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Evaluation of North Dakota's Aggregate Characteristics and Performance in Locally Produced HMA Mixtures Using the Aspahalt Pavement Analyzer	Work Plan ☐ Construction ☐ Evaluation ☐ **Final** ☒	

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15. Abstract

Objective

The main objectives of this study are: (1) To examine the effects of specified fine aggregate angularities and binder grades on the volumetric properties, rutting resistance and tensile strength of Superpave HMA mixes; and (2) To evaluate and compare the rutting resistance of local Superpave HMA mixes of different combinations of aggregate blends and binder grades using the asphalt pavement analyzer.

Scope

In this project, the appropriate laboratory tests and analysis were done on the HMA mixes to evaluate the effect of the fine aggregate angularities and the binder grades on the HMA properties and performance. The performance of the various Superpave were evaluated based on their deformation under the wheel load of the asphalt pavement analyzer. A 0.276 inch (7.0 mm) deformation under the wheel load of the APA is considered the minimum criterion for rutting failure. The relative performance of the mixes was also examined based on comparing their APA deformation values.

Summary

For the dry condition, the 45-70 mix design outperformed all other design cases followed by the rest of the FAA of 45 cases. The FAA 43 mix cases had performed slightly better than the FAA 42 cases. But the 42-64 mix had a better result than the 43-58 mix indicating that the positive influence of a higher binder grade overweighs the negative influence of a slightly lower FAA value. The rutting values for both of the FAA 42 mix design cases were hovering around the 7.0 mm specification value. All of the mix design cases under dry condition passed the 7.0 mm specification except for the FAA 40 mix design cases.

For the wet condition, only the FAA 45 mix design cases have actually passed the specification. The FAA 43 and FAA 42 mix design cases did fail the specification but the FAA 40 mix design cases triggered the maximum APA failure value of 14.0 mm.

The 45-64 mix design case performed really well with a TSR value of 96%. The 45-58 mix design also did well with a TSR value of 90%. Even though the TSR values for the FAA 42 mix cases were lower than the TSRs for the FAA 45 mix cases as expected, the 42-64 mix design case presented an anomaly. The 42-64 case not only performed inferior to the 42-58 mix design case but the dry and wet strengths were much higher than all the other design cases. The 42-64 mix design case was repeated and the same results were obtained.

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UNIVERSITY OF NORTH DAKOTA
Grand Forks

Evaluation of North Dakota's Aggregate Characteristics and Performance in Locally Produced HMA Mixtures Using the Asphalt Pavement Analyzer

Final Report

May 2008

SCHOOL OF ENGINEERING AND MINES

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT	EXPERIMENTAL PROJECT NO. 1 — STATE: UND, Y EAR: 2006 - NUMBER: 02, SURF:	CONSTRUCTION PROJ NO 8	LOCATION: Grand Forks 28
	EVALUATION FUNDING 48 — 1 X HP&R; 2 CONSTRUCTION; 3 DEMONSTRATION; 4 IMPLEMENTATION	NEEP NO. 49	PROPRIETARY FEATURE? 51 Yes; X No
SHORT TITLE	TITLE 52 — Evaluation of North Dakota's Asphalt Cement Binder Properties and Performance in Locally Produced HMA Mixtures		
THIS FORM	DATE 140 — MO. 12 -- YR. 05	REPORTING: 1 INITIAL; 2 ANNUAL; 3 FINAL X	

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CHRONOLOGY	Date Work Plan Approved	Date Feature Constructed:	Evaluation Scheduled Until:	Evaluation Extended Until:	Date Evaluation Terminated:
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QUANTITY AND COST	QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS)	UNITS	UNIT COST (*Dollars, Cents*)
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	315		X

EVALUATION	CONSTRUCTION PROBLEMS	PERFORMANCE
	318 — 1 NONE; 2 SLIGHT; 3 MODERATE; 4 SIGNIFICANT; 5 SEVERE	319 — 1 EXCELLENT; 2 GOOD; 3 SATISFACTORY; 4 MARGINAL; 5 UNSATISFACTORY

APPLICATION			
	320 — 1 ADOPTED AS PRIMARY STD.; 2 PERMITTED ALTERNATIVE; 3 ADOPTED CONDITIONALLY	4 PENDING; 5 REJECTED; 6 NOT CONSTRUCTED	*(Explain in remarks if 3, 4, 5, or 6 is checked)*

REMARKS

321 For the dry condition, the 45-70 mix design outperformed all other design cases followed by the rest of the FAA of 45 cases. The FAA 43 mix cases had performed slightly better than the FAA 42 cases. But the 42-64 mix had a better result than the 43-58 mix indicating that the positive influence of a higher binder grade overweighs the negative influence of a slightly lower FAA value. The rutting values for both of the FAA 42 mix design cases were hovering around the 7.0 mm specification value. All of the mix design cases under dry condition passed the 7.0 mm specification except for the FAA 40 mix design cases.

For the wet condition, only the FAA 45 mix design cases have actually passed the specification. The FAA 43 and FAA 42 mix design cases did fail the specification but the FAA 40 mix design cases triggered the maximum APA failure value of 14.0 mm.

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University of North Dakota
Department of Civil Engineering

Evaluation of North Dakota's Aggregate Characteristics and Performance in Locally Produced HMA Mixtures Using the Asphalt Pavement Analyzer

Final Report Submitted to the

North Dakota Department of Transportation
Bismarck, ND

By:

Dr. Nabil Suleiman, Principal Investigator

May 2008

Disclaimer

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

BACKGROUND

The product of the SHRP asphalt research program was a materials selection, testing, and evaluation design system called Superpave (1, 2). The Superpave binder specification is performance based, resulting in the classification of performance-graded (PG) binders (2). It delineates engineering properties of the binder that are believed to be related to the expected performance of the pavement. Thus, a designer can anticipate the performance of the pavement. This represents a significant improvement over the penetration and the one temperature viscosity grading systems previously used for binders in North Dakota. In addition, the Superpave binder specification factors in the climatic conditions associated with the construction project location (1, 2).

The main parameters that affect performance in asphalt pavements are rutting, fatigue and thermal cracking, and moisture susceptibility. Loaded wheel testers such as the APA are used to evaluate and/or test bituminous mix designs; plant produced mixtures, and cored field pavement samples for these test parameters in a controlled environment of temperature and moisture (3, 4, 5). Thus, the APA has the potential to predict the performance of a pavement before an investment is made to build the road (4).

The APA has recently earned an AASHTO provisional status as "Standard Method of Test for Determining Rutting Susceptibility of Asphalt Paving Mixtures." The given AASHTO designation is: TP 63-03 (4, 5). Furthermore, many departments of transportation have moved toward including the APA test in their QC/QA specifications and use it as criteria for acceptance or verification of job mix formula.

PURPOSE AND NEED

The adoption of the Performance Graded (PG) Binder Specifications developed in the Strategic Highway Research Program Superpave study has improved asphalt concrete mixture properties, particularly in the northern states. Asphalt, as a viscoelastic material, can now be specifically engineered for North Dakota's climatic conditions so that the properties of the asphalt binder, concurrently, can be specified to provide the high temperature deformation resistant properties for extreme summer temperatures and the low temperature thermal cracking resistance necessary for extreme cold winter temperatures. Typically, to meet the expanded PG specifications for high traffic volume or extreme temperature conditions, asphalt suppliers have a number of options including the use of plastomers and elastomers such as SBS and SBR and other styrene compounds, or turn to crude treatment alternatives such as acid treatment, foaming, air blowing, and blending (6, 7).

North Dakota's local aggregates typically undergo a selection process that involves crushing, sizing, and scalping to meet the perspective Superpave aggregate blend specifications (8, 9, 10). The complexity and cost of aggregate processing depends on the intended highway class of construction. Therefore, a study will be devised to evaluate and compare the hot mix asphalt properties and performance of the Superpave mix design method and utilizing North Dakota's locally processed aggregates.

OBJECTIVES AND SCOPE

The main objectives of this study are: (1) To examine the effects of specified fine aggregate angularities and binder grades on the volumetric properties, rutting resistance and tensile strength of Superpave HMA mixes; and (2) To evaluate and compare the rutting resistance of local Superpave HMA mixes of different combinations of aggregate blends and binder grades using the asphalt pavement analyzer.

In this research study, Superpave mix designs were prepared using North Dakota's locally processed aggregates that have fine aggregate angularity (FAA) values of 40, 42, 43, and 45 which meet the NDDOT specifications (Sections 816, and 410) that have been historically employed for NDDOT projects. Three asphalt binder grades (PG 58-28, PG 64-28, and PG 70-28) were used in this study.

In this project, the appropriate laboratory tests and analysis were done on the HMA mixes to evaluate the effect of the fine aggregate angularities and the binder grades on the HMA properties and performance. The performance of the various Superpave mixes were evaluated based on their deformation under the wheel load of the asphalt pavement analyzer. A 0.276

inch (7.0 mm) deformation under the wheel load of the APA is considered the minimum criterion for rutting failure. The relative performance of the mixes were also examined based on comparing their APA deformation values.

MATERIAL SELECTION, PROPERTIES, AND GRADATIONS

MATERIAL SELECTION

Three different grade asphalt binders, PG 70-28, PG 64-28, and PG 58-28 were chosen for this study. All of the binders were supplied by one asphalt producer. On the other hand, the aggregates adopted for this study were from two sources: (1) Valley City aggregates, Project NH-2-281(025)049; and (2) a combination of Northwood natural fines, project NH-8-018(040)124 and Valley City aggregates. Both aggregates were specified to meet the requirements of Superpave mixes. The aggregates were chosen in a way to obtain fine aggregate angularities of 45, 43, 42, and 40. The Northwood natural fines provided the lower FAA values of 40 and 42 to the aggregate blends.

The properties of the selected binders were provided by the NDDOT asphalt laboratory. The consensus and source properties of aggregates were conducted on the Superpave blends. The test results for the Valley City location were reported in the first phase of the study and summarized in this report. As for the combined Northwood and Valley City aggregates, the test results are provided in the subsequent sections of this report.

MATERIAL PROPERTIES

Since NDDOT is part of the combined state binder group on certification method of acceptance for asphalt binders, asphalt binder suppliers shall furnish all specification tests and maintain acceptable quality control procedures. The properties of the selected binders for this study were to be performed by the NDDOT asphalt laboratory. The properties shall meet NDDOT asphalt binder specifications.

The aggregate tests conducted for this study were (9, 11): splitting of aggregate samples using ASTM D75 and AASHTO T248; sieve analysis of the fine and coarse aggregates using AASHTO T11 and T27; bulk specific gravity of fine and coarse aggregates using AASHTO T84 and T85; lightweight pieces of aggregate using AASHTO T113; coarse aggregate angularity according to NDDOT Field Sampling and Testing Manual (one fractured face requirement); the L.A. Abrasion Test using AASHTO T96; fine aggregate angularity using

AASHTO T304; clay content using AASHTO T176; and flat & elongated particles using ASTM D 4791.

Fine aggregate angularity (FAA) is the percentage of air voids present in loosely compacted aggregates smaller than 2.36 mm (or US Sieve #8). The FAA property ensures a high degree of fine aggregate internal friction and rutting resistance. The FAA property was the main emphasis of this study.

For Valley City aggregates, specific gravities for coarse and fine aggregates, water absorption, and consensus properties for individual stockpiles were conducted by the PI and found to be consistent with Superpave aggregate requirements. A summary of such properties are shown in Tables 1, 2, and 3 below.

Table 1 Valley City Aggregate Properties for Individual Stockpiles

	Agg #1	Agg #2	Agg #3	Agg #4
	Rock	Crushed Fines	Nat. Fines 1	Nat. Fines 2
Bulk SpG (G_{sb})				
Coarse	2.628	2.628	2.628	2.628
Fine	2.631	2.631	2.572	2.543
Apparent SpG (G_{sa})				
Coarse	2.774	2.774	2.774	2.774
Fine	2.771	2.771	2.733	2.736
Water Absorption				
Coarse	2.000	2.000	2.000	2.000
Fine	1.920	1.920	2.280	2.770
Combined				
Bulk SpG (G_{sb})	2.628	2.631	2.580	2.558
Apparent SpG (G_{sa})	2.774	2.771	2.739	2.743
Water Absorption	1.998	1.924	2.235	2.588

Table 2 Valley City Consensus Aggregate Properties

Aggregate Properties	Agg #1 Rock	Agg #2 Crushed Fines	Agg #3 Nat. Fines 1	Agg #4 Nat. Fines 2	Agg. Blend	Spec's
Fine Agg. Angularity (% FAA)	47.4	47.4	40.9	42.8	45.1	45 Min
Clay Content (% Sand Equivalent)	71	71	37	47	59.0	40 Min
Coarse Agg. Angularity (%)	On Plus #4 Material				100.00	75 Min
Thin & Elongated Pieces					1.1	10 Max

Table 3 Valley City Aggregate Blend Properties

Bulk SpG (G_{sb})	2.607
Apparent SpG (G_{sa})	2.762
Water Absorption (%)	2.108
Light Wt Particles (%)	1.14
Toughness (% Loss)	22.6

The natural fines were the only aggregate stockpile that was taken from the Northwood location. The Northwood aggregates were a blend of the two locations to obtain a low FAA of 42 and 40. For Northwood aggregate blend, Table 4 displays the results of aggregate properties for individual stockpiles; Table 5 shows the consensus aggregate properties; and Table 6 illustrates the aggregate blend properties.

Table 4 Northwood Aggregate Properties for Individual Stockpiles

	Agg #1	Agg #2	Agg #3
	Rock	Crushed Fines	N.W. Nat. Fines
Bulk SpG (G_{sb})			
Coarse	2.628	2.628	2.529
Fine	2.631	2.631	2.529
Apparent SpG (G_{sa})			
Coarse	2.774	2.774	2.625
Fine	2.771	2.771	2.625
Water Absorption			
Coarse	2.000	2.000	0.770
Fine	1.920	1.920	0.770
Combined			
Bulk SpG (G_{sb})	2.628	2.631	2.529
Apparent SpG (G_{sa})	2.774	2.771	2.625
Water Absorption	1.998	1.924	0.770

Table 5 Northwood Consensus Aggregate Properties

Aggregate Properties	Agg #1	Agg #2	Agg. 3	Agg. Blend	Spec's
	Rock	Crushed Fines	N.W. Nat. Fines		
Fine Agg. Angularity (% FAA)	47.4	47.4	36	42, 40	N/A
Clay Content (% Sand Equivalent)	71	71	57	61.9, 64.3	40 Min
Coarse Agg. Angularity (%)	On Plus #4 Material			100.00	75 Min
Thin & Elongated Pieces				1.1	10 Max

Table 6 Northwood Aggregate Blend Properties

Fine Aggregate Angularity (FAA)	40	42
Bulk SpG (G_{sb})	2.582	2.596
Apparent SpG (G_{sa})	2.703	2.724
Water Absorption (%)	1.146	1.311
Light Wt Particles (%)	1.1	1.1
Toughness (% Loss)	22.6	22.6

GRADATIONS

Gradations for this study were chosen based on the Valley City and Northwood project gradations. Table 7 displays the individual gradations for all the stockpiles used in this study.

Table 7 Individual Aggregate Gradations

	Agg #1	**Agg #2**	**Agg #3**	**Agg #4**	**Agg #5**
Aggregate Description --->	**Rock**	**Crushed Fines**	**Nat. Fines 1**	**Nat. Fines 2**	**N.W. Nat. Fines**
If Agg. is Crushed, Enter 1	1	1	0	0	0
Sieve Size	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**
5/8" (16mm)	100.0	100.0	100.0	100.0	100.0
1/2" (12.5mm)	75.1	100.0	99.6	98.7	100.0
3/8" (9.5mm)	26.5	99.0	97.2	95.0	100.0
#4 (4.75mm)	2.3	94.9	85.5	81.7	96.2
#8 (2.36mm)	1.7	71.8	76.7	66.1	86.1
#16 (1.18mm)	1.5	47.1	63.5	41.3	71.3
#30 (0.6mm)	1.4	31.0	46.6	15.8	50.7
#50 (0.3mm)	1.3	18.8	25.2	6.3	25.4
#100 (0.15mm)	1.1	11.9	12.4	3.9	8.5
#200 (0.075mm)	0.8	8.9	9.0	3.1	5.5

Tables 8 through 11 display the blend gradations for FAA values of 45, 43, 42, and 40 respectively.

Table 8 Aggregate Gradations for the Blend with FAA of 45

Aggregate Description	Aggregate #	Blend %	Sieve Size	Blend Gradation	Control Points Lower	Control Points Upper
Rock	1	33	5/8"	100.0	100	100
Crushed Fines	2	33	1/2"	91.4	90	100
Nat. Fines 1	3	9	3/8"	73.9		
Nat. Fines 2	4	25	#4	60.2		
Sum of % =100			#8	47.7	28	58
			#16	32.1		
			#30	18.8		
Nominal Maximum Size = 1/2 inch			#50	10.5		
			#100	6.4		
			#200	4.8	2	7

Table 9 Aggregate Gradations for the Blend with FAA of 43

Aggregate Description	Aggregate #	Blend %	Sieve Size	Blend Gradation	Control Points Lower	Control Points Upper
Rock	1	30	5/8"	100.0	100	100
Crushed Fines	2	12	1/2"	92.0	90	100
Nat. Fines 1	3	25	3/8"	75.5		
Nat. Fines 2	4	33	#4	60.4		
Sum of % =100			#8	50.1	28	58
			#16	35.6		
			#30	21.0		
Nominal Maximum Size = 1/2 inch			#50	11.0		
			#100	6.1		
			#200	4.6	2	7

Table 10 Aggregate Gradations for the Blend with FAA of 42

Aggregate Description	Aggregate #	Blend %	Sieve Size	Blend Gradation	Control Points Lower	Control Points Upper
Rock	1	33	5/8"	100.0	100	100
Crushed Fines	2	35	1/2"	91.8	90	100
N.W. Nat. Fines	3	32	3/8"	75.4		
			#4	64.8		
Sum of % =100			#8	47.6	28	58
			#16	31.9		
			#30	18.7		
Nominal Maximum Size = 1/2 inch			#50	10.4		
			#100	6.4		
			#200	4.8	2	7

Table 11 Aggregate Gradations for the Blend with FAA of 40

Aggregate Description	Aggregate #	Blend %	Sieve Size	Blend Gradation	Control Points Lower	Control Points Upper
Rock	1	30	5/8"	100.0	100	100
Crushed Fines	2	24	1/2"	92.5	90	100
N.W. Nat. Fines	3	46	3/8"	77.7		
			#4	67.7		
Sum of % =100			#8	57.3	28	58
			#16	44.6		
			#30	31.2		
Nominal Maximum Size = 1/2 inch			#50	16.6		
			#100	7.1		
			#200	4.9	2	7

LABORATORY MIX DESIGN AND ANALYSIS

BACKGROUND

This research study entailed nine mix designs: three mix designs involved aggregates with FAA values of 45 and PG 70-28, PG 64-28, and PG 58-28 binders. Six more mix designs involved FAA values of 43, 42, and 40 and PG 64-28 and PG 58-28 binders. The aggregate blend used for FAA values of 45 and 43 (5 mix designs total) was picked from the Valley City location. The remaining 4 mixes involving FAA values of 42 and 40 were designed using aggregates from both locations. The natural fines stockpile from the Northwood location had a low FAA value of 36 that helped to obtain the blend with 42 and 40 angularities.

Several measurements and calculations were performed to obtain the various mixtures' volumetric properties. The methods used were consistent with the procedures of the NDDOT Field Sampling and Testing Manual. The volumetric results and their specifications are presented in this chapter.

MIX DESIGN RESULTS

The Superpave mix design procedures based on the NDDOT Field Sampling and Testing Manual were adopted for this study. A Superpave gyratory compactor (SGC) was used to produce specimens that are 6-inch (150 mm) in diameter and 4.6-inch (117 mm) in height. A 4 hour of short term aging was used since water absorption was as high as 2 percent.

Tables 12 and 13 display the void analysis results at the different AC contents. Tables 14 and 15 present the mix properties at the design (optimal) AC contents of the mixes. For terms such as 45-64, the first number indicates the FAA value and the second number after the dash indicates the high end of the PG grade.

Table 12 Voids Analysis for High FAA Mixes @ Ndes for Various Binder Contents

Study Mix Designs	**Properties @ Different AC Contents**				
AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**
FAA 45 & PG 70-28					
Bulk Specific Gravity of the Mix (Gmb)	2.288	2.339	2.347	2.355	2.365
Percent Aggregate	95.0	94.5	94.0	93.5	93.0
Theor. Maximum SpG of Mix (Gmm)	2.518	2.484	2.468	2.462	2.449
Air Voids, Va (%)	9.1	5.8	4.9	4.4	3.4
Voids in Mineral Agg. (VMA)	16.6	15.2	15.4	15.5	15.6
Voids in Mineral Agg. Filled (VFA)	45.1	61.7	68.0	72.0	78.1
FAA 45 & PG 64-28					
Bulk Specific Gravity of the Mix (Gmb)	2.288	2.301	2.317	2.338	
Percent Aggregate	95.0	94.5	94.0	93.5	
Theor. Maximum SpG of Mix (Gmm)	2.494	2.466	2.439	2.421	
Air Voids, Va (%)	8.3	6.7	5.0	3.5	
Voids in Mineral Agg. (VMA)	16.6	16.6	16.4	16.1	
Voids in Mineral Agg. Filled (VFA)	50.2	59.7	69.5	78.6	
FAA 45 & PG 58-28					
Bulk Specific Gravity of the Mix (Gmb)	2.315	2.328	2.372	2.386	
Percent Aggregate	95.0	94.5	94.0	93.5	
Theor. Maximum SpG of Mix (Gmm)	2.503	2.482	2.470	2.453	
Air Voids, Va (%)	7.5	6.2	3.9	2.7	
Voids in Mineral Agg. (VMA)	15.6	15.6	14.5	14.4	
Voids in Mineral Agg. Filled (VFA)	52.0	60.1	72.7	81.0	
FAA 43 & PG 64-28					
Bulk Specific Gravity of the Mix (Gmb)	2.267	2.292	2.322	2.349	
Percent Aggregate	95.0	94.5	94.0	93.5	
Theor. Maximum SpG of Mix (Gmm)	2.483	2.463	2.452	2.427	
Air Voids, Va (%)	8.7	6.9	5.3	3.2	
Voids in Mineral Agg. (VMA)	16.9	16.5	15.8	15.3	
Voids in Mineral Agg. Filled (VFA)	48.8	57.8	66.5	79.0	
FAA 43 & PG 58-28					
Bulk Specific Gravity of the Mix (Gmb)	2.282	2.303	2.331	2.350	
Percent Aggregate	95.0	94.5	94.0	93.5	
Theor. Maximum SpG of Mix (Gmm)	2.502	2.481	2.446	2.422	
Air Voids, Va (%)	8.8	7.2	4.7	3.0	
Voids in Mineral Agg. (VMA)	16.4	16.1	15.5	15.3	
Voids in Mineral Agg. Filled (VFA)	46.4	55.2	69.8	80.5	

Table 13 Voids Analysis for Low FAA Mixes @ Ndes for Various Binder Contents

Study Mix Designs	Properties @ Different AC Contents				
AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**
FAA 42 & PG 64-28					
Bulk Specific Gravity of the Mix (Gmb)	2.321	2.333	2.348	2.363	2.383
Percent Aggregate	95.0	94.5	94.0	93.5	93.0
Theor. Maximum SpG of Mix (Gmm)	2.529	2.502	2.474	2.461	2.416
Air Voids, Va (%)	8.2	6.8	5.1	4.0	1.4
Voids in Mineral Agg. (VMA)	15.1	15.1	15.0	14.9	14.7
Voids in Mineral Agg. Filled (VFA)	45.4	55.2	66.0	73.3	90.7
FAA 42 & PG 58-28					
Bulk Specific Gravity of the Mix (Gmb)	2.326	2.341	2.361	2.370	
Percent Aggregate	95.0	94.5	94.0	93.5	
Theor. Maximum SpG of Mix (Gmm)	2.518	2.500	2.484	2.464	
Air Voids, Va (%)	7.6	6.4	4.9	3.8	
Voids in Mineral Agg. (VMA)	14.9	14.8	14.5	14.7	
Voids in Mineral Agg. Filled (VFA)	49.0	57.0	66.0	73.9	
FAA 40 & PG 64-28					
Bulk Specific Gravity of the Mix (Gmb)	2.303	2.323	2.334	2.350	2.374
Percent Aggregate	95.0	94.5	94.0	93.5	93.0
Theor. Maximum SpG of Mix (Gmm)	2.519	2.498	2.476	2.450	2.422
Air Voids, Va (%)	8.6	7.0	5.7	4.1	2.0
Voids in Mineral Agg. (VMA)	15.3	15.0	15.0	14.9	14.5
Voids in Mineral Agg. Filled (VFA)	43.9	53.1	62.0	72.4	86.4
FAA 40 & PG 58-28					
Bulk Specific Gravity of the Mix (Gmb)	2.302	2.318	2.336	2.356	2.363
Percent Aggregate	95.0	94.5	94.0	93.5	93.0
Theor. Maximum SpG of Mix (Gmm)	2.531	2.497	2.470	2.452	2.415
Air Voids, Va (%)	9.0	7.2	5.4	3.9	2.2
Voids in Mineral Agg. (VMA)	15.3	15.2	15.0	14.7	14.9
Voids in Mineral Agg. Filled (VFA)	41.0	52.8	63.9	73.3	85.5

Table 14 Mix Properties for High FAA Mixes at Recommended Asphalt Contents

Mix Properties	45-70	45-64	45-58	43-64	43-58	Spec's
Optimum AC (%)	6.7	6.3	6.0	6.3	6.2	
Density (pcf)	147.2	146.0	148.0	145.9	146.0	
Air Voids (%)	4.0	4.0	4.0	4.0	4.0	3.0-5.0
VMA (%)	15.4	16.2	14.5	15.5	15.4	14.0 Min
VFA (%)	74.4	75.0	72.7	74.0	74.0	65.0-78.0
%Gmm @ Ninitial	88.7	87.9	87.8	88.9	89.0	89.0 Max
%Gmm @ Nmaximum	92.8	98.1	95.9	96.6	95.7	98.0 Max
AC Film Thickness (m)	10.5	10.7	9.3	10.1	9.7	7.5-13.0
Dust/Effective AC Ratio	0.9	0.9	1.0	0.9	0.9	0.6-1.3
Asphalt Absorption (%)	1.64	1.09	1.49	1.33	1.44	
Maximum SpG @ Ndes	2.457	2.437	2.471	2.436	2.437	
Effective (Gme)	2.720	2.681	2.709	2.683	2.691	

Table 15 Mix Properties for Low FAA Mixes at Recommended Asphalt Contents

Mix Properties	42-64	42-58	40-64	40-58	Spec's
Optimum AC (%)	6.5	6.4	6.5	6.5	
Density (pcf)	147.2	147.8	146.6	147.0	
Air Voids (%)	4.0	4.0	4.0	4.0	3.0-5.0
VMA (%)	14.9	14.7	14.9	14.7	14.0 Min
VFA (%)	73.3	72.3	72.4	73.3	65.0-78.0
%Gmm @ Ninitial	87.6	87.2	87.7	87.7	89.0 Max
%Gmm @ Nmaximum	94.9	94.4	94.6	94.3	98.0 Max
AC Film Thickness (m)	8.3	7.9	7.7	7.7	7.5-13.0
Dust/Effective AC Ratio	1.1	1.1	1.1	1.0	0.6-1.3
Asphalt Absorption (%)	1.8	1.9	1.96	1.95	
Maximum SpG @ Ndes	2.457	2.467	2.447	2.454	
Effective (Gme)	2.720	2.727	2.715	2.715	

Comparing the mix properties in Tables 14 and 15, one can observe that the asphalt absorption values are consistent in Table 15 while wider variation exists among those values in Table 14. The mixes in Table 15 were blended from the Northwood aggregate source while the aggregate blends for the mixes in Table 14 were taken from both the Northwood and the Valley City aggregate sources. Even though care was taken in obtaining blends with the specified FAA values, other properties such as asphalt absorption were not consistent.

Figure 1 presents an example with plots of unit weight, air voids, VMA, VFA, % Gmm @ Ninitial, and the theoretical maximum specific gravity versus %AC content for FAA 42 and PG 64-28 mix design.

The optimal AC content percentages for the high FAA mix design cases were 6.7, 6.3, 6.0, 6.3, and 6.2 corresponding to design cases of 45-70, 45-64, 45-58, 43-64, and 43-58, respectively. Also the optimal %AC content percentages for the low FAA mix design cases were 6.5, 6.4, 6.5, and 6.5 corresponding to 42-64, 42-58, 40-64, and 40-58 design mixes, respectively.

The volumetric properties of the HMA were found in accordance with Superpave Volumetric Mix Design (AASHTO M 323). Obviously, the design air voids (4%) for all Superpave mix designs meets the specifications for percent air voids. Typically, when air voids are low (< 3%), mix stability is compromised; while high air voids mixes (> 8%) produce water permeable mixes that accelerates oxidation and eventually causing moisture damage and loss of pavement life. Since the VMA is a function of the nominal maximum aggregate size (1/2″ in this study), a minimum of 14% VMA is specified. The results indicate that all the design mixes have met the 14% minimum VMA.

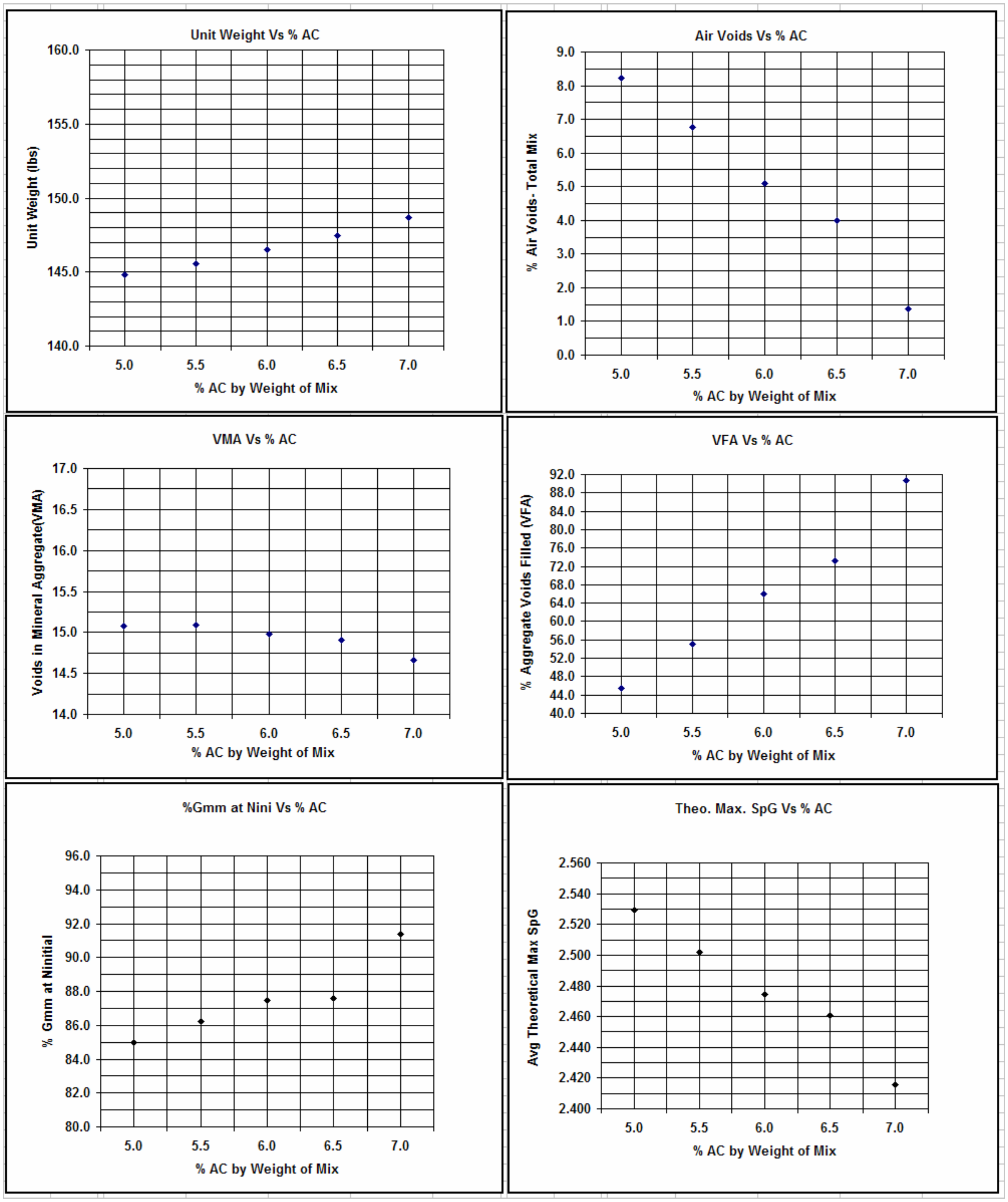

Figure 1 Graphs for FAA 42 and PG 64-28 Mix Design at Various %AC

The VFA is inversely related to the air voids and the specifications are based on the ESALs of the project being considered. For this study, a traffic level of 0.3 to < 3.0 million ESALs was adopted to represent traffic on North Dakota's Highways. The main purpose of the VFA is to limit maximum levels of VMA and subsequently maximum levels of binder content. The VFA specification restricts the allowable air voids content of the HMA that are near the minimum, thus, ensuring sufficient film thickness and consequently good durability. The VFA specification was achieved for all the Superpave mixes.

The Dust/Effective Asphalt Ratio results were within specification limits. This ratio is proportional to the air voids in the mixture and aids in the quality of the HMA by producing mastic that is neither very stiff nor very soft. The low value in the specification is designed to ensure that sufficient asphalt binder is covering the aggregates to improve durability. The upper value of the specification is to safeguard from excessive asphalt binder that may drain down or cause bleeding. The results show that all design mixes were with limits of this specification.

The %Gmm @ Nini is a measure of consolidation at a low number of gyrations. The specification limit of 89% is specified to ensure that the mix does not compact too easily. Mixes that compact easily are usually tender or unstable. Therefore, this parameter is a performance indicator of the aggregate and binder properties. The %Gmm @ Nmax specifies the %Gmm (consolidation) at a high number of gyrations. The importance of this parameter is to prevent having mixes that continue to compact under traffic loading. Therefore, this parameter works as a safety factor if traffic levels increase. The %Gmm @ Nini and Nmax were also within specification limits.

LABORATORY PERFORMANCE TESTING AND ANALYSIS

BACKGROUND

One of the drawbacks of the Superpave method is that there were no strength tests developed along with the mix design method to compliment the volumetric mixture design procedures. The addition of a torture test to evaluate the rutting potential of an asphalt mixture is highly valued by DOTs and the pavement industry.

The Asphalt Pavement Analyzer has been used to evaluate rutting, fatigue, and moisture resistance of HMA mixtures. In this study, testing with the APA was conducted according to 63-03 "Standard Method of Test for Determining Rutting Susceptibility of Asphalt Paving Mixtures," a provisional AASHTO designation with modifications to accommodate NDDOT project requirements.

Laboratory specimens were tested at 70^{o}C, 64^{o}C, and 58^{o}C, corresponding with the high temperature of the binder's performance grades. Testing was carried out at 8,000 cycles for dry specimens and 25,000 cycles for submerged (wet) specimens. Specimens were conditioned in a water bath at 70^{o}C, 64^{o}C, or 58^{o}C for 24 hours before moisture susceptibility testing. All specimens were prepared at 7.0 ± 0.5% air voids to conform to actual densities of newly constructed pavements.

The modified Lottman Test (or TSR) was done to test resistance of compacted bituminous mixtures to moisture induced damage (AASHTO T283) on 6-inch diameter Superpave specimens at 7.0 ± 0.5% air voids. A TSR value of less than 70% is considered moisture susceptible. The NDDOT procedure according to Field Sampling and Testing Manual was used for this study. The TSR results were then compared with the APA results.

APA RESULTS AND ANALYSIS

The APA rut results for the mix design cases are shown in Tables 16 and 17 and Figure 2. The numbers 1 through 108 in Tables 16 and 17 represent the specimens used for all the design cases. The values shown represent the rut depth (in mm) under the corresponding wheel of the APA

Table 16 APA Dry Rut Resistance Results

Mix Design Cases	Left Side Depth (mm)		Center Depth (mm)		Right Side Depth (mm)		AVE (mm)
45-70 Dry	*1*	*2*	*3*	*4*	*5*	*6*	**5.33**
	5.87	**6.13**	**5.69**	**5.85**	**4.23**	**4.19**	
45-64 Dry	7	8	9	10	11	12	**5.53**
	5.46	**5.43**	**5.34**	**5.68**	**5.57**	**5.68**	
45-58 Dry	*13*	*14*	*15*	*16*	*17*	*18*	**5.86**
	5.47	**4.95**	**6.93**	**6.88**	**4.62**	**6.30**	
43-64 Dry	19	20	21	22	23	24	**5.83**
	5.12	**6.13**	**4.98**	**6.24**	**6.68**	**5.81**	
43-58 Dry	*25*	*26*	*27*	*28*	*29*	*30*	**6.65**
	6.05	**7.48**	**7.11**	**6.83**	**5.86**	**6.59**	
42-64 Dry	*31*	*32*	*33*	*34*	*35*	*36*	**6.34**
	6.81	**6.38**	**6.22**	**6.11**	**6.15**	**6.40**	
42-58 Dry	*37*	*38*	*39*	*40*	*41*	*42*	**6.95**
	6.85	**6.54**	**7.18**	**7.42**	**6.49**	**7.23**	
40-64 Dry	*43*	*44*	*45*	*46*	*47*	*48*	**7.10**
	6.28	**7.83**	**6.91**	**7.30**	**7.19**	**7.16**	
40-58 Dry	*49*	*50*	*51*	*52*	*53*	*54*	**7.47**
	6.60	**7.49**	**8.48**	**7.27**	**7.88**	**7.12**	

Table 17 APA Wet Rut Resistance Results

Mix Design Cases	Left Side Depth (mm)		Center Depth (mm)		Right Side Depth (mm)		AVE (mm)
45-70 Wet	*55*	*56*	*57*	*58*	*59*	*60*	**5.74**
	4.67	**5.89**	**6.65**	**6.63**	**5.23**	**5.38**	
45-64 Wet	*61*	*62*	*63*	*64*	*65*	*66*	**6.80**
	8.26	**6.24**	**6.41**	**5.84**	**7.04**	**7.02**	
45-58 Wet	*67*	*68*	*69*	*70*	*71*	*72*	**6.99**
	7.25	**6.65**	**7.28**	**6.05**	**7.39**	**7.30**	
43-64 Wet	73	74	75	76	77	78	**7.93**
	8.03	**7.81**	**7.34**	**8.24**	**7.79**	**8.39**	
43-58 Wet	*79*	*80*	*81*	*82*	*83*	*84*	**8.60**
	8.68	**8.35**	**9.06**	**7.77**	**9.25**	**8.52**	
42-64 Wet	*85*	*86*	*87*	*88*	*89*	*90*	**9.15**
	8.79	**9.56**	**9.76**	**8.93**	**8.73**	**9.11**	
42-58 Wet	*91*	*92*	*93*	*94*	*95*	*96*	**9.47**
	9.26	**9.40**	**9.63**	**9.95**	**9.38**	**9.19**	
40-64 Wet	*97*	*98*	*99*	*100*	*101*	*102*	**14.00**
	Failed	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	
40-58 Wet	*103*	*104*	*105*	*106*	*107*	*108*	**14.00**
	Failed	**Failed**	**Failed**	**Failed**	**Failed**	**Failed**	

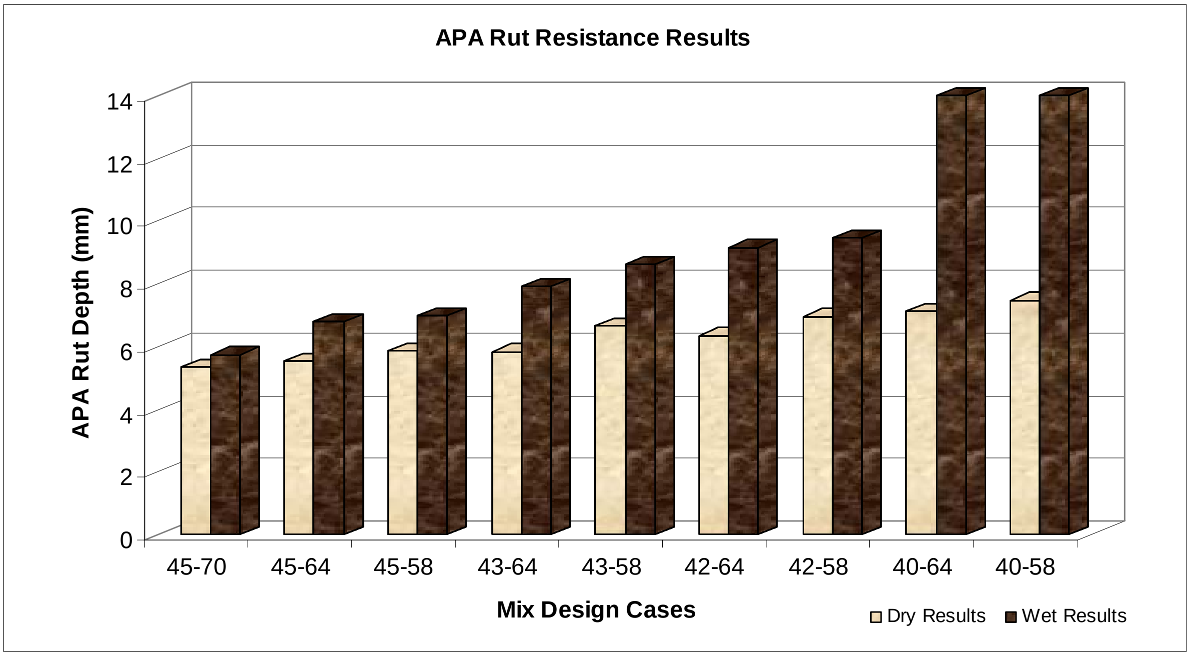

Figure 2 APA Average Performance Results for the Different Mix Design Cases

The Analysis of Variance (ANOVA) statistical analysis was performed on the APA rut results. The ANOVA statistical analysis of the APA results is presented in Table 18. The null hypothesis is given as, H_o: the means of the results are equal. On the other hand, the alternate hypothesis, H_1: the means of the results are not equal. Rejection of the null hypothesis indicates that the results are significantly different and can be compared.

Observation of the statistical results indicates that the P-value is much less than the significance value ($P = 1.69132E\text{-}54 < 0.05$); therefore, the null hypothesis is rejected. This means that the results between groups of dry versus wet, different FAA values, and different PG grades can be compared.

Table 18 Analysis of Variance (ANOVA) Statistics on the APA Results

Groups	Count	Sum	Average	Variance
45-70 dry	6	31.96	5.326666667	0.768226667
45-64 dry	6	33.16	5.526666667	0.019506667
45-58 dry	6	35.15	5.858333333	0.979336667
43-64 dry	6	34.96	5.826666667	0.441506667
43-58 dry	6	39.92	6.653333333	0.384106667
42-64 dry	6	38.07	6.345	0.06587
42-58 dry	6	41.71	6.951666667	0.148376667
40-64 dry	6	42.67	7.111666667	0.258456667
40-58 dry	6	44.84	7.473333333	0.421586667
45-70 wet	6	34.45	5.741666667	0.635456667
45-64 wet	6	40.81	6.801666667	0.724976667
45-58 wet	6	41.92	6.986666667	0.281386667
43-64 wet	6	47.6	7.933333333	0.139946667
43-58 wet	6	51.63	8.605	0.27963
42-64 wet	6	54.88	9.146666667	0.179226667
42-58 wet	6	56.81	9.468333333	0.078296667
40-64 wet	6	84	14	0
40-58 wet	6	84	14	0

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	670.1769741	17	39.42217495	122.2204936	1.69132E-54	1.737465283
Within Groups	29.02946667	90	0.32254963			
Total	699.2064407	107				

In comparing the results, the APA performance specification adopted in this study is an average of 7.0 mm rut depth under the APA wheels (for traffic levels of 0.3 to < 3 million design ESALs). The expression "wet" here refers to a 24-hour submersion in a water bath at specified temperature followed by APA testing (also submerged at the same specified temperature). The condition temperatures were 70^{o}C, 64^{o}C, and 58^{o}C corresponding to the high end temperature of each of the binder grades.

The results indicate that each mix design performed better when tested dry rather than wet throughout all the mix design cases. The 24-hour conditioning effect can be seen when comparing wet versus dry results. Comparisons of the rut results for the different PG grades and FAA values indicate that average ruts were lower for higher PG grades or higher FAA values. For the cases of high PG grades and low FAA values or low PG grades and high FAA values, the rut results were generally close but the PG grade influence was more pronounced.

For the dry condition, the 45-70 mix design outperformed all other design cases followed by the rest of the cases of FAA values of 45. Generally, the cases with FAA 43 cases had performed slightly better than the FAA 42 cases. But the 42-64 mix had a better result than the 43-58 mix indicating that the positive influence of a higher binder grades overweighs the negative influence of a slightly lower FAA value. The rutting for the FAA 42 mix design cases were hovering around the 7.0 mm specification value. Overall, all mix design cases under dry condition passed the 7.0 mm specification except for the FAA 40 mix designs.

For the wet condition, only the FAA 45 mixes passed the specification. The FAA 43 and FAA 42 mixes failed the 7.0 mm specification. The rutting for the FAA 40 mix design cases reached the maximum APA failure value of 14.0 mm[1] and thus triggered the automatic stopping of the test.

MOISTURE SENSITIVITY RESULTS AND ANALYSIS

The AASHTO T-283, as modified by the NDDOT Field Sampling and Testing Manual, was adopted for this study. The specimens were produced using the Superpave gyratory. The following mix designs were tested for this study, 45-64, 45-58, 42-64, and 42-58. Six specimens for each mix design were produced with air voids of 7.0 ± 0.5%. The higher percentage of air voids helps to accelerate moisture damage on the cores.

Two groups of three specimens were used. The first group is the control group (dry). The second group is vacuum saturated between 70 and 80 percent and is placed in a water bath at 140°F (60°C) for 24 hours. After conditioning, the indirect tensile strength (ITS) test was performed. The ITS Test was performed on both the dry and wet specimen sets at 77°F (25°C) with a loading rate of 2 in/min. The minimum acceptable TSR used is 70%.

The moisture sensitivity test results for each mix design case are shown in Table 19 and graphically plotted in Figures 3 and 4. The wet and dry strengths are given in pounds per square inch (psi), and the TSR values are in percentage (%).

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[1] The APA automatically stops the test when the 14.0 mm maximum failure value is triggered.

Table 19 Moisture Sensitivity Test Results

Mix Designs	Wet Strength (psi)	Dry Strength (psi)	TSR (%)
45-64	58.0	60.5	95.9
45-58	46.8	52.1	89.8
42-64	89.6	123.0	72.8
42-58	47.4	58.1	81.6

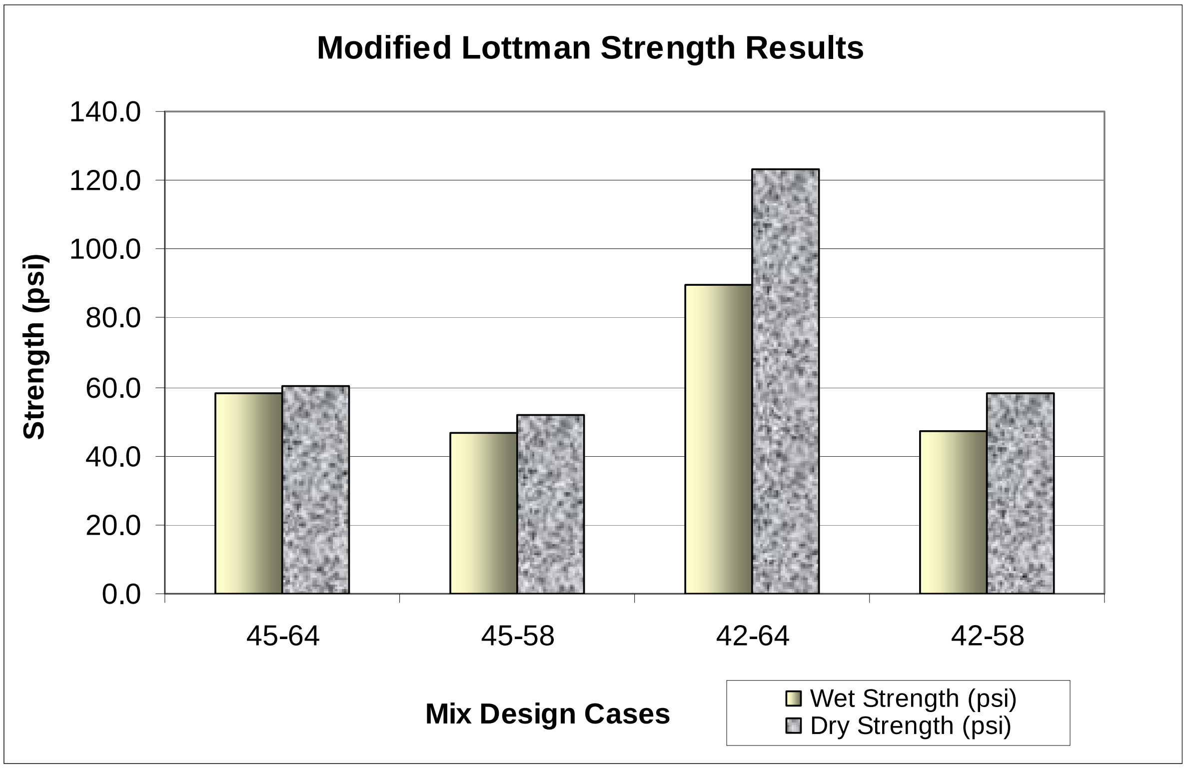

Figure 3 Moisture Sensitivity Strength Results

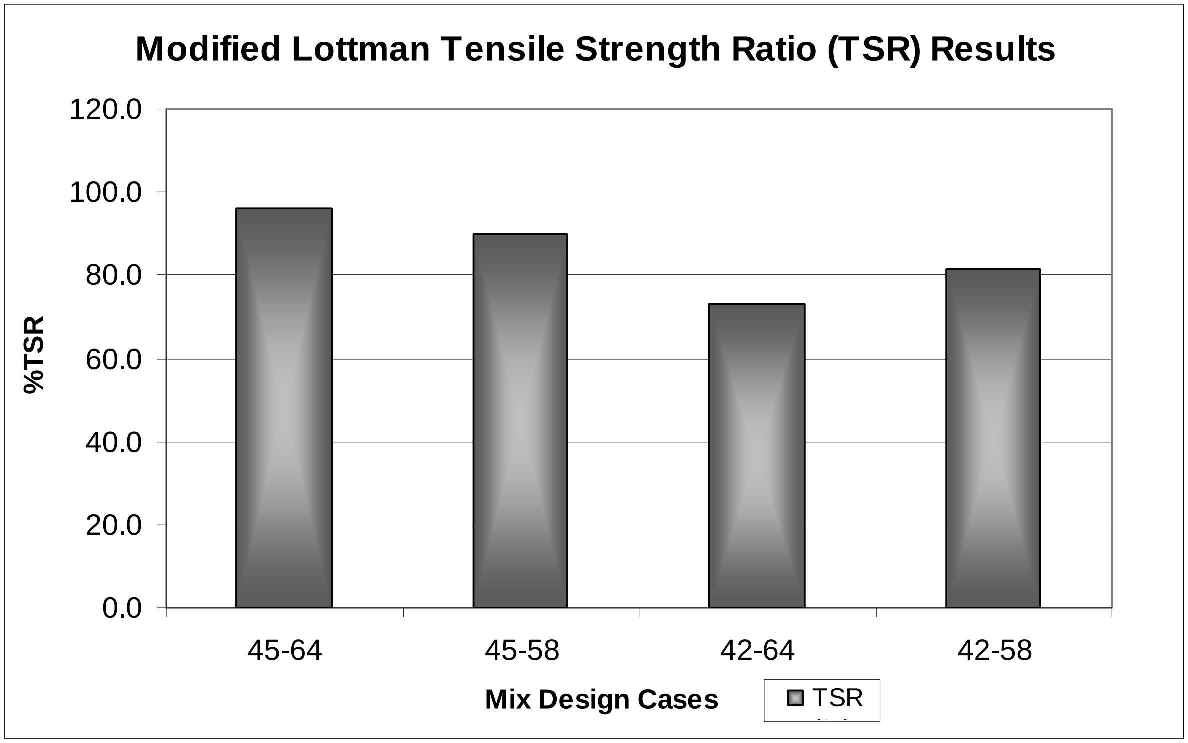

Figure 4 Moisture Sensitivity Test (TSR) Results

All mix designs passed the TSR specification of 70%. TSR values were significantly higher for design cases with higher FAA values. Also TSR values were greater for higher PG grades.

The 45-64 mix design case performed really well with a TSR value of 96%. The 45-58 mix design also did well with a TSR value of 90%. Even though the TSR values for the FAA 42 mix cases were lower than the TSRs for the FAA 45 mix cases as expected, the 42-64 mix design case presented an anomaly. The 42-64 case not only performed inferior to the 42-58 mix design case but the dry and wet strengths were much higher than all the other design cases. The 42-64 mix design case was repeated and the same results were obtained.

SUMMARY AND CONCLUSIONS

Many laboratory tests, data analysis, and result comparisons were done to complete this study. The aggregate blends and the binder grades were obtained. The aggregates were taken from Valley City and Northwood. Aggregate blends were batched to form design blends with specified fine aggregate angularities of 45, 43, 42, and 40. The asphalt binders were acquired from an asphalt supplier via the NDDOT. The binder grades were PG 70-28, PG 64-28, and PG 58-28. Aggregate and binder properties were either tested or obtained from the NDDOT. Aggregates consensus and source properties were within specification limits for the entire mix design blends. Binder properties were tested by the NDDOT.

Nine Superpave mix designs were established based on three binder grades and four FAA values. There was only one mix design that involved the PG 70-28 binder since the NDDOT practice does not allow to mix PG 70-28 binder with any FAA value less that 45. Volumetric properties suggest that all mix designs were within specifications.

The performance of the mix design cases were tested using the APA and the moisture sensitivity tests. Six-inch diameter specimens at 7% air voids were used to perform the tests. The ANOVA statistical analysis was performed on the APA rut results and found that the data results were significantly different and can be compared. A 7.0 mm rut depth specification was adopted for the study.

Observation of the APA results indicates that the dry samples performed better than the wet samples. Comparisons of the rut results among the subset groups indicate that average ruts were lower for higher PG grades or FAA values. For opposite cases of PG grades and FAA values, the rut results were close with a slight advantage given to the higher PG grades.

For the dry condition, the 45-70 mix design outperformed all other design cases followed by the rest of the FAA of 45 cases. The FAA 43 mix cases had performed slightly better than the FAA 42 cases. But the 42-64 mix had a better result than the 43-58 mix indicating that the positive influence of a higher binder grade overweighs the negative influence of a slightly lower FAA value. The rutting values for both of the FAA 42 mix design cases were hovering around the 7.0 mm specification value. All of the mix design cases under dry condition passed the 7.0 mm specification except for the FAA 40 mix design cases.

For the wet condition, only the FAA 45 mix design cases have actually passed the specification. The FAA 43 and FAA 42 mix design cases did fail the specification but the FAA 40 mix design cases triggered the maximum APA failure value of 14.0 mm.

Inspection of the moisture sensitivity test results indicate that all the mix design cases passed the TSR specification of 70%. TSR values were significantly higher for design cases with higher FAA values. Also TSR values were greater for higher PG grades.

The 45-64 mix design case performed really well with a TSR value of 96%. The 45-58 mix design also did well with a TSR value of 90%. Even though the TSR values for the FAA 42 mix cases were lower than the TSRs for the FAA 45 mix cases as expected, the 42-64 mix design case presented an anomaly. The 42-64 case not only performed inferior to the 42-58 mix design case but the dry and wet strengths were much higher than all the other design cases. The 42-64 mix design case was repeated and the same results were obtained.

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