8.47		6.077		
WV-1	74	U320-64-45.48	9.5	8/00/1999	70-22	2.27	6.50	6.50	6.013	6.013	
WV-1	75	U320-64-45.48	9.5	8/00/1999	70-22	2.27	6.67	6.67	8.210	8.210	
WV-1	76	U320-64-45.48	9.5	8/00/1999	70-22	2.24	7.67	7.67	8.827	8.827	
WV-1	77	U320-64-45.48	9.5	8/00/1999	70-22	2.24	7.87	7.87	6.043	6.043	
WV-1	78	U320-64-45.48	9.5	8/00/1999	70-22	2.26	7.13	7.13	5.397	5.397	
WV-1	79	U320-64-45.48	9.5	8/00/1999	70-22	2.25	7.27	7.27	7.190	7.190	
WV-1	80	U320-64-45.48	9.5	8/00/1999	70-22	2.14	11.90		13.280		
WV-1	81	U320-64-45.48	9.5	8/00/1999	70-22	2.24	8.03		6.657		
WV-1	82	U320-64-45.48	9.5	8/00/1999	70-22	2.25	7.20	7.20	5.547	5.547	
WV-2	19	S306-64-29.47	9.5	10/28/1999	70-22	2.20	9.97		3.683		4.368
WV-2	20	S306-64-29.47	9.5	10/28/1999	70-22	2.31	5.93		3.947		
WV-2	25	S306-64-29.47	9.5	10/28/1999	70-22	2.20	10.23		5.580		
WV-2	26	S306-64-29.47	9.5	10/28/1999	70-22	2.23	9.20		5.377		
WV-2	27	S306-64-29.47	9.5	10/28/1999	70-22						
WV-2	28	S306-64-29.47	9.5	10/28/1999	70-22						
WV-2	31	S306-64-29.47	9.5	10/28/1999	70-22	2.30	6.30	6.30	4.340	4.340	
WV-2	32	S306-64-29.47	9.5	10/28/1999	70-22	2.29	6.73	6.73	4.397	4.397	
WV-3	213	U320-119-11.70	37.5	9/10/2001	64-22	2.33	6.73	6.73	3.773	3.773	3.902
WV-3	214	U-320-119-11.70	37.5	9/10/2001	64-22	2.35	5.80		2.003		
WV-3	215	U-320-119-11.70	37.5	9/10/2001	64-22	2.33	6.73	6.73	4.373	4.373	
WV-3	216	U-320-119-11.70	37.5	9/10/2001	64-22	2.30	7.67	7.67	3.667	3.667	
WV-3	217	U-320-119-11.70	37.5	9/10/2001	64-22	2.32	7.00	7.00	3.793	3.793	
WV-4	176	S318-77-137.92	9.5	6/29/2000	64-22	2.23	7.20	7.20	6.510	6.510	5.730
WV-4	177	S318-77-137.92	9.5	6/29/2000	64-22						
WV-4	178	S318-77-137.92	9.5	6/29/2000	64-22	2.23	7.20	7.20	6.350	6.350	
WV-4	179	S318-77-137.92	9.5	6/29/2000	64-22	2.23	7.03	7.03	4.787	4.787	
WV-4	180	S318-77-137.92	9.5	6/29/2000	64-22	2.23	7.40	7.40	6.040	6.040	
WV-4	181	S318-77-137.92	9.5	6/30/2000	64-22	2.23	7.25	7.25	4.965	4.965	
WV-5	182	S318-77-149.00	9.5	7/24/2000	64-22	2.22	7.50	7.50	6.310	6.310	7.272
WV-5	183	S318-77-149.00	9.5	7/24/2000	64-22	2.23	7.10	7.10	6.273	6.273	
WV-5	184	S318-77-149.00	9.5	7/24/2000	64-22	2.23	7.23	7.23	8.170	8.170	
WV-5	185	S318-77-149.00	9.5	7/24/2000	64-22	2.24	6.90	6.90	5.705	5.705	
WV-5	186	S318-77-149.00	9.5	7/24/2000	64-22	2.23	6.97	6.97	9.903	9.903	
WV-5	187	S318-77-149.00	9.5	7/24/2000	64-22						
WV-6	188	S354-77-173.24	9.5	8/28/2000	70-22	2.27	6.50	6.50	2.710	2.710	4.171
WV-6	189	S354-77-173.24	9.5	8/28/2000	70-22	2.26	6.70	6.70	4.910	4.910	
WV-6	190	S354-77-173.24	9.5	8/28/2000	70-22	2.26	6.83	6.83	4.700	4.700	
WV-6	191	S354-77-173.24	9.5	8/28/2000	70-22	2.26	6.57	6.57	4.080	4.080	
WV-6	192	S354-77-173.24	9.5	8/28/2000	70-22	2.26	6.83	6.83	4.490	4.490	

West Virginia Laboratory Database											
APA Test at 60°C with wheel load of 100 lbf and hose pressure of 100 psi											
Project ID WV - #	Sample Number	Project Number	NMAAS	Date Sampled	PG	Gmb	Average				
							Air Voids %		Ruts (mm) 8,000 Cycles		Project Ruts
							General	7±1	General	7±1% AV	7±1% AV
WV-6	193	S354-77-173.24	9.5	8/28/2000	70-22	2.27	6.30	6.30	4.137	4.137	
WV-7	194	S331-68-4.31	9.5	6/20/2002	70-22	2.28	7.70	7.70	4.470	4.470	5.188
WV-7	195	S331-68-431	9.5	6/20/2002	70-22	2.31	6.00	6.00	4.920	4.920	
WV-7	196	S331-68-431	9.5	6/20/2002	70-22	2.27	7.63	7.63	5.947	5.947	
WV-7	197	S331-68-431	9.5	6/20/2002	70-22	2.28	6.97	6.97	5.000	5.000	
WV-7	198	S331-68-431	9.5	6/20/2002	70-22	2.28	7.23	7.23	6.063	6.063	
WV-7	199	S331-68-431	9.5	6/20/2002	70-22	2.27	7.37	7.37	4.727	4.727	
WV-8	206	S331-79-154.91	19	7/24/2001	70-22	2.38	5.83		2.870		2.830
WV-8	207	S331-79-154.91	19	7/24/2001	70-22	2.35	6.50	6.50	2.567	2.567	
WV-8	208	S331-79-154.91	19	7/24/2001	70-22	2.44	6.10	6.10	3.890	3.890	
WV-8	209	S331-79-154.91	19	7/24/2001	70-22	2.38	5.70		3.717		
WV-8	210	S331-79-154.91	19	7/24/2001	70-22	2.37	5.97		2.020		
WV-8	211	S331-79-154.91	19	7/24/2001	70-22	2.34	7.40	7.40	2.033	2.033	
WV-8	212	S331-79-154.91	19	7/24/2001	70-22						
WV-9	164	S339-68-22.91	19	9/7/2000	70-22						3.092
WV-9	165	S339-68-22.91	19	9/7/2000	70-22	2.40	4.33		5.127		
WV-9	166	S339-68-22.91	19	9/7/2000	70-22	2.35	6.17	6.17	1.400	1.400	
WV-9	167	S339-68-22.91	19	9/7/2000	70-22	2.35	6.20	6.20	3.940	3.940	
WV-9	168	S339-68-22.91	19	9/7/2000	70-22	2.33	6.77	6.77	3.923	3.923	
WV-9	169	S339-68-22.91	19	9/7/2000	70-22	2.34	6.50	6.50	3.105	3.105	
WV-10	170	U317-79-121.30	37.5	8/31/2000	64-22	2.44	4.23		4.297		3.823
WV-10	171	U317-79-121.30	37.5	8/31/2000	64-22	2.35	7.73	7.73	3.823	3.823	
WV-10	172	U317-79-121.30	37.5	8/31/2000	64-22	2.33	8.40		7.110		
WV-10	173	U317-79-121.30	37.5	8/31/2000	64-22	2.40	5.80		5.133		
WV-10	174	U317-79-121.30	37.5	8/31/2000	64-22	2.44	3.97		3.443		
WV-10	175	U317-79-121.30	37.5	8/31/2000	64-22	2.40	5.57		5.067		
WV-11	113	S302-81-15.95	37.5	5/9/2000	70-22						2.875
WV-11	114	S302-81-15.95	37.5	5/9/2000	70-22	2.39	6.50	6.50	2.430	2.430	
WV-11	115	S302-81-15.95	37.5	5/9/2000	70-22	2.38	6.80	6.80	3.320	3.320	
WV-11	116	S302-81-15.95	37.5	5/9/2000	70-22	2.44	4.37		4.113		
WV-11	117	S302-81-15.95	37.5	5/9/2000	70-22	2.44	4.63		2.927		
WV-11	118	S302-81-15.95	37.5	5/9/2000	70-22						
WV-12	105	S321-79-95.82	19	7/25/2000	70-22	2.34	6.80	6.80	5.640	5.640	5.367
WV-12	106	S321-79-95.82	19	7/25/2000	70-22	2.34	6.80	6.80	5.787	5.787	
WV-12	107	S321-79-95.82	19	7/25/2000	70-22	2.27	9.60		7.410		
WV-12	108	S321-79-95.82	19	7/25/2000	70-22	2.35	6.27	6.27	5.207	5.207	
WV-12	109	S321-79-95.82	19	7/25/2000	70-22	2.10	16.40		4.760		
WV-12	110	S321-79-95.82	19	7/25/2000	70-22	2.37	5.60		5.437		
WV-12	111	S321-79-95.82	19	7/25/2000	70-22	2.28	9.20		5.840		
WV-12	112	S321-79-95.82	19	7/25/2000	70-22	2.33	7.07	7.07	4.833	4.833	
WV-13	113	IM 0793 (190E)	9.5	11/5/2003	70-22	2.30	7.40	7.40	3.010	3.010	3.589
WV-13	114	IM 0793 (190E)	9.5	11/5/2003	70-22	2.30	7.30	7.30	3.667	3.667	
WV-13	115	IM 0793 (190E)	9.5	11/5/2003	70-22	2.31	7.03	7.03	4.790	4.790	
WV-13	116	IM 0793 (190E)	9.5	11/5/2003	70-22	2.32	6.77	6.77	3.263	3.263	
WV-13	117	IM 0793 (190E)	9.5	11/5/2003	70-22	2.31	6.90	6.90	3.423	3.423	
WV-13	118	IM 0793 (190E)	9.5	11/5/2003	70-22	2.31	6.90	6.90	3.383	3.383	
WV-14	430	NH-0068(102)E	9.5	9/5/2003	70-22	2.25	7.60	7.60	6.070	6.070	4.686

West Virginia Laboratory Database											
APA Test at 60°C with wheel load of 100 lbf and hose pressure of 100 psi											
Project ID WV - #	Sample Number	Project Number	NMAS	Date Sampled	PG	Average					
						Gmb	Air Voids %		Ruts (mm) 8,000 Cycles		Project Ruts 7±1% AV
							General	7±1	General	7±1% AV	
WV-14	431	NH-0068(102)E	9.5	9/5/2003	70-22	2.26	7.33	7.33	3.413	3.413	
WV-14	432	NH-0068(102)E	9.5	9/5/2003	70-22	2.26	7.33	7.33	4.157	4.157	
WV-14	433	NH-0068(102)E	9.5	9/5/2003	70-22	2.26	7.20	7.20	4.680	4.680	
WV-14	434	NH-0068(102)E	9.5	9/5/2003	70-22	2.26	7.33	7.33	4.880	4.880	
WV-14	435	NH-0068(102)E	9.5	9/5/2003	70-22	2.26	7.33	7.33	4.913	4.913	
WV-15	436	IM0792(122)C	19	8/5/2000	70-22	2.38	6.30	6.30	3.087	3.087	3.790
WV-15	437	IM0792(122)C	19	8/5/2000	70-22	2.37	6.70	6.70	4.603	4.603	
WV-15	438	IM0792(122)C	19	8/5/2000	70-22	2.36	7.10	7.10	2.790	2.790	
WV-15	439	IM0792(122)C	19	8/5/2000	70-22	2.37	6.70	6.70	3.237	3.237	
WV-15	440	IM0792(122)C	19	8/5/2000	70-22	2.37	6.83	6.83	5.207	5.207	
WV-15	441	IM0792(122)C	19	8/5/2000	70-22	2.37	6.70	6.70	3.853	3.853	
WV-15	442	IM0792(122)C	19	8/5/2000	70-22	2.35	6.17	6.17	2.990	2.990	
WV-15	443	IM0792(122)C	19	8/5/2000	70-22	2.34	6.57	6.57	2.820	2.820	
WV-15	444	IM0792(122)C	19	8/5/2000	70-22	2.33	7.23	7.23	4.250	4.250	
WV-15	445	IM0792(122)C	19	8/5/2000	70-22	2.33	7.10	7.10	4.757	4.757	
WV-15	446	IM0792(122)C	19	8/5/2000	70-22	2.34	6.70	6.70	3.970	3.970	
WV-15	447	IM0792(122)C	19	8/5/2000	70-22	2.32	7.27	7.27	3.913	3.913	
WV-16a	148	S303-119-9.44	19	8/3/2000	64-22	2.30	6.43	6.43	4.660	4.660	5.018
WV-16a	149	S303-119-9.44	19	8/3/2000	64-22	2.30	6.43	6.43	4.543	4.543	
WV-16a	150	S303-119-9.44	19	8/3/2000	64-22	2.32	5.50		5.495		
WV-16a	151	S303-119-9.44	19	8/3/2000	64-22	2.30	6.43	6.43	5.850	5.850	
WV-16a	152	S303-119-9.44	19	8/3/2000	64-22						
WV-16b	153	S303-119-9.44	19	8/3/2000	64-22	2.30	6.73	6.73	4.057	4.057	4.029
WV-16b	154	S303-119-9.44	19	8/3/2000	64-22	2.30	6.60	6.60	4.187	4.187	
WV-16b	155	S303-119-9.44	19	8/3/2000	64-22	1.99	19.20		9.450		
WV-16b	156	S303-119-9.44	19	8/3/2000	64-22	2.30	6.47	6.47	2.720	2.720	
WV-16b	157	S303-119-9.44	19	8/3/2000	64-22	2.30	6.47	6.47	5.153	5.153	
WV-A1	17	S354-77-176.20	9.5	10/13/1999	70-22						6.363
WV-A1	18	S354-77-176.20	9.5	10/13/1999	70-22	2.21	7.00	7.00	4.710	4.710	
WV-A1	21	S354-77-176.20	9.5	10/13/1999	70-22	2.21	7.27	7.27	5.860	5.860	
WV-A1	22	S354-77-176.20	9.5	10/13/1999	70-22	2.21	7.27	7.27	7.523	7.523	
WV-A1	23	S354-77-176.20	9.5	10/13/1999	70-22	2.22	7.00	7.00	5.983	5.983	
WV-A1	24	S354-77-176.20	9.5	10/13/1999	70-22	2.22	7.00	7.00	6.390	6.390	
WV-A1	37	S354-77-176.20	9.5	10/13/1999	70-22	2.22	6.90	6.90	7.140	7.140	
WV-A1	38	S354-77-176.20	9.5	10/13/1999	70-22	2.22	7.20	7.20	6.933	6.933	
WV-A2	35	S354-77-176.20	19	8/24/1999	70-22						4.546
WV-A2	36	S354-77-176.20	19	8/24/1999	70-22	2.26	9.50		4.710		
WV-A2	39	S354-77-176.20	19	8/24/1999	70-22	2.34	6.50	6.50	5.400	5.400	
WV-A2	40	S354-77-176.20	19	8/24/1999	70-22	2.34	6.30	6.30	3.275	3.275	
WV-A2	43	S354-77-176.20	19	8/24/1999	70-22	2.34	6.70	6.70	5.970	5.970	
WV-A2	45	S354-77-176.20	19	8/24/1999	70-22						
WV-A2	47	S354-77-176.20	19	8/24/1999	70-22	2.35	6.50	6.50	3.540	3.540	
WV-A2	48	S354-77-176.20	19	8/24/1999	70-22						
WV-B1	49	S331-79-158.31	9.5	6/18/2002	70-22	2.31	7.20	7.20	5.280	5.280	5.438
WV-B1	50	S331-79-158.31	9.5	6/18/2002	70-22	2.35	5.27		5.083		
WV-B1	51	S331-79-158.31	9.5	6/18/2002	70-22	2.30	7.53	7.53	5.117	5.117	

West Virginia Laboratory Database											
APA Test at 60°C with wheel load of 100 lbf and hose pressure of 100 psi											
Project ID WV - #	Sample Number	Project Number	NMAS	Date Sampled	PG	Average					
						Gmb	Air Voids %		Ruts (mm) 8,000 Cycles		Project Ruts
							General	7±1	General	7±1% AV	7±1% AV
WV-B1	52	S331-79-158.31	9.5	6/18/2002	70-22	2.29	7.80	7.80	4.563	4.563	
WV-B1	53	S331-79-158.31	9.5	6/18/2002	70-22	2.30	7.40	7.40	6.510	6.510	
WV-B1	54	S331-79-158.31	9.5	6/18/2002	70-22	2.31	7.13	7.13	5.720	5.720	
WV-B2	308	S331-79-158.31	19	6/18/2002	70-22	2.36	6.30	6.30	4.845	4.845	5.650
WV-B2	309	S331-79-158.31	19	6/18/2002	70-22	2.32	6.67	6.67	5.863	5.863	
WV-B2	310	S331-79-158.31	19	6/18/2002	70-22	2.31	7.07	7.07	5.237	5.237	
WV-B2	311	S331-79-158.31	19	6/18/2002	70-22	2.32	6.67	6.67	6.000	6.000	
WV-B2	312	S331-79-158.31	19	6/18/2002	70-22	2.32	6.80	6.80	7.220	7.220	
WV-B2	313	S331-79-158.31	19	6/18/2002	70-22	2.31	7.20	7.20	4.733	4.733	
WV-B2	313	S331-79-158.31	19	6/18/2002	70-22	2.31	7.20	7.20	4.733	4.733	
WV-D1	158	S331-79-152.62	9.5	7/5/2000	70-22	2.19	11.50		6.930		4.017
WV-D1	159	S331-79-152.62	9.5	7/5/2000	70-22	2.24	9.50		7.080		
WV-D1	160	S331-79-152.62	9.5	7/5/2000	70-22	2.22	12.60		3.580		
WV-D1	161	S331-79-152.62	9.5	7/5/2000	70-22	2.30	7.23	7.23	4.017	4.017	
WV-D1	162	S331-79-152.62	9.5	7/5/2000	70-22	2.04	19.70		6.750		
WV-D1	163	S331-79-152.62	9.5	7/5/2000	70-22						
WV-D2	91	S-331-79-152.62	19	6/8/2000	70-22	2.34	6.07	6.07	4.903	4.903	6.172
WV-D2	92	S-331-79-152.62	19	6/8/2000	70-22	2.38	5.60		5.003		
WV-D2	93	S-331-79-152.62	19	6/8/2000	70-22	2.38	5.53		4.900		
WV-D2	94	S-331-79-152.62	19	6/8/2000	70-22	2.38	5.57		4.760		
WV-D2	95	S-331-79-152.62	19	6/8/2000	70-22						
WV-D2	96	S-331-79-152.62	19	6/8/2000	70-22	2.33	7.53	7.53	7.440	7.440	
WV-E1	4	S339-68-26.76	9.5	9/15/1999	70-22						4.927
WV-E1	6	S339-68-26.76	9.5	9/15/1999	70-22	2.26	6.87	6.87	5.000	5.000	
WV-E1	8	S339-68-26.76	9.5	9/15/1999	70-22						
WV-E1	9	S339-68-26.77	9.5	9/15/1999	70-22	2.25	7.40	7.40	4.853	4.853	
WV-E1	10	S339-68-26.77	9.5	9/15/1999	70-22						
WV-E1	11	S339-68-26.78	9.5	9/15/1999	70-22						
WV-E1	12	S339-68-26.78	9.5	9/15/1999	70-22						
WV-E1	14	S339-68-26.79	9.5	9/15/1999	70-22						
WV-E2	1	S339-68-26.75	19	8/30/1999	70-22						3.961
WV-E2	2	S339-68-26.75	19	8/30/1999	70-22						
WV-E2	3	S339-68-26.75	19	8/30/1999	70-22	2.35	6.40	6.40	5.675	5.675	
WV-E2	5	S339-68-26.75	19	8/30/1999	70-22						
WV-E2	7	S339-68-26.75	19	8/30/1999	70-22	2.36	6.07	6.07	3.777	3.777	
WV-E2	13	S339-68-26.75	19	8/30/1999	70-22	2.36	6.93	6.93	3.290	3.290	
WV-E2	15	S339-68-26.75	19	8/30/1999	70-22	2.35	6.40	6.40	4.263	4.263	
WV-E2	16	S339-68-26.75	19	8/30/1999	70-22	2.37	6.20	6.20	2.800	2.800	
WV-F1	138	U302-81-13.65	9.5	7/31/2000	70-22	2.31	7.30	7.30	5.150	5.150	5.633
WV-F1	139	U302-81-13.65	9.5	7/31/2000	70-22	2.12	14.90		9.280		
WV-F1	140	U302-81-13.65	9.5	7/31/2000	70-22	2.29	7.97	7.97	5.033	5.033	
WV-F1	141	U302-81-13.65	9.5	7/31/2000	70-22	2.39	4.07		3.907		
WV-F1	142	U302-81-13.65	9.5	7/31/2000	70-22						
WV-F1	143	U302-81-13.65	9.5	7/31/2000	70-22	2.37	4.77		5.500		
WV-F1	144	U302-81-13.65	9.5	7/31/2000	70-22	2.31	7.43	7.43	6.213	6.213	
WV-F1	145	U302-81-13.65	9.5	7/31/2000	70-22	2.32	7.03	7.03	5.837	5.837	
WV-F1	146	U302-81-13.65	9.5	7/31/2000	70-22	2.30	7.57	7.57	6.353	6.353	

West Virginia Laboratory Database											
APA Test at 60°C with wheel load of 100 lbf and hose pressure of 100 psi											
Project ID WV - #	Sample Number	Project Number	NMA	Date Sampled	PG	Average					
						Gmb	Air Voids %		Ruts (mm) 8,000 Cycles		Project Ruts 7±1% AV
							General	7±1	General	7±1% AV	
WV-F1	147	U302-81-13.65	9.5	7/31/2000	70-22	2.30	7.57	7.57	5.210	5.210	
WV-F2	118	U302-81-13.65	37.5	7/18/2000	70-22						3.885
WV-F2	119	U302-81-13.65	37.5	7/18/2000	70-22	2.37	6.57	6.57	4.237	4.237	
WV-F2	120	U302-81-13.65	37.5	7/18/2000	70-22	2.37	6.70	6.70	3.490	3.490	
WV-F2	121	U302-81-13.65	37.5	7/18/2000	70-22	2.40	5.63		3.393		
WV-F2	122	U302-81-13.65	37.5	7/18/2000	70-22	2.10	17.30		3.810		
WV-F2	123	U302-81-13.65	37.5	7/20/2000	70-22	2.37	6.70	6.70	3.477	3.477	
WV-F2	124	U302-81-13.65	37.5	7/20/2000	70-22	2.38	6.43	6.43	4.337	4.337	
WV-F2	125	U302-81-13.65	37.5	7/20/2000	70-22	2.32	8.70		5.160		
WV-F2	126	U302-81-13.65	37.5	7/20/2000	70-22	2.27	10.60		5.810		
WV-F2	127	U302-81-13.65	37.5	7/20/2000	70-22	2.27	10.60		6.680		
WV-F2	128	U302-81-13.65	37.5	7/25/2000	70-22	2.37	5.07		3.273		6.628
WV-F2	129	U302-81-13.65	37.5	7/25/2000	70-22	2.38	4.93		4.553		
WV-F2	130	U302-81-13.65	37.5	7/25/2000	70-22	2.38	4.80		7.627		
WV-F2	131	U302-81-13.65	37.5	7/25/2000	70-22	2.34	6.53	6.53	7.380	7.380	
WV-F2	132	U302-81-13.65	37.5	7/25/2000	70-22	2.33	6.80	6.80	5.530	5.530	
WV-F2	133	U302-81-13.65	37.5	7/25/2000	70-22	2.32	7.20	7.20	5.090	5.090	
WV-F2	134	U302-81-13.65	37.5	7/25/2000	70-22	2.29	8.27		4.893		
WV-F2	135	U302-81-13.65	37.5	7/25/2000	70-22	2.39	4.27		5.443		
WV-F2	136	U302-81-13.65	37.5	7/25/2000	70-22	2.30	8.00	8.00	6.510	6.510	
WV-F2	137	U302-81-13.65	37.5	7/25/2000	70-22	2.30	8.00	8.00	8.630	8.630	
WV-G1	138	S304-79-71.39	9.5	5/6/2002	70-22	2.29	7.30	7.30	5.830	5.830	5.521
WV-G1	139	S304-79-71.39	9.5	5/6/2002	70-22	2.29	7.30	7.30	5.340	5.340	
WV-G1	140	S304-79-71.39	9.5	5/6/2002	70-22	2.29	7.17	7.17	5.427	5.427	
WV-G1	141	S304-79-71.39	9.5	5/6/2002	70-22	2.29	7.17	7.17	5.413	5.413	
WV-G1	142	S304-79-71.39	9.5	5/6/2002	70-22	2.29	7.17	7.17	5.410	5.410	
WV-G1	143	S304-79-71.39	9.5	5/6/2002	70-22	2.30	6.90	6.90	5.707	5.707	
WV-G2	144	S304-79-71.39	19	5/6/2002	64-22	2.33	7.50	7.50	10.020	10.020	8.616
WV-G2	145	S304-79-71.39	19	5/6/2002	64-22	2.35	6.83	6.83	7.803	7.803	
WV-G2	146	S304-79-71.39	19	5/6/2002	64-22	2.36	6.17	6.17	6.623	6.623	
WV-G2	147	S304-79-71.39	19	5/6/2002	64-22	2.34	6.97	6.97	9.830	9.830	
WV-G2	148	S304-79-71.39	19	5/6/2002	64-22	2.36	6.43	6.43	8.463	8.463	
WV-G2	149	S304-79-71.39	19	5/6/2002	64-22	2.35	6.83	6.83	8.953	8.953	
WV-G2	150	S304-79-71.39	19	5/6/2002	70-22	2.35	6.60	6.60	3.565	3.565	4.346
WV-G2	151	S304-79-71.39	19	5/6/2002	70-22	2.36	6.20	6.20	4.543	4.543	
WV-G2	152	S304-79-71.39	19	5/6/2002	70-22	2.35	6.60	6.60	4.423	4.423	
WV-G2	153	S304-79-71.39	19	5/6/2002	70-22	2.35	6.60	6.60	4.897	4.897	
WV-G2	154	S304-79-71.39	19	5/6/2002	70-22	2.35	6.47	6.47	4.553	4.553	
WV-G2	155	S304-79-71.39	19	5/6/2002	70-22	2.34	7.07	7.07	4.093	4.093	
WV-H1	29	S304-79-64.85	9.5	8/19/1999	70-22						3.841
WV-H1	33	S304-79-64.85	9.5	8/19/1999	70-22						
WV-H1	34	S304-79-64.85	9.5	8/19/1999	70-22	2.25	6.90	6.90	3.713	3.713	
WV-H1	41	S304-79-64.85	9.5	8/19/1999	70-22	2.25	7.27	7.27	3.817	3.817	
WV-H1	42	S304-79-64.85	9.5	8/19/1999	70-22	2.25	6.90	6.90	4.933	4.933	
WV-H1	50	S304-79-64.85	9.5	8/19/1999	70-22	2.26	6.80	6.80	3.240	3.240	
WV-H1	52	S304-79-64.85	9.5	8/19/1999	70-22	2.19	9.70		5.450		

West Virginia Laboratory Database											
APA Test at 60°C with wheel load of 100 lbf and hose pressure of 100 psi											
Project ID WV - #	Sample Number	Project Number	NMAAS	Date Sampled	PG	Average					
						Gmb	Air Voids %		Ruts (mm) 8,000 Cycles		Project Ruts 7±1% AV
							General	7±1	General	7±1% AV	
WV-H1	55	S304-79-64.85	9.5	8/19/1999	70-22	2.26	6.80	6.80	3.500	3.500	
WV-H2	30	S304-79-64.85	19	8/17/1999	70-22						4.756
WV-H2	44	S304-79-64.85	19	8/17/1999	70-22	2.34	6.50	6.50	3.170	3.170	
WV-H2	46	S304-79-64.85	19	8/17/1999	70-22	2.34	6.50	6.50	5.423	5.423	
WV-H2	49	S304-79-64.86	19	8/17/1999	70-22	2.33	6.90	6.90	5.450	5.450	
WV-H2	51	S304-79-64.86	19	8/17/1999	70-22	2.28	8.90		5.300		
WV-H2	53	S304-79-64.87	19	8/17/1999	70-22	2.25	10.10		7.140		
WV-H2	54	S304-79-64.87	19	8/17/1999	70-22	2.28	8.90		4.930		
WV-H2	56	S304-79-64.88	19	8/17/1999	70-22	2.33	6.90	6.90	4.980	4.980	
WV-I1	272	S304-79-54.21	9.5	6/10/2002	70-22	2.26	7.70	7.70	5.275	5.275	6.544
WV-I1	273	S304-79-54.21	9.5	6/10/2002	70-22	2.25	7.90	7.90	5.647	5.647	
WV-I1	274	S304-79-54.21	9.5	6/10/2002	70-22	2.27	7.00	7.00	7.003	7.003	
WV-I1	275	S304-79-54.21	9.5	6/10/2002	70-22	2.27	6.87	6.87	7.910	7.910	
WV-I1	276	S304-79-54.21	9.5	6/10/2002	70-22	2.28	6.60	6.60	7.290	7.290	
WV-I1	277	S304-79-54.21	9.5	6/10/2002	70-22	2.27	6.87	6.87	6.140	6.140	
WV-I1	278	S304-79-54.21	9.5	6/3/2002	70-22	2.27	7.30	7.30	7.950	7.950	7.936
WV-I1	279	S304-79-54.21	9.5	6/3/2002	70-22	2.25	7.90	7.90	9.300	9.300	
WV-I1	280	S304-79-54.21	9.5	6/4/2002	70-22	2.27	7.10	7.10	8.957	8.957	
WV-I1	281	S304-79-54.21	9.5	6/5/2002	70-22	2.26	7.37	7.37	5.577	5.577	
WV-I1	282	S304-79-54.21	9.5	6/6/2002	70-22	2.27	6.97	6.97	8.007	8.007	
WV-I1	283	S304-79-54.21	9.5	6/7/2002	70-22	2.28	6.70	6.70	7.827	7.827	
WV-I2	266	S304-79-54.21	19	5/1/2002	70-22	2.35	7.00	7.00	6.465	6.465	5.521
WV-I2	267	S304-79-54.21	19	5/1/2002	70-22	2.33	7.80	7.80	6.133	6.133	
WV-I2	268	S304-79-54.21	19	5/1/2002	70-22	2.34	7.27	7.27	7.543	7.543	
WV-I2	269	S304-79-54.21	19	5/1/2002	70-22	2.34	7.40	7.40	7.483	7.483	
WV-I2	270	S304-79-54.21	19	5/1/2002	70-22	2.35	7.13	7.13	1.300	1.300	
WV-I2	271	S304-79-54.21	19	5/1/2002	70-22	2.34	7.40	7.40	4.200	4.200	
WV-J1	278	S313-64-155.60	9.5	4/9/2002	70-22	2.25	7.80	7.80	6.840	6.840	5.461
WV-J1	279	S313-64-155.60	9.5	4/9/2002	70-22	2.27	7.00	7.00	5.143	5.143	
WV-J1	280	S313-64-155.60	9.5	4/9/2002	70-22	2.27	7.00	7.00	6.533	6.533	
WV-J1	281	S313-64-155.60	9.5	4/9/2002	70-22	2.27	7.00	7.00	5.863	5.863	
WV-J1	282	S313-64-155.60	9.5	4/9/2002	70-22	2.26	7.43	7.43	2.880	2.880	
WV-J1	283	S313-64-155.60	9.5	4/9/2002	70-22	2.27	7.00	7.00	5.503	5.503	
WV-J2	284	S313-64-155.60	19	5/1/2002	70-22	2.36	6.40	6.40	6.580	6.580	4.887
WV-J2	285	S313-64-155.60	19	5/1/2002	70-22	2.34	7.00	7.00	5.533	5.533	
WV-J2	286	S313-64-155.60	19	5/1/2002	70-22	2.35	6.73	6.73	4.220	4.220	
WV-J2	287	S313-64-155.60	19	5/1/2002	70-22	2.33	7.27	7.27	5.543	5.543	
WV-J2	288	S313-64-155.60	19	5/1/2002	70-22	2.33	7.27	7.27	1.503	1.503	
WV-J2	289	S313-64-155.60	19	5/1/2002	70-22	2.34	7.00	7.00	5.943	5.943	
WV-K1	290	X328-52-11.16	9.5	6/25/2002	70-22	2.29	7.00	7.00	4.470	4.470	5.140
WV-K1	291	X328-52-11.16	9.5	6/25/2002	70-22	2.26	8.13		5.043		
WV-K1	292	X328-52-11.16	9.5	6/25/2002	70-22	2.26	7.73	7.73	5.637	5.637	
WV-K1	293	X328-52-11.16	9.5	6/25/2002	70-22	2.29	6.80	6.80	5.063	5.063	
WV-K1	294	X328-52-11.16	9.5	6/25/2002	70-22	2.29	6.80	6.80	5.527	5.527	
WV-K1	295	X328-52-11.16	9.5	6/25/2002	70-22	2.29	6.80	6.80	5.003	5.003	
WV-K2	296	X325-52-11-16	37.5	5/23/2002	70-22	2.44	5.00		5.200		4.247

West Virginia Laboratory Database											
APA Test at 60°C with wheel load of 100 lbf and hose pressure of 100 psi											
Project ID WV - #	Sample Number	Project Number	NMAS	Date Sampled	PG	Average					
						Gmb	Air Voids %		Ruts (mm) 8,000 Cycles		Project Ruts 7±1% AV
							General	7±1	General	7±1% AV	
WV-K2	297	X328-52-11.16	37.5	5/23/2002	70-22	2.40	6.53	6.53	3.700	3.700	
WV-K2	298	X328-52-11.16	37.5	5/23/2002	70-22	2.37	5.93		7.400		
WV-K2	299	X328-52-11.16	37.5	5/23/2002	70-22	2.36	7.87	7.87	6.593	6.593	
WV-K2	300	X328-52-11.16	37.5	5/23/2002	70-22	2.38	7.33	7.33	1.753	1.753	
WV-K2	301	X328-52-11.16	37.5	5/23/2002	70-22	2.38	7.20	7.20	4.940	4.940	
WV-L1	302	NH-0019(225)E	9.5	11/8/2001	70-22	2.26	7.00	7.00	2.930	2.930	2.555
WV-L1	303	NH-0019(225)E	9.5	11/8/2001	70-22	2.26	6.90	6.90	4.013	4.013	
WV-L1	304	NH-0019(225)E	9.5	11/8/2001	70-22	2.26	6.83	6.83	1.557	1.557	
WV-L1	305	NH-0019(225)E	9.5	11/8/2001	70-22	2.27	6.73	6.73	1.497	1.497	
WV-L1	306	NH-0019(225)E	9.5	11/8/2001	70-22	2.27	6.73	6.73	1.380	1.380	
WV-L1	307	NH-0019(225)E	9.5	11/8/2001	70-22	2.26	6.87	6.87	3.953	3.953	
WV-L2	308	NH-0019(225)E	19	11/8/2001	70-22	2.31	7.57	7.57	6.963	6.963	6.913
WV-L2	309	NH-0019(225)E	19	11/8/2001	70-22	2.30	8.10		5.400		
WV-L2	310	NH-0019(225)E	19	11/8/2001	70-22	2.33	6.77	6.77	4.523	4.523	
WV-L2	311	NH-0019(225)E	19	11/8/2001	70-22	2.36	5.83		4.913		
WV-L2	312	NH-0019(225)E	19	11/8/2001	70-22	2.29	8.5		4.813		
WV-L2	313	NH-0019(225)E	19	11/8/2001	70-22	2.33	6.8	6.77	9.253	9.253	
WV-M1	412	S304-79-42.22	9.5	5/1/2003	70-22	2.26	7.20	7.20	7.445	7.445	7.541
WV-M1	413	S304-79-42.22	9.5	5/1/2003	70-22	2.27	6.67	6.67	9.210	9.210	
WV-M1	414	S304-79-42.22	9.5	5/1/2003	70-22	2.27	6.70	6.70	6.477	6.477	
WV-M1	415	S304-79-42.22	9.5	5/1/2003	70-22	2.26	7.00	7.00	8.000	8.000	
WV-M1	416	S304-79-42.22	9.5	5/1/2003	70-22	2.26	7.00	7.00	8.417	8.417	
WV-M1	417	S304-79-42.22	9.5	5/1/2003	70-22	2.26	7.10	7.10	5.695	5.695	
WV-M2	406	S304-79-42.22	19	6/26/2003	70-22	2.36	6.00	6.00	6.500	6.500	4.994
WV-M2	407	S304-79-42.22	19	6/26/2003	70-22	2.35	6.27	6.27	5.557	5.557	
WV-M2	408	S304-79-42.22	19	6/26/2003	70-22	2.34	6.53	6.53	4.660	4.660	
WV-M2	409	S304-79-42.22	19	6/26/2003	70-22	2.33	6.77	6.77	5.497	5.497	
WV-M2	410	S304-79-42.22	19	6/26/2003	70-22	2.33	7.03	7.03	1.533	1.533	
WV-M2	411	S304-79-42.22	19	6/26/2003	70-22	2.34	6.53	6.53	6.217	6.217	
WV-O1	NA	S350-52-27.47	12.5	6/6/2003	76-22	NA	6.20	6.20	1.390	1.390	1.625
WV-O1	NA	S350-52-27.47	12.5	6/6/2003	76-22	NA	6.60	6.60	1.880	1.880	
WV-O1	NA	S350-52-27.47	12.5	6/6/2003	76-22	NA	6.60	6.60	1.590	1.590	
WV-O1	NA	S350-52-27.47	12.5	6/6/2003	76-22	NA	6.47	6.47	1.640	1.640	
WV-O1	NA	S350-52-27.47	12.5	6/6/2003	76-22	NA					
WV-O1	NA	S350-52-27.47	12.5	6/6/2003	76-22	NA					
WV-O2	NA	S350-52-27.47	37.5	6/6/2003	76-22	NA	6.37	6.37	1.930	1.930	1.978
WV-O2	NA	S350-52-27.47	37.5	6/6/2003	76-22	NA	6.37	6.37	1.240	1.240	
WV-O2	NA	S350-52-27.47	37.5	6/6/2003	76-22	NA	6.63	6.63	2.070	2.070	
WV-O2	NA	S350-52-27.47	37.5	6/6/2003	76-22	NA	6.50	6.50	2.670	2.670	
WV-O2	NA	S350-52-27.47	37.5	6/6/2003	76-22	NA					
WV-O2	NA	S350-52-27.47	37.5	6/6/2003	76-22	NA					

APPENDIX 2 FIELD DATA

Summary of 2000 West Virginia Field Database																
Project ID	District	NMAS	PG	Contractor	Project Number	Date Sampled	Interstate or Route	Project County	Project Mile Post	Project Length MI	ARAN 2000					
											IRI*			Rut**		
											NE	SW	Total	NE	SW	Total
WV-4	3	9.5	64-22	WV Paving	S318-77-137.92	6/28/2000	I-77	Jackson	137.92	8.05	83.6	86.1	84.9	0.1	0.2	0.2
WV-5	3	9.5	64-22	Carl Kelly	S318-77-149.00	7/24/2000	I-77	Jackson	149.00	4.00	59.5	81.3	70.4	0.1	0.2	0.1
WV-1	1	9.5	70-22	WV Paving	U320-64-45.48	8/00/1999	I-64	Kanawha	45.48	4.50	45.5	49.2	47.3	0.1	0.1	0.1
WV-2	1	9.5	70-22	WV Paving	S306-64-29.47	10/28/1999	I-64	Putnam	29.47	3.66	67.2	71.1	69.2	0.1	0.2	0.1
WV-6	3	9.5	70-22	WV Paving	S354-77-173.24	8/28/2000	I-77	Wood	173.24	2.93	124.3	85.8	105.1	0.2	0.1	0.2
WV-A1	3	9.5	70-22	Carl Kelly	S354-77-176.20	10/23/1999	I-77	Wood	176.2	7.75	62.2	58.3	60.2	0.1	0.1	0.1
WV-7	4	9.5	70-22	Buckeye Asphalt	S331-68-4.31	6/20/2002	I-68	Monongalia	4.31	2.90	156.0	NA	156.0	0.0	NA	0.0
WV-B1	4	9.5	70-22	Buckeye Asphalt	S331-79-158.31	6/28/2002	I-79	Monongalia	158.31	2.26	152.3	NA	152.3	0.0	NA	0.0
WV-D1	4	9.5	70-22	Greer	S331-79-152.63	7/5/2000	I-79	Monongalia	152.62	2.25	146.4	NA	146.4	0.0	NA	0.0
WV-E1	4	9.5	70-22	WV Paving	S339-68-26.75	9/25/1999	I-68	Preston	26.75	3.28	51.4	NA	51.4	0.1	NA	0.1
WV-14	4	9.5	70-22	Buckeye Asphalt	NH-0068-(102)E	9/5/2003	I-68	Preston	14.35	3.69	81.9	NA	81.9	0.2	NA	0.2
WV-F1	5	9.5	70-22	Valley Quarries	U302-81-13.65	7/31/2000	I-81	Berkeley	13.65	3.37	145.4	NA	145.4	0.3	NA	0.3
WV-G1	7	9.5	70-22	J F Allen	S304-79-71.39	5/6/2000	I-79	Braxton	71.39	4.16	132.1	NA	132.1	0.0	NA	0.0
WV-H1	7	9.5	70-22	Southern WV Asph	S304-79-64.85	8/19/1999	I-79	Braxton	64.85	2.67	61.4	NA	61.4	0.2	NA	0.2
WV-13	7	9.5	70-22	Southern WV Asph	IM0793(190)E	11/5/2003	I-79	Lewis	98.63	3.69	91.4	NA	91.4	0.2	NA	0.2
WV-I1	9	9.5	70-22	Southern WV Asph	S304-79-54.21	6/3/2002	I-79	Braxton	54.21	3.61	145.5	NA	145.5	0.0	NA	0.0
WV-I1	9	9.5	70-22	Southern WV Asph	S304-79-54.21	6/18/2002	I-79	Braxton	54.21	3.61	145.5	NA	145.5	0.0	NA	0.0
WV-J1	9	9.5	70-22	Southern WV Asph	S313-64-155.60	4/9/2002	I-64	Greenbrier	155.60	2.51	141.6	139.0	141.1	0.0	0.0	0.0
WV-M1	9	9.5	70-22	Southern WV Asph	S304-79-42.22	5/1/2003	I-79	Braxton	42.22	5.25	88.9	NA	88.9	0.1	NA	0.1
WV-L1	9	9.5	70-22	Southern WV Asph	NH-0019(225)E	11/8/2001	Rt-19	Fayette	10.21	4.09	131.8	NA	131.8	0.0	NA	0.0
WV-K1	10	9.5	70-22	Southern WV Asph	X328-52-11.16	6/25/2002	US460/US52	Mercer	11.16	0.58	65.0	73.0	69.0	0.1	0.2	0.2
WV-O1	2	12.5	76-22	Mountain Enterprise	S350-52-27.47	6/6/2003	Rt 52	Wayne	27.47	0.30	150.1	NA	150.1	0.1	NA	0.1
WV-16a	1	19	64-22	WV Paving	S303-119-9.44	8/3/2000	Rt-119	Boone	9.44	2.92	132.1	130.0	131.0	0.0	0.0	0.0
WV-16b	1	19	64-22	WV Paving	S303-119-9.44	8/3/2000	Rt-119	Boone	9.44	2.92	132.1	130.0	131.0	0.0	0.0	0.0
WV-G2	7	19	64-22	J F Allen	S304-79-71.39	5/6/2002	I-79	Braxton	71.39	4.16	132.1	NA	132.1	0.0	NA	0.0
WV-A2	3	19	70-22	Carl Kelly	S354-77-176.20	8/24/1999	I-77	Wood	176.20	7.75	62.2	58.3	60.2	0.1	0.1	0.1
WV-B2	4	19	70-22	Buckeye Asphalt	S331-79-158.31	6/18/2002	I-79	Monongalia	158.31	2.26	152.3	NA	152.3	0.0	NA	0.0
WV-8	4	19	70-22	Buckeye Asphalt	S331-79-154.91	7/24/2001	I-79	Monongalia	154.91	3.40	172.0	NA	172.0	0.0	NA	0.0
WV-D2	4	19	70-22	Greer	S331-79-152.62	6/8/2002	I-79	Monongalia	152.62	2.25	146.4	NA	146.4	0.0	NA	0.0
WV-E2	4	19	70-22	WV Paving	S339-68-26.75	8/20/1999	I-68	Preston	26.75	3.28	51.4	NA	51.4	0.1	NA	0.1
WV-9	4	19	70-22	WV Paving	S339-68-22.91	9/7/2000	I-68	Preston	22.91	3.78	160.0	NA	160.0	0.0	NA	0.0
WV-15	7	19	70-22	Carl Kelly Paving	IM0792(122)C	8/5/2000	I-79	Braxton	67.65	4.72	132.3	NA	132.3	0.0	NA	0.0
WV-G2	7	19	70-22	J F Allen	S304-79-71.39	5/6/2002	I-79	Braxton	71.39	4.16	132.1	NA	132.1	0.0	NA	0.0

Summary of 2000 West Virginia Field Database																
Project ID	District	NMAS	PG	Contractor	Project Number	Date Sampled	Interstate or Route	Project County	Project Mile Post	Project Length MI	ARAN 2000					
											IRI*			Rut**		
											NE	SW	Total	NE	SW	Total
WV-12	7	19	70-22	J F Allen	S321-79-95.82	7/25/2000	I-79	Lewis	95.82	2.58	131.9	NA	131.9	0.0	NA	0.0
WV-H2	7	19	70-22	Southern WV Asph	S304-79-64.85	8/17/1999	I-79	Braxton	64.85	2.67	61.4	NA	61.4	0.2	NA	0.2
WV-M2	9	19	70-22	Southern WV Asph	S304-79-42.22	6/26/2003	I-79	Braxton	42.22	5.25	88.9	NA	88.9	0.1	NA	0.1
WV-I2	9	19	70-22	Southern WV Asph	S304-79-54.21	5/1/2002	I-79	Braxton	54.21	3.61	145.5	NA	145.5	0.0	NA	0.0
WV-J2	9	19	70-22	Southern WV Asph	S313-64-155.60	4/9/2002	I-64	Greenbrier	155.6	2.52	141.6	139.0	141.1	0.0	0.0	0.0
WV-L2	9	19	70-22	Southern WV Asph	NH-0019(225)E	11/8/2001	Rt-19	Fayette	10.21	4.09	131.8	NA	131.8	0.0	NA	0.0
WV-3	1	37.5	64-22	WV Paving	U320-119-11.70	9/10/2001	Rt-119	Kanawha	11.70	2.19	71.4	80.0	75.7	0.3	0.4	0.4
WV-10	4	37.5	64-22	Cascade Asphalt	U317-79-121.30	8/31/2000	I-79	Harrison	121.30	3.70	128.4	NA	128.4	0.0	NA	0.0
WV-11	5	37.5	70-22	APAC of VA	S302-81-15.95	5/9/2000	I-81	Berkeley	15.95	0.05	165.6	NA	165.6	0.2	NA	0.2
WV-F2	5	37.5	70-22	Valley Quarries	U302-81-13.65	7/18/2000	I-81	Berkeley	13.65	3.37	145.4	NA	145.4	0.3	NA	0.3
WV-F2	5	37.5	70-22	Valley Quarries	U302-81-13.65	7/25/2000	I-81	Berkeley	13.65	3.37	145.4	NA	145.4	0.3	NA	0.3
WV-K2	10	37.5	70-22	Southern WV Asph	X328-52-11.16	5/23/2002	US460/US52	Mercer	11.16	0.58	65.0	73.0	69.0	0.1	0.2	0.2
WV-O2	2	37.5	76-22	Mountain Enterprise	S350-52-27.47	6/6/2003	Rt 52	Wayne	27.47	0.30	150.1	NA	150.1	0.1	NA	0.1

*IRI Mean: The average IRI over a distance of 0.10 miles

** Rut Mean: The average rut over a distance of 0.10 miles.

NA: Not available

Summary of 2002 West Virginia Field Database																
Project ID	District	NMAS	PG	Contractor	Project Number	Date Sampled	Interstate or Route	Project County	Project Mile Post	Project Length MI	ARAN 2002					
											IRI*			Rut*		
											NE	SW	Total	NE	SW	Total
WV-4	3	9.5	64-22	WV Paving	S318-77-137.92	6/28/2000	I-77	Jackson	137.92	8.05	71.4	72.8	72.1	0.1	0.1	0.1
WV-5	3	9.5	64-22	Carl Kelly	S318-77-149.00	7/24/2000	I-77	Jackson	149.00	4.00	52.0	86.6	69.3	0.1	0.2	0.2
WV-1	1	9.5	70-22	WV Paving	U320-64-45.48	8/00/1999	I-64	Kanawha	45.48	4.50	47.0	53.3	50.2	0.1	0.2	0.2
WV-2	1	9.5	70-22	WV Paving	S306-64-29.47	10/28/1999	I-64	Putnam	29.47	3.66	72.8	73.9	73.4	0.2	0.2	0.2
WV-6	3	9.5	70-22	WV Paving	S354-77-173.24	8/28/2000	I-77	Wood	173.24	2.93	76.1	78.2	77.1	0.2	0.2	0.2
WV-A1	3	9.5	70-22	Carl Kelly	S354-77-176.20	10/23/1999	I-77	Wood	176.2	7.75	59.9	58.1	59.0	0.2	0.2	0.2
WV-7	4	9.5	70-22	Buckeye Asphalt	S331-68-4.31	6/20/2002	I-68	Monongalia	4.31	2.90	161.4	153.6	157.4	0.0	0.0	0.0
WV-B1	4	9.5	70-22	Buckeye Asphalt	S331-79-158.31	6/28/2002	I-79	Monongalia	158.31	2.26	155.1	166.2	160.8	0.0	0.0	0.0
WV-D1	4	9.5	70-22	Greer	S331-79-152.63	7/5/2000	I-79	Monongalia	152.62	2.25	61.8	55.1	58.5	0.2	0.2	0.2
WV-E1	4	9.5	70-22	WV Paving	S339-68-26.75	9/25/1999	I-68	Preston	26.75	3.28	52.0	55.7	53.9	0.1	0.1	0.1
WV-14	4	9.5	70-22	Buckeye Asphalt	NH-0068-(102)E	9/5/2003	I-68	Preston	14.35	3.69	89.6	80.9	85.2	0.2	0.2	0.2
WV-F1	5	9.5	70-22	Valley Quarries	U302-81-13.65	7/31/2000	I-81	Berkeley	13.65	3.37	69.7	71.3	70.5	0.2	0.1	0.2
WV-G1	7	9.5	70-22	J F Allen	S304-79-71.39	5/6/2000	I-79	Braxton	71.39	4.16	134.3	129.7	132.0	0.0	0.0	0.0
WV-H1	7	9.5	70-22	Southern WV Asph	S304-79-64.85	8/19/1999	I-79	Braxton	64.85	2.67	57.9	58.3	58.1	0.1	0.1	0.1
WV-13	7	9.5	70-22	Southern WV Asph	IM0793(190E)	11/5/2003	I-79	Lewis	98.63	3.69	83.5	77.9	80.9	0.2	0.2	0.2
WV-I1	9	9.5	70-22	Southern WV Asph	S304-79-54.21	6/3/2002	I-79	Braxton	54.21	3.61	154.0	152.1	153.1	0.0	0.0	0.0
WV-I1	9	9.5	70-22	Southern WV Asph	S304-79-54.21	6/18/2002	I-79	Braxton	54.21	3.61	154.0	152.1	153.1	0.0	0.0	0.0
WV-J1	9	9.5	70-22	Southern WV Asph	S313-64-155.60	4/9/2002	I-64	Greenbrier	155.60	2.51	137.3	138.3	137.8	0.0	0.0	0.0
WV-M1	9	9.5	70-22	Southern WV Asph	S304-79-42.22	5/1/2003	I-79	Braxton	42.22	5.25	81.7	84.8	83.2	0.1	0.1	0.1
WV-L1	9	9.5	70-22	Southern WV Asph	NH-0019(225)E	11/8/2001	Rt-19	Fayette	10.21	4.09	56.3	56.1	56.2	0.1	0.1	0.1
WV-K1	10	9.5	70-22	Southern WV Asph	X328-52-11.16	6/25/2002	US460/US52	Mercer	11.16	0.58	73.0	70.7	71.8	0.1	0.1	0.1
WV-O1	2	12.5	76-22	Mountain Enterprise	S350-52-27.47	6/6/2003	Rt 52	Wayne	27.47	0.30	138.3	NA	138.3	0.1	NA	0.1
WV-16a	1	19	64-22	WV Paving	S303-119-9.44	8/3/2000	Rt-119	Boone	9.44	2.92	54.6	53.0	58.8	0.1	0.1	0.1
WV-16b	1	19	64-22	WV Paving	S303-119-9.44	8/3/2000	Rt-119	Boone	9.44	2.92	54.6	53.0	58.8	0.1	0.1	0.1
WV-G2	7	19	64-22	J F Allen	S304-79-71.39	5/6/2002	I-79	Braxton	71.39	4.16	134.3	129.7	132.0	0.0	0.0	0.0
WV-A2	3	19	70-22	Carl Kelly	S354-77-176.20	8/24/1999	I-77	Wood	176.20	7.75	59.9	58.1	59.0	0.2	0.2	0.2
WV-B2	4	19	70-22	Buckeye Asphalt	S331-79-158.31	6/18/2002	I-79	Monongalia	158.31	2.26	155.1	166.2	160.8	0.0	0.0	0.0
WV-8	4	19	70-22	Buckeye Asphalt	S331-79-154.91	7/24/2001	I-79	Monongalia	154.91	3.40	73.6	67.3	70.5	0.1	0.2	0.1
WV-D2	4	19	70-22	Greer	S331-79-152.62	6/8/2002	I-79	Monongalia	152.62	2.25	61.8	55.1	58.5	0.2	0.2	0.2
WV-E2	4	19	70-22	WV Paving	S339-68-26.75	8/20/1999	I-68	Preston	26.75	3.28	52.0	55.7	53.9	0.1	0.1	0.1
WV-9	4	19	70-22	WV Paving	S339-68-22.91	9/7/2000	I-68	Preston	22.91	3.78	55.4	52.9	54.1	0.2	0.2	0.2
WV-15	7	19	70-22	Carl Kelly Paving	IM0792(122)C	8/5/2000	I-79	Braxton	67.65	4.72	71.9	65.0	68.5	0.2	0.1	0.1
WV-G2	7	19	70-22	J F Allen	S304-79-71.39	5/6/2002	I-79	Braxton	71.39	4.16	134.3	129.7	132.0	0.0	0.0	0.0

Summary of 2002 West Virginia Field Database																
Project ID	District	NMAS	PG	Contractor	Project Number	Date Sampled	Interstate or Route	Project County	Project Mile Post	Project Length MI	ARAN 2002					
											IRI*			Rut*		
											NE	SW	Total	NE	SW	Total
WV-12	7	19	70-22	J F Allen	S321-79-95.82	7/25/2000	I-79	Lewis	95.82	2.58	68.2	65.7	67.0	0.1	0.1	0.1
WV-H2	7	19	70-22	Southern WV Asph	S304-79-64.85	8/17/1999	I-79	Braxton	64.85	2.67	57.9	58.3	58.1	0.1	0.1	0.1
WV-M2	9	19	70-22	Southern WV Asph	S304-79-42.22	6/26/2003	I-79	Braxton	42.22	5.25	81.7	84.8	83.2	0.1	0.1	0.1
WV-I2	9	19	70-22	Southern WV Asph	S304-79-54.21	5/1/2002	I-79	Braxton	54.21	3.61	154.0	152.1	153.1	0.0	0.0	0.0
WV-J2	9	19	70-22	Southern WV Asph	S313-64-155.60	4/9/2002	I-64	Greenbrier	155.6	2.52	137.3	138.3	137.8	0.0	0.0	0.0
WV-L2	9	19	70-22	Southern WV Asph	NH-0019(225)E	11/8/2001	Rt-19	Fayette	10.21	4.09	56.3	56.1	56.2	0.1	0.1	0.1
WV-3	1	37.5	64-22	WV Paving	U320-119-11.70	9/10/2001	Rt-119	Kanawha	11.70	2.19	52.3	46.7	49.5	0.1	0.1	0.1
WV-10	4	37.5	64-22	Cascade Asphalt	U317-79-121.30	8/31/2000	I-79	Harrison	121.30	3.70	44.4	43.2	43.8	0.2	0.1	0.2
WV-11	5	37.5	70-22	APAC of VA	S302-81-15.95	5/9/2000	I-81	Berkeley	15.95	0.05	78.8	81.4	80.1	0.1	0.1	0.1
WV-F2	5	37.5	70-22	Valley Quarries	U302-81-13.65	7/18/2000	I-81	Berkeley	13.65	3.37	69.7	71.3	70.5	0.2	0.1	0.2
WV-F2	5	37.5	70-22	Valley Quarries	U302-81-13.65	7/25/2000	I-81	Berkeley	13.65	3.37	69.7	71.3	70.5	0.2	0.1	0.2
WV-K2	10	37.5	70-22	Southern WV Asph	X328-52-11.16	5/23/2002	US460/US52	Mercer	11.16	0.58	73.0	70.7	71.8	0.1	0.1	0.1
WV-O2	2	37.5	76-22	Mountain Enterprise	S350-52-27.47	6/6/2003	Rt 52	Wayne	27.47	0.30	138.3	NA	138.3	0.1	NA	0.1

*IRI Mean: The average IRI over a distance of 0.10 miles

** Rut Mean: The average rut over a distance of 0.10 miles.

NA: Not available

Summary of 2004 West Virginia Field Database																
Project ID	District	NMAS	PG	Contractor	Project Number	Date Sampled	Interstate or Route	Project County	Project Mile Post	Project Length MI	2004					
											IRI*			Rut**		
											NE	SW	Total	NE	SW	Total
WV-4	3	9.5	64-22	WV Paving	S318-77-137.92	6/28/2000	I-77	Jackson	137.92	8.05	74.0	73.9	73.9	0.2	0.2	0.2
WV-5	3	9.5	64-22	Carl Kelly	S318-77-149.00	7/24/2000	I-77	Jackson	149.00	4.00	67.1	65.8	66.4	0.2	0.2	0.2
WV-1	1	9.5	70-22	WV Paving	U320-64-45.48	8/00/1999	I-64	Kanawha	45.48	4.50	60.4	57.0	58.1	0.2	0.2	0.2
WV-2	1	9.5	70-22	WV Paving	S306-64-29.47	10/28/1999	I-64	Putnam	29.47	3.66	73.5	75.6	74.5	0.2	0.2	0.2
WV-6	3	9.5	70-22	WV Paving	S354-77-173.24	8/28/2000	I-77	Wood	173.24	2.93	82.3	86.9	84.5	0.2	0.2	0.2
WV-A1	3	9.5	70-22	Carl Kelly	S354-77-176.20	10/23/1999	I-77	Wood	176.2	7.75	60.5	60.8	60.6	0.1	0.1	0.1
WV-7	4	9.5	70-22	Buckeye Asphalt	S331-68-4.31	6/20/2002	I-68	Monongalia	4.31	2.90	65.9	69.4	67.6	0.1	0.1	0.1
WV-B1	4	9.5	70-22	Buckeye Asphalt	S331-79-158.31	6/28/2002	I-79	Monongalia	158.31	2.26	79.0	75.3	77.1	0.1	0.1	0.1
WV-D1	4	9.5	70-22	Greer	S331-79-152.63	7/5/2000	I-79	Monongalia	152.62	2.25	54.5	58.3	56.4	0.1	0.1	0.1
WV-E1	4	9.5	70-22	WV Paving	S339-68-26.75	9/25/1999	I-68	Preston	26.75	3.28	59.7	69.0	64.2	0.2	0.1	0.2
WV-14	4	9.5	70-22	Buckeye Asphalt	NH-0068-(102)E	9/5/2003	I-68	Preston	14.35	3.69	77.7	79.2	78.4	0.1	0.1	0.1
WV-F1	5	9.5	70-22	Valley Quarries	U302-81-13.65	7/31/2000	I-81	Berkeley	13.65	3.37	58.6	59.6	59.1	0.1	0.1	0.1
WV-G1	7	9.5	70-22	J F Allen	S304-79-71.39	5/6/2000	I-79	Braxton	71.39	4.16	82.0	78.5	80.3	0.1	0.1	0.1
WV-H1	7	9.5	70-22	Southern WV Asph	S304-79-64.85	8/19/1999	I-79	Braxton	64.85	2.67	65.0	61.6	63.3	0.2	0.1	0.2
WV-13	7	9.5	70-22	Southern WV Asph	IM0793(190E)	11/5/2003	I-79	Lewis	98.63	3.69	55.3	59.7	57.5	0.2	0.2	0.2
WV-I1	9	9.5	70-22	Southern WV Asph	S304-79-54.21	6/3/2002	I-79	Braxton	54.21	3.61	74.9	68.2	71.5	0.1	0.1	0.1
WV-I1	9	9.5	70-22	Southern WV Asph	S304-79-54.21	6/18/2002	I-79	Braxton	54.21	3.61	74.9	68.2	71.5	0.1	0.1	0.1
WV-J1	9	9.5	70-22	Southern WV Asph	S313-64-155.60	4/9/2002	I-64	Greenbrier	155.60	2.51	56.9	56.9	56.9	0.2	0.1	0.1
WV-M1	9	9.5	70-22	Southern WV Asph	S304-79-42.22	5/1/2003	I-79	Braxton	42.22	5.25	65.8	66.3	66.0	0.1	0.1	0.1
WV-L1	9	9.5	70-22	Southern WV Asph	NH-0019(225)E	11/8/2001	Rt-19	Fayette	10.21	4.09	62.0	129.1	95.6	0.1	0.2	0.2
WV-K1	10	9.5	70-22	Southern WV Asph	X328-52-11.16	6/25/2002	US460/US52	Mercer	11.16	0.58	80.3	84.5	82.4	0.1	0.1	0.1
WV-O1	2	12.5	76-22	Mountain Enterprise	S350-52-27.47	6/6/2003	Rt 52	Wayne	27.47	0.30	110.3	163.0	132.9	0.2	0.4	0.3
WV-16a	1	19	64-22	WV Paving	S303-119-9.44	8/3/2000	Rt-119	Boone	9.44	2.92	57.4	59.5	58.5	0.1	0.1	0.1
WV-16b	1	19	64-22	WV Paving	S303-119-9.44	8/3/2000	Rt-119	Boone	9.44	2.92	57.4	59.5	58.5	0.1	0.1	0.1
WV-G2	7	19	64-22	J F Allen	S304-79-71.39	5/6/2002	I-79	Braxton	71.39	4.16	82.0	78.5	80.3	0.1	0.1	0.1
WV-A2	3	19	70-22	Carl Kelly	S354-77-176.20	8/24/1999	I-77	Wood	176.20	7.75	60.5	60.8	60.6	0.1	0.1	0.1
WV-B2	4	19	70-22	Buckeye Asphalt	S331-79-158.31	6/18/2002	I-79	Monongalia	158.31	2.26	79.0	75.3	77.1	0.1	0.1	0.1
WV-8	4	19	70-22	Buckeye Asphalt	S331-79-154.91	7/24/2001	I-79	Monongalia	154.91	3.40	72.7	62.0	64.4	0.1	0.1	0.1
WV-D2	4	19	70-22	Greer	S331-79-152.62	6/8/2002	I-79	Monongalia	152.62	2.25	54.5	58.3	56.4	0.1	0.1	0.1
WV-E2	4	19	70-22	WV Paving	S339-68-26.75	8/20/1999	I-68	Preston	26.75	3.28	59.7	69.0	64.2	0.2	0.1	0.2
WV-9	4	19	70-22	WV Paving	S339-68-22.91	9/7/2000	I-68	Preston	22.91	3.78	62.8	63.5	63.1	0.2	0.1	0.1
WV-15	7	19	70-22	Carl Kelly Paving	IM0792(122)C	8/5/2000	I-79	Braxton	67.65	4.72	70.3	66.2	68.3	0.1	0.2	0.1
WV-G2	7	19	70-22	J F Allen	S304-79-71.39	5/6/2002	I-79	Braxton	71.39	4.16	82.0	78.5	80.3	0.1	0.1	0.1

Summary of 2004 West Virginia Field Database																
Project ID	District	NMA	PG	Contractor	Project Number	Date Sampled	Interstate or Route	Project County	Project Mile Post	Project Length MI	2004					
											IRI*			Rut**		
											NE	SW	Total	NE	SW	Total
WV-12	7	19	70-22	J F Allen	S321-79-95.82	7/25/2000	I-79	Lewis	95.82	2.58	66.4	67.6	67.0	0.1	0.1	0.1
WV-H2	7	19	70-22	Southern WV Asph	S304-79-64.85	8/17/1999	I-79	Braxton	64.85	2.67	65.0	61.6	63.3	0.2	0.1	0.2
WV-M2	9	19	70-22	Southern WV Asph	S304-79-42.22	6/26/2003	I-79	Braxton	42.22	5.25	65.8	66.3	66.0	0.1	0.1	0.1
WV-I2	9	19	70-22	Southern WV Asph	S304-79-54.21	5/1/2002	I-79	Braxton	54.21	3.61	74.9	68.2	71.5	0.1	0.1	0.1
WV-J2	9	19	70-22	Southern WV Asph	S313-64-155.60	4/9/2002	I-64	Greenbrier	155.6	2.52	56.9	56.9	56.9	0.2	0.1	0.1
WV-L2	9	19	70-22	Southern WV Asph	NH-0019(225)E	11/8/2001	Rt-19	Fayette	10.21	4.09	62.0	129.1	95.6	0.1	0.2	0.2
WV-3	1	37.5	64-22	WV Paving	U320-119-11.70	9/10/2001	Rt-119	Kanawha	11.70	2.19	65.7	65.2	65.4	0.2	0.2	0.2
WV-10	4	37.5	64-22	Cascade Asphalt	U317-79-121.30	8/31/2000	I-79	Harrison	121.30	3.70	55.1	52.2	53.7	0.1	0.1	0.1
WV-11	5	37.5	70-22	APAC of VA	S302-81-15.95	5/9/2000	I-81	Berkeley	15.95	0.05	109.7	78.2	94.0	0.1	0.1	0.1
WV-F2	5	37.5	70-22	Valley Quarries	U302-81-13.65	7/18/2000	I-81	Berkeley	13.65	3.37	58.6	59.6	59.1	0.1	0.1	0.1
WV-F2	5	37.5	70-22	Valley Quarries	U302-81-13.65	7/25/2000	I-81	Berkeley	13.65	3.37	58.6	59.6	59.1	0.1	0.1	0.1
WV-K2	10	37.5	70-22	Southern WV Asph	X328-52-11.16	5/23/2002	US460/US52	Mercer	11.16	0.58	80.3	84.5	82.4	0.1	0.1	0.1
WV-O2	2	37.5	76-22	Mountain Enterprise	S350-52-27.47	6/6/2003	Rt 52	Wayne	27.47	0.30	110.3	163.0	132.9	0.2	0.4	0.3

*IRI Mean: The average IRI over a distance of 0.10 miles

** Rut Mean: The average rut over a distance of 0.10 miles.

NA: Not available

APPENDIX 3 STATISTICAL ANALYSIS

Rutting Potential vs Air Voids.

▪ 9.5mm PG 64-22; PG 70-22

Ruts vs Air Voids 9.5 mm PG 64-22, PG 70-22

PAGE 1

13:55 Friday, November 5, 2004

The GLM Procedure

Class Level Information

Class	Levels	Values
PG	2	64-22 70-22
Number of Observations Read		123
Number of Observations Used		123

Dependent Variable: Ruts

Sum of					
Source	DF	Squares	Mean Square	F Value	Pr > F
Model	3	34.3308964	11.4436321	4.19	0.0074
Error	119	324.7285549	2.7288114		
Corrected Total	122	359.0594513			
R-Square Coeff Var Root MSE Ruts Mean					
0.095613 30.24263 1.651911 5.462195					

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Voids	1	13.93097972	13.93097972	5.11	0.0257
PG	1	20.31790721	20.31790721	7.45	0.0073
Voids*PG	1	0.08200947	0.08200947	0.03	0.8627

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Voids	1	3.60868710	3.60868710	1.32	0.2525
PG	1	0.01405127	0.01405127	0.01	0.9429
Voids*PG	1	0.08200947	0.08200947	0.03	0.8627

Standard					
Parameter	Estimate	Error	t Value	Pr > t	
slope 9.5mm PG 64-22	1.16479467	1.70573593	0.68	0.4960	
slope 9.5mm PG 70-22	0.85961489	0.43527138	1.97	0.0506	

Standard					
Parameter	Estimate	Error	t Value	Pr > t	
Intercept	-.7998209065 B	3.09738587	-0.26	0.7967	
Voids	0.8596148856 B	0.43527138	1.97	0.0506	
PG 64-22	-.9067197320 B	12.63577778	-0.07	0.9429	
PG 70-22	0.0000000000 B	.	.	.	
Voids*PG 64-22	0.3051797894 B	1.76039662	0.17	0.8627	
Voids*PG 70-22	0.0000000000 B	.	.	.	

■ 12.5 mm PG 76-22.

Ruts vs Air Voids 12.5 mm PG 76-22

Page 1

14:22 Friday, November 5, 2004

The GLM Procedure
 Class Level Information

Class	Levels	Values
PG	1	76-22
Number of Observations Read		4
Number of Observations Used		4

Dependent variable: Ruts

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.07943007	0.07943007	3.76	0.1921
Error	2	0.04226993	0.02113497		
Corrected Total	3	0.12170000			

	R-Square	Coeff Var	Root MSE	Ruts Mean
	0.652671	8.946381	0.145379	1.625000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Voids	1	0.07943007	0.07943007	3.76	0.1921
PG	0	0.00000000	.	.	.
Voids*PG	0	0.00000000	.	.	.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Voids	1	0.07943007	0.07943007	3.76	0.1921
PG	0	0.00000000	.	.	.
Voids*PG	0	0.00000000	.	.	.

Parameter	Estimate	Standard Error	t Value	Pr > t
slope 12.5mm PG 76-22	0.86290134	0.44511215	1.94	0.1921

Parameter	Estimate	Standard Error	t value	Pr > t
Intercept	-3.955814389 B	2.87968041	-1.37	0.3032
Voids	0.862901336 B	0.44511215	1.94	0.1921
PG 76-22	0.000000000 B	.	.	.
Voids*PG 76-22	0.000000000 B	.	.	.

■ 19 mm PG 64-22, PG 70-22.

Ruts vs Air Voids 19 mm PG 64-22, PG 70-22

PAGE 1

13:16 Friday, November 5, 2004

The GLM Procedure			
Class Level Information			
Class	Levels	Values	
PG	2	64-22	70-22
Number of Observations Read			84
Number of Observations Used			84

Dependent variable: Ruts

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	65.3878555	21.7959518	8.24	<.0001
Error	80	211.6294275	2.6453678		
Corrected Total	83	277.0172830			
	R-Square	Coeff Var	Root MSE	Ruts Mean	
	0.236043	33.06923	1.626459	4.918345	

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Voids	1	12.35122308	12.35122308	4.67	0.0337
PG	1	36.74259648	36.74259648	13.89	0.0004
Voids*PG	1	16.29403592	16.29403592	6.16	0.0152

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Voids	1	32.25677873	32.25677873	12.19	0.0008
PG	1	13.86951113	13.86951113	5.24	0.0247
Voids*PG	1	16.29403592	16.29403592	6.16	0.0152

Parameter	Estimate	Standard Error	t Value	Pr > t
slope 19mm PG 64-22	4.36256371	1.38181728	3.16	0.0022*
slope 19mm PG 70-22	0.73767665	0.47313172	1.56	0.1229

Parameter	Estimate	Standard Error	t Value	Pr > t
Intercept	-0.32012369 B	3.19474439	-0.10	0.9204
Voids	0.73767665 B	0.47313172	1.56	0.1229
PG 64-22	-22.26323190 B	9.72300857	-2.29	0.0247
PG 70-22	0.00000000 B	.	.	.
Voids*PG 64-22	3.62488707 B	1.46057271	2.48	0.0152
Voids*PG 70-22	0.00000000 B	.	.	.

■ 37.5 mm PG 64-22; PG 70-22; PG 76-22.

Ruts vs Air Voids 37.5 mm PG 64-22, PG 70-22, PG 76-22

PAGE 1

13:55 Friday, November 5, 2004

The GLM Procedure

Class Level Information

Class	Levels	Values
PG	3	64-22 70-22 76-22
Number of Observations Read		27
Number of Observations Used		27

The GLM Procedure

Dependent Variable: Ruts

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	39.64359102	7.92871820	4.44	0.0065
Error	21	37.54079417	1.78765687		
Corrected Total	26	77.18438519			

	R-Square	Coeff Var	Root MSE	Ruts Mean		
	0.513622	32.47386	1.337033	4.117259		
Source	DF	Type I SS	Mean Square	F Value	Pr > F	
Voids	1	21.10559484	21.10559484	11.81	0.0025	
PG	2	15.78703588	7.89351794	4.42	0.0251	
Voids*PG	2	2.75096030	1.37548015	0.77	0.4759	
Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Voids	1	0.78349025	0.78349025	0.44	0.5152	
PG	2	2.28530171	1.14265086	0.64	0.5377	
Voids*PG	2	2.75096030	1.37548015	0.77	0.4759	

Standard

Parameter	Estimate	Error	t Value	Pr > t
slope 37.5mm PG 64-22	0.04976898	1.21448113	0.04	0.9677
slope 37.5mm PG 70-22	1.69628487	0.56573627	3.00	0.0068*
slope 37.5mm PG 76-22	2.45454545	6.20200885	0.40	0.6963

Standard

Parameter	Estimate	Error	t Value	Pr > t
Intercept	-13.89727273 B	40.11706272	-0.35	0.7325
Voids	2.45454545 B	6.20200885	0.40	0.6963
PG 64-22	17.55578329 B	41.07819980	0.43	0.6735
PG 70-22	6.82208161 B	40.30867701	0.17	0.8672
PG 76-22	0.00000000 B	.	.	.

Dependent Variable: Ruts

Standard

Parameter	Estimate	Error	t Value	Pr > t
Voids*PG 64-22	-2.40477648 B	6.31980048	-0.38	0.7074
Voids*PG 70-22	-0.75826059 B	6.22775812	-0.12	0.9043
Voids*PG 76-22	0.00000000 B	.	.	.

Rutting Potential vs NMAS.

Ruts vs NMAS

PAGE 1

09:50 Friday, November 12, 2004

The GLM Procedure

Class Level Information

Class	Levels	Values
PG	3	64-22 70-22 76-22
Number of observations		50

Dependent Variable: Ruts

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	38.0908382	7.6181676	4.32	0.0028
Error	44	77.6577071	1.7649479		
Corrected Total	49	115.7485453			

R-Square	Coeff Var	Root MSE	Ruts Mean
0.329083	27.22297	1.328513	4.880120

Source	DF	Type I SS	Mean Square	F Value	Pr > F
PG	2	25.06449496	12.53224748	7.10	0.0021
NMAS	1	8.98908701	8.98908701	5.09	0.0290
NMAS*PG	2	4.03725626	2.01862813	1.14	0.3279

Source	DF	Type III SS	Mean Square	F Value	Pr > F
PG	2	14.49963940	7.24981970	4.11	0.0231
NMAS	1	3.27216898	3.27216898	1.85	0.1803
NMAS*PG	2	4.03725626	2.01862813	1.14	0.3279

Standard

Parameter	Estimate	Error	t Value	Pr > t
slope PG64-22	-0.09124044	0.03808990	-2.40	0.0209*
slope PG70-22	-0.02975814	0.02322342	-1.28	0.2068
slope PG76-22	0.00200000	0.07515207	0.03	0.9789

Standard

Parameter	Estimate	Error	t Value	Pr > t
Intercept	1.605000000 B	2.10056414	0.76	0.4489
PG 64-22	5.970400877 B	2.30449170	2.59	0.0129
PG 70-22	3.772752833 B	2.14579976	1.76	0.0857
PG 76-22	0.000000000 B	.	.	.
NMAS	0.002000000 B	0.07515207	0.03	0.9789

Dependent Variable: Ruts

Standard

Parameter	Estimate	Error	t Value	Pr > t
NMAS*PG 64-22	-0.093240444 B	0.08425363	-1.11	0.2745
NMAS*PG 70-22	-0.031758136 B	0.07865850	-0.40	0.6884
NMAS*PG 76-22	0.000000000 B	.	.	.

Rutting Potential vs Binder Type.

Ruts vs Binder Type

PAGE 1

09:27 Friday, November 12, 2004

The GLM Procedure

Class Level Information

Class	Levels	Values
NMAS	3	19 37.5 9.5
Number of observations		49

The GLM Procedure

Dependent Variable: Ruts

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5	23.7348444	4.7469689	2.51	0.0441
Error	43	81.2348437	1.8891824		
Corrected Total	48	104.9696881			

	R-Square	Coeff Var	Root MSE	Ruts Mean
	0.226111	27.78711	1.374475	4.946449

Source	DF	Type I SS	Mean Square	F Value	Pr > F
NMAS	2	12.02926727	6.01463363	3.18	0.0514
PG2	1	10.81257997	10.81257997	5.72	0.0212
PG2*NMAS	2	0.89299718	0.44649859	0.24	0.7905

Source	DF	Type III SS	Mean Square	F Value	Pr > F
NMAS	2	1.21280769	0.60640384	0.32	0.7272
PG2	1	11.28915819	11.28915819	5.98	0.0187
PG2*NMAS	2	0.89299718	0.44649859	0.24	0.7905

Parameter	Estimate	Error	t Value	Pr > t
slope 9.5 mm	-0.26086389	0.14183192	-1.84	0.0728
slope 19mm	-0.18574206	0.14574226	-1.27	0.2093
slope 37.5mm	-0.13247396	0.12148760	-1.09	0.2816

Parameter	Estimate	Error	t value	Pr > t
Intercept	23.37362222 B	9.82141815	2.38	0.0218
NMAS 19	-5.59846349 B	14.05441268	-0.40	0.6923
NMAS 37.5	-10.32263264 B	12.89424712	-0.80	0.4278
NMAS 9.5	0.00000000 B	.	.	.
G2	-0.26086389 B	0.14183192	-1.84	0.0728

Dependent variable: Ruts

Parameter	Estimate	Error	t value	Pr > t
PG2*NMAS 19	0.07512183 B	0.20336446	0.37	0.7136
PG2*NMAS 37.5	0.12838993 B	0.18674992	0.69	0.4955
PG2*NMAS 9.5	0.00000000 B	.	.	.