UNIVERSITY OF NORTH DAKOTA
Grand Forks

Evaluation of Coarse-Graded Superpave HMA Pavements in North Dakota Using the Asphalt Pavement Analyzer

Final Report

February 2007

SCHOOL OF ENGINEERING AND MINES

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT	EXPERIMENTAL PROJECT NO.	STATE	Y EAR		NUMBER	SURF	CONSTRUCTION PROJ NO	LOCATION
	1	UND	06	-	03	B	NH-6-081(053)192 8	Grafton, ND 28
	EVALUATION FUNDING						NEEP NO.	PROPRIETARY FEATURE?
	48	1 HP&R		3 DEMONSTRATION			49	51 Yes / No X
		2 X CONSTRUCTION		4 IMPLEMENTATION				
SHORT TITLE	TITLE 52 Evaluation of Coarse-Graded Superpave HMA Pavements in North Dakota Using Asphalt Pavement Analyzer							
THIS FORM	DATE 140	MO. 12	--	YR. 2008	REPORTING 1 INITIAL	2 ANNUAL	3 X FINAL	
KEY WORDS	KEY WORD 1 Asphalt 145				KEY WORD 2 Superpave 167			
	KEY WORD 3 Rutting 189				KEY WORD 4 Aggregate 211			
	UNIQUE WORD 233				PROPRIETARY FEATURE NAME 255			

CHRONOLOGY	Date Work Plan Approved	Date Feature Constructed:	Evaluation Scheduled Until:	Evaluation Extended Until:	Date Evaluation Terminated:
	2006 277	2006 281	2007 285	2008 289	2008 293

QUANTITY AND COST	QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS)	UNITS		UNIT COST (*Dollars, Cents*)
	297	305 1 LIN. FT 2 SY 3 SY-IN 4 CY	5 TON 6 LBS 7 EACH 8 LUMP SUM	306

AVAILABLE EVALUATION REPORTS	CONSTRUCTION	PERFORMANCE	FINAL
	315		X

EVALUATION	CONSTRUCTION PROBLEMS	PERFORMANCE
	318 1 X **None** 2 ___ Slight 3 ___ Moderate 4 ___ Significant 5 ___ Severe	319 1 ___ Excellent 2 X **Good** 3 ___ Satisfactory 4 ___ Marginal 5 ___ Unsatisfactory

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

REMARKS

321
This project consisted of using cores from a HBP pavement with a coarse graded aggregate. The results from the Asphalt Pavement Analyzer were that the mix performed satisfactory in dry conditions but performed unsatisfactory in wet conditions.

University of North Dakota
Department of Civil Engineering

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Final Report Submitted to the

North Dakota Department of Transportation
Bismarck, ND

By:

Dr. Nabil Suleiman, Principal Investigator

February 2007

Disclaimer

The contents of this report reflect the views of the author or authors who are responsible for the facts and accuracy of the data presented herein. The contents do not reflect the official views of the North Dakota Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Finally, the author hopes that NDDOT will maintain its research activities with UND and continue to fund CE department projects.

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INTRODUCTION

Background

The aggregate gradation used in Superpave hot mix asphalt (HMA) mix design is required to be within control points at 0.075 mm (No. 200), 2.36 mm (No. 8), and nominal maximum aggregate size (*1, 2*). Both coarse- and fine-graded mixtures can be designed within these control points (1, *3*). A majority of states accept both coarse- and fine-graded Superpave mixtures if the Superpave volumetric properties such as voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA) are met. However, some states have begun to specify only fine-graded Superpave mixtures whereas others specify only coarse-graded Superpave mixtures. The states that specify coarse-graded mixtures define them as those mixtures with gradations below the maximum density line (*4*) and believe that coarse gradation provides a “strong aggregate structure.” This belief is not essentially based on any significant mix strength test data. After some coarse-graded Superpave mixtures exhibited premature and excessive rutting (more than the fine-graded mixtures) on WesTrack and exhibited excessive in-situ permeability in many other states, some states have started to specify only fine-graded mixtures which were defined generally as those mixtures with gradation above the maximum density line (*5*).

Asphalt-aggregate mixture sensitivity has long been recognized for its potential negative impact on performance if mixture variables, such as the asphalt content (AC) and the fine material content (the percent that passes the #200 sieve) are not carefully controlled during the production of hot-mix asphalt concrete (HMAC) (*6*). Construction variability is large enough that tight control of these properties may not be possible with existing construction equipment. Mixtures can be defined as sensitive and critical when the physical properties and performance are greatly affected by the typical variability in the asphalt content and mineral filler material (finer than the #200 sieve). Sensitive mixtures typically result from the use of one or more of the following (*6*):

- Rounded or subrounded aggregates,
- Aggregates with smooth surface textures,
- An aggregate blend with a high natural sand content,
- An aggregate blend with a high to intermediate sand content,
- A soft asphalt cement or binder.

It is important in the construction of hot mix asphalt (HMA) that the mix be adequately compacted in-place so that the initial permeability is low and there will not be significant additional densification under traffic (*7, 8*). For dense-graded mixes, numerous studies have shown that initial in-place air void content should not be below approximately 3 percent or above approximately 8 percent. Low in-place air voids have been shown to result in rutting, bleeding, and shoving, while high air voids allow water and air to penetrate into the pavement leading to an increased potential for water damage, oxidation, raveling, and cracking. Earlier studies have shown that most conventional dense-graded mixtures become excessively permeable at in-place air voids above 8 percent. However, recent studies indicate that coarse-graded Superpave mixes can be excessively permeable to water at in-place air voids less than 8 percent (*7*, *8*).

The compaction of coarse-graded Superpave designed mixtures is sometimes more difficult than with some of the more fine-graded mixtures that had previously been designed using the Marshall procedure. One problem with compacting coarse-graded mixes has been the “tender zone,” which sometimes occurs during compaction. The tender zone typically occurs within a temperature range of 245 to 180°F (*3*, *4*).

The problem of tender mixes is not new; it has been around for many years. There are many possible characteristics of a mixture which may lead to tenderness being exhibited during field compaction. Among these is the use of an excessive amount of rounded fine aggregates (natural sands), a low asphalt binder viscosity, a high asphalt binder content, a reduced filler content, the presence of internal moisture in the aggregate, etc. All of the above-mentioned characteristics can alone, or in combination, cause a mix to exhibit tender behavior. With coarse-graded

Superpave mixes, the tenderness typically occurs within a range of temperatures referred to previously as the “tender zone.”

Purpose and Need

Aggregate gradation is an important factor that influences the permanent deformation potential of hot-mix asphalt (HMA). One common way of characterizing aggregate gradation is by making a gradation plot on a 0.45 power chart, which also contains the maximum density line.

Numerous factors can potentially affect the permeability of HMA pavements. Such factors include aggregate particle size distribution, aggregate particle shape, pavement density (air voids or percent compaction), nominal maximum aggregate size (NMAS), and lift thickness for a given NMAS (*3*).

Unlike stone matrix asphalt mixtures (SMA), coarse-graded asphalt mixtures are affected mainly by the % retained on no. 4 sieve and not much by the nominal maximum aggregate size (NMAS). Furthermore, the use of no. 4 sieve size as a NMAS can be advantageous since thin lifts can be utilized. This has been a hot issue in cost saving especially in maintenance operations.

Objectives and Scope

The main objectives of this proposed study are:

- To evaluate the rutting resistance performance of coarse-graded Superpave HMA pavement cores using the asphalt pavement analyzer.
- To carry out permeability tests on coarse-graded field specimen cores obtained from different locations on US Highway 81 north of Grafton, ND.
- To identify the in-place air void percentage of coarse-graded Superpave HMA pavement from Highway 81 north of Grafton, ND.

The scope of the work consists of receiving coarse-graded Superpave field cores from three different locations on US Highway 81 north of Grafton, ND and testing their rut resistance performance and permeability. Rut resistance performance will be tested under dry and wet conditions using the APA. Permeability

and in-place air void content tests will be done on the field cores to explore potential durability problems, if any. A total of fifteen 6-inch diameter field cores will be extracted[1] from each location to carry out the aforementioned tests. The coarse-graded pavement study will entail the following tasks:

Task 1: NDDOT will provide forty five 6-inch diameter core samples of coarse-graded Superpave HMA pavement from three different locations[2] on US Highway 81 north of Grafton, ND. The PI or staff under the PI's guidance will trim samples to testing size. Deliverable will be a report of test results for NDDOT M&R Staff. **[%project = 4%]**

Task 2: NDDOT will provide gradation, aggregate and binder properties, as well as mix design information for the pavement sections of US Highway 81 where the core samples were taken. **[%project = 0%]**

Task 3: The PI or staff under the PI's guidance will carry out rut resistance tests on the core samples utilizing the asphalt pavement analyzer. For each location, six core specimens will be tested for rut resistance under dry condition and six other cores will be tested under wet condition. The number of cycles for APA testing will be 8,000 and 25,000 cycles for dry and wet conditions, respectively. The adopted rut depth failure criterion under the APA wheels is 0.276 inch (or 7 mm)[3]. Deliverable will be a report of test results for NDDOT M&R Staff. **[%project = 70%]**

Task 4: The PI or staff under the PI's guidance will perform permeability tests[4] on the core samples. Three cores from each location will be tested for permeability. The in-place air voids will also be determined. Deliverable will be a report of test results for NDDOT M&R Staff. **[%project = 15%]**

Task 5: The PI or staff under the PI's guidance will examine and compare the rut resistance results, the permeability results, and the in-place air voids with the mixture analysis results and identify any significant variations.

---

[1] NDDOT will extract the samples
[2] NDDOT will identify the locations the samples
[3] For a highway design of up to 3,000,000 ESALs (based on literature review)
[4] According to ASTM Standard PS 129-01 or as advised by NDDOT

Deliverable will be a report of test results for NDDOT M&R Staff. **[%project = 3%]**

Task 6: Prepare a final report. **[*%project = 8%*]**

***Deliverable*:** A final report that includes details on the original coarse-graded pavement material and mix design information, APA test results, permeability test results, analysis procedures, conclusions, and recommendations will be delivered to the NDDOT. A total of 28 original colored copies will be provided to the NDDOT as well as an electronic copy. Also a presentation will be given.

PROJECT SELECTION AND SAMPLING

Project Selection

NDDOT project "NH-6-081(053)192" on US Highway 81 north of Grafton, ND was selected for this study. The project entailed a Superpave coarse-graded mix design. The pavement was an overlay job and was placed in August 2005. Field core samples were obtained from centerline locations within three sections of US Highway 81. The first section (S1) ran from reference point (RP) 192.4 to RP 196.0. The second section (S2) was located between RP 196.0 and RP 203.0, while the third section (S3) was between RP 203.0 and RP 204.5. Fifteen samples from each section were cored for a total of 45 core samples. Twelve samples out of the 15 from each section were used for APA testing (6 dry and 6 wet) and the remaining 3 cores were used for permeability determination.

The first section entailed a 3 ½ inch overlay that was placed in two lifts. The top lift was 2 inches thick. In the second section, 5 inches of overlay was used and placed in 3 lifts where the top lift was 2 inches thick. A 7 inch mine and blend was used in the third section and placed in 4 lifts. The top lift was also paved at 2 inches.

Project Materials

Two binder grades were used for the project, PG 58-34 for the top 2 inches of the mine and blend section and PG 58-28 for the rest of the pavement sections.

Aggregates for the project were taken from Pit # NW ¼ of 10-155-56 owned by Pioneer-Fordville. The blend and consensus properties of the aggregates are displayed in Tables 1 and 2 below. The consensus and blend properties were within Superpave specification limits except for the percent FAA. The individual and blend aggregate gradations are shown in Figures 3 and 4.

Table 1 Aggregate Blend Properties

Bulk SpG (G_{sb})	2.546
Apparent SpG (G_{sa})	2.670
Water Absorption (%)	1.743
Light Wt Particles (%)	3.5
Toughness (% Loss)	N/A

Table 2 Consensus Aggregate Properties

Aggregate Properties	Agg #1	Agg #2	Agg #3	Agg #4	Agg #5	Agg. Blend	Spec's
	Pioneer	Pioneer	Pioneer	Pioneer	Pioneer		
Fine Agg. Angularity (% FAA)	41.3	47.0	47.0	47.0	46.0	44.8	45 Min
Clay Content (% Sand Equivalent)	55	47	0	0	58	51.4	40 Min
Coarse Agg. Angularity (% CAA)	On Plus #4 Material					94.1	75 Min
Thin & Elongated Pieces						2.0	10 Max

Table 3 Individual Aggregate Gradation

	Agg #1	Agg #2	Agg #3	Agg #4	Agg #5
Aggregate Description --->	Pioneer Fines	Pioneer Dust	Pioneer 5/8x4	Pioneer 1/2x4	Pioneer Washed Dust
If Agg. is Crushed, Enter 1		1	1	1	1
Sieve Size	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**
5/8" (16mm)	100.0	100.0	100.0	100.0	100.0
1/2" (12.5mm)	99.0	100.0	79.0	100.0	100.0
3/8" (9.5mm)	98.0	99.0	34.0	56.0	100.0
#4 (4.75mm)	81.0	77.0	1.0	3.3	70.0
#8 (2.36mm)	64.0	61.0	0.0	0.0	47.0
#16 (1.18mm)	42.0	43.0	0.0	0.0	29.0
#30 (0.6mm)	20.0	28.0	0.0	0.0	19.0
#50 (0.3mm)	10.0	19.0	0.0	0.0	11.0
#100 (0.15mm)	7.0	14.0	0.0	0.0	7.0
#200 (0.075mm)	6.6	11.6	0.0	0.0	5.0

Table 4 Aggregate Gradations for the Superpave Blend

Aggregate Description	Aggregate #	Blend %	Sieve Size	Blend Gradation	Control Points (Superpave)	
					Lower	**Upper**
Pioneer	1	17	5/8"	100.0	100	100
Pioneer	2	20	1/2"	94.6	90	100
Pioneer	3	25	3/8"	72.8		
Pioneer	4	23	#4	40.7		
Pioneer	5	15	#8	30.1	28	58
Sum of % =100			#16	20.1		
			#30	11.9		
			#50	7.2		
Nominal Maximum Size = 1/2 inch			#100	5.0		
			#200	4.2	2	7

Examination of the aggregate blend gradation indicates that the Superpave specifications were met. Most notable, the percent passing #4 was 40.7 percent which is consistent with typical coarse-graded mixes gradations.

Project Mix Design

Superpave mix design in accordance with NDDOT section 410 was performed for the project. The voids analysis and mix properties are shown in Tables 5 and 6 below.

Table 5 Voids Analysis of the Mix @ Ndes for Various Binder Contents

Superpave Mix Designs	**Properties @ Different AC Contents**				
AC Content (%)	**4.8**	**5.3**	**5.8**	**6.3**	**6.8**
Bulk Specific Gravity of the Mix (Gmb)	2.300	2.314	2.321	2.331	2.349
Percent Aggregate	95.2	94.7	94.2	93.7	93.2
Theor. Maximum SpG of Mix (Gmm)	2.447	2.437	2.418	2.410	2.401
Air Voids, Va (%)	6.0	5.1	4.0	3.3	2.2
Voids in Mineral Agg. (VMA)	14.0	14.0	14.1	14.2	14.0
Voids in Mineral Agg. Filled (VFA)	57.0	63.7	71.5	77.1	84.6

Table 6 Mix Properties at Recommended Asphalt Content

Mix Properties	**Coarse-Graded Superpave Mix**	**Specification**
Optimum AC (%)	5.8	
Density (pcf)	144.8	
Air Voids (%)	4.0	3.0-5.0
VMA (%)	14.1	14.0 Min
VFA (%)	71.5	65.0-78.0
%Gmm @ Ninitial	86.5	89.0 Max
%Gmm @ Nmaximum	97.1	98.0 Max
AC Film Thickness (m)	11.6	7.5-13.0
Dust/Effective AC Ratio	1.0	0.6-1.3
Asphalt Absorption (%)	1.49	
Maximum SpG @ Ndes	2.417	
Effective (Gme)	2.644	

The displayed results in the above two tables indicate that the volumetric properties have fallen within specifications. A 5.8 percent asphalt binder was recommended. An average 14.1 percent VMA was determined for the project.

Sample Preparation

The dimensions of the cored samples were 6 inch in diameter and variable heights. The height depended on the core location since coring was extended to the base layer to ease the core recovery process. The samples were then sawed down to the proper height by cutting the bottom side of the specimen. The original top surface was always maintained intact (without cutting) for all of the core samples (both for APA and permeability testing).

Specimens were trimmed to a 3 inch height for APA testing and to about 2 inches for permeability testing. The main concern for the permeability specimens was to insure the removal of the tack coat which lies at about 2 inches from the top surface. Otherwise, the presence of the tack coat would affect the permeability results. For APA testing, maintaining a level surface at the bottom as well as vertical sides is warranted for the accuracy of the APA results.

PERMEABILITY TESTING AND ANALYSIS

Introduction

Adequate in-place compaction during the construction of hot mix asphalt (HMA) is essential in producing low permeability asphalt mixes. For dense-graded mixes, numerous studies have shown that initial in-place air void content should not be below approximately 3 percent or above approximately 8 percent (*7*). Low in-place air voids have been shown to result in rutting, bleeding, and shoving, while high air voids allow water and air to penetrate into the pavement leading to an increased potential for water damage, oxidation, raveling, and cracking. However, due to problems associated with coarse-graded Superpave mixes, the size and interconnectivity of air voids have been shown to greatly influence permeability (*7*).

Numerous factors such as aggregate particle size distribution, nominal maximum aggregate size (NMAS), aggregate particle shape, pavement density (or air voids), and lift thickness can affect pavement permeability (*8*). In this study, the only available variable is the in-place density (or air voids) of the different core samples. Based on literature review of several asphalt permeability studies (7, 8, 9), the ranges of permeability coefficients (K) that correspond to high, low, and impervious designations are displayed in table 7 below.

Table 7 Permeability Designations Based on Permeability Coefficient Ranges

Permeability Designation	Range of Permeability Coefficient, k
High Permeability	1×10^{-1} cm/s to 1×10^{-4} cm/s
Low Permeability	1×10^{-4} cm/s to 1×10^{-6} cm/s
Practically Impervious	1×10^{-6} cm/s to 1×10^{-9} cm/s

Air Voids Results and Analysis

Air voids for the collected core samples were measured to explore any link between air voids (or field densities) of samples and permeability values. Air void measurements were developed from samples that later were used for measuring permeability or APA testing. The in-place air voids were generally between 4% and 7%.

Asphalt Permeability Results and Analysis

For this project, the ASTM Standard PS 129-01 was adopted to perform the permeability tests. Table 8 below displays the permeability results.

Table 8 Asphalt Permeability Determination for Field Core Samples

Plug No.	Specimen Thickness *l* (cm)	X-section Area A (cm^2)	Water Temp (ºC)	Temp Corr. RT	Water Height h2	Permeability Coeff. Uncorrected	Permeability Coeff. (corr.) K (cm/sec)
4	4.727	166.201	25.0	0.889	63.00	0.000E+00	0.000E+00
9	4.873	164.080	25.0	0.889	61.05	4.076E-06	3.623E-06
13	4.795	164.041	25.0	0.889	8.85	2.504E-04	2.226E-04
16	4.198	164.696	25.0	0.889	63.00	0.000E+00	0.000E+00
20	4.426	163.542	25.0	0.889	63.00	0.000E+00	0.000E+00
27	4.682	164.349	25.0	0.889	39.20	5.899E-05	5.244E-05
34	4.036	164.715	25.0	0.889	40.05	4.844E-05	4.307E-05
37	4.123	169.488	24.0	0.910	36.90	5.680E-05	5.168E-05
43	3.990	164.888	24.0	0.910	63.00	0.000E+00	0.000E+00

Generally, low permeability coefficient values were observed for all the test sections including several specimens that yielded zero permeability (K) values. The zero permeability values were observed in specimens with low air voids. The average permeability coefficient values for S2, S3, and S1 sections were 1.75×10^{-5}, 3.16×10^{-5}, and 7.54×10^{-5}, respectively. According to table 7 for permeability designation, the average sections K values correspond to the low permeability category.

RUT RESISTANCE TESTING AND ANALYSIS

Introduction

The Asphalt Pavement Analyzer which is a new generation of the Georgia Load Wheel Tester (GLWT) has been used to evaluate rutting, fatigue, and moisture resistance of HMA mixtures (*10*). 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 (*11*).

In this study, Superpave specimens were tested at 58°C, corresponding with the high end temperature of the binder's performance grade. Testing was carried out to 8,000 cycles for the dry condition and 25,000 cycles for the submerged (wet) condition. Specimens were conditioned in a 58°C water bath for 24 hours before moisture susceptibility testing. The expression wet here refers to the 24-hour submersion in a 58 ^{o}C water bath followed by the APA moisture sensitivity testing (also submerged at 58 ^{o}C). The 58 ^{o}C was chosen to represent the high end temperature of the top lift binder grade (PG 58-34). All specimens were sawed to a 75 mm height before they were placed in the APA molds.

APA Results and Analysis

The APA performance (rut resistance) results of dry and wet tests for the coarse-graded core specimens are shown in Table 9 and Figure 1 below. Each of the dry or wet case is broken down by three sections (S1, S2, and S3). The values shown in Table 9 and plotted in Figure 1 represent the rut depth (in mm) under the corresponding wheel of the APA. The APA rut failure criterion adopted for this study is 0.276 inch (7 mm) APA rut depth for traffic levels between 0.3 and 3 million design ESALs. The design ESAL for US Highway 81 has been estimated at 0.6 million ESALs, so the 0.276 inch (7 mm) failure criterion applies. The terms S1-Dry, S2-Dry, S3-Dry, S1-Wet, S2-Wet, and S3-Wet indicate the section number and APA testing condition. The numbers that appear above the rut depth in Table 9 indicate the core specimen number.

Table 9 APA Rut Resistance Results for the APA Test Cases

APA Test Cases	Left Side Depth (mm)		Center Depth (mm)		Right Side Depth (mm)		AVE (mm)
S1 - Dry	2	5	7	10	11	15	7.4302
	7.16713	6.820004	7.524571	7.70017	7.337085	8.032138	
S2 - Dry	18	21	23	25	28	29	7.1139
	6.582399	8.293899	6.892414	6.406771	6.728894	7.778832	
S3 - Dry	32	35	39	41	42	45	6.8190
	7.649766	7.746293	6.120988	6.875604	6.440859	6.080349	
S1 - Wet	1	3	6	8	12	14	8.1999
	7.146101	8.440671	6.941986	8.150669	7.821176	10.69885	
S2 - Wet	17	19	22	24	26	30	9.0609
	8.896924	9.254876	8.113305	9.355614	9.448572	9.296235	
S3 - Wet	31	33	36	38	40	44	8.7193
	8.516713	8.368339	9.394846	10.93232	7.601959	7.50164	

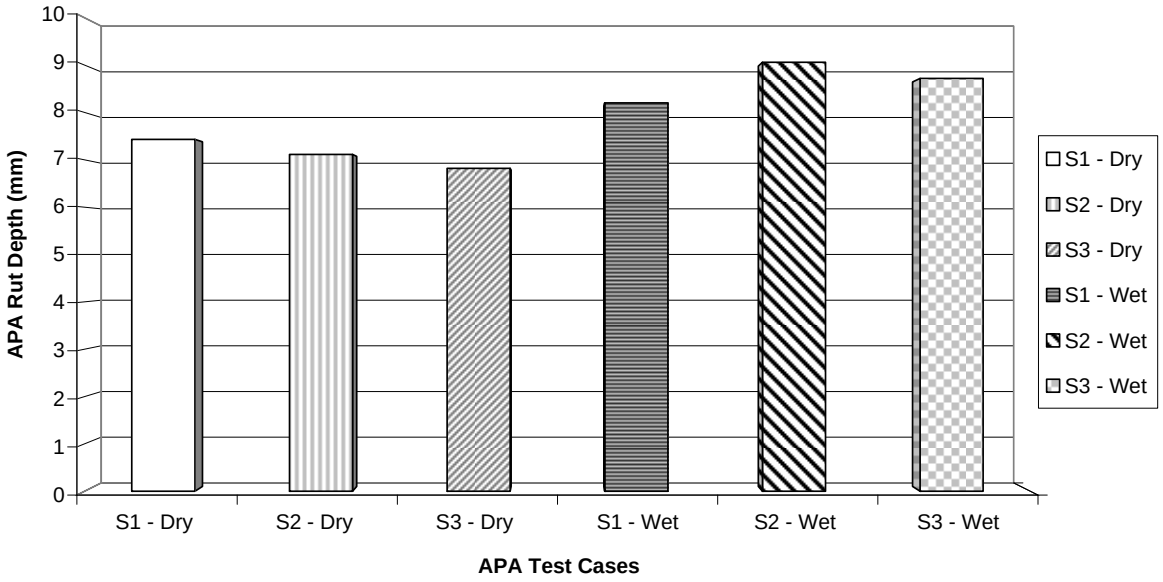

Figure 1 APA Average Rut Resistance Results for the APA Test Cases

The statistical Analysis of Variance (ANOVA) was performed on the APA results within wet versus dry subsets and for the three sections. The ANOVA statistical analysis of the APA results for the dry and wet conditions is presented in Table 10 below. 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.

Table 10 Analysis of Variance (ANOVA) Statistics on the APA Results

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
S1-Dry	6	44.5811	7.430183	0.178867
S2-Dry	6	42.68321	7.113868	0.562868
S3-Dry	6	40.91386	6.818976	0.545813
S1-Wet	6	49.19945	8.199908	1.828279
S2-Wet	6	54.36553	9.060921	0.250996
S3-Wet	6	52.31582	8.719303	1.649836

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	24.69447	5	4.938894	5.906991	0.000648	2.533554
Within Groups	25.0833	30	0.83611			
Total	49.77777	35				

Observation of the statistical results indicates that the P-value is less than the significance value ($P = 0.000648 < 0.05$); therefore, the null hypothesis is rejected. This means that the results within the subsets of wet versus dry and across the three sections are significantly different and can be compared. Conversely, the ANOVA statistical analysis of the APA results within each section has been insignificant. The P values of 0.2999 and 0.4247 for the dry and wet cases were both greater than the 0.05 significance level ($P > 0.05$). Thus, the results within each section are considered similar and can not be compared.

Examination of the results indicates that 9 out of the 18 dry specimens failed the APA rut test, while all but one of the submerged specimens failed the APA rut test. In other words, the average APA rut depths for the dry and submerged specimens were 0.28 inch (7.1 mm) and 0.34 inch (8.7 mm), respectively. So, under dry conditions, the coarse-graded Superpave mixes exceeded the high end of the failure specification by 1.4 percent. Meanwhile, the average rutting under the APA wheels for the submerged specimens was higher than the failure specification value by 24.3 percent which is absolutely unacceptable. In other words, the presence of

moisture reduced the coarse-graded mixes rutting resistance by 22 percent when compared to the dry case average.

Further inspection of the APA results shows interesting trends between the APA rutting values and the pavement sections. For the dry cases, APA rut values decreased with an increase in the section number (S1, S2, and S3). This means that, on average, S2 is more rut resistant than S1 and S3 is more rut resistance than S1 and S2. For the wet cases, the APA rut values did not follow the same pattern of the dry cases. So S2 exhibited the highest rut depth followed by S3 and then S1. This means that under submerged conditions, S3 specimens are more rut resistance than S2 specimens and that S1 specimens are more rut resistance than S2 or S3 specimens.

SUMMARY AND CONCLUSIONS

A 12 mile long coarse-graded asphalt overlay project [NH-6-081(053)192] was designed and placed on US Highway 81 north of Grafton, North Dakota. The project aggregate properties, gradation, and mix design information indicate that NDDOT section 410 Superpave mix design specifications were achieved.

The project was divided into three sections: S1, S2, and S3. Regarding the structures of the different sections, S1 received a total of 3 ½ inch overlay, S2 had a 5 inch overlay, and S3 got a 7 inch overlay in addition to a mine and blend job. S1 and S2 sections received a PG 58-28 binder for the entire overlay, but the S3 section contained a PG 58-34 binder in the top 2 inches of the overlay.

For this study, the rutting resistance of the coarse-graded mix was evaluated on field cores and tested using the asphalt pavement analyzer. Asphalt permeability and the air voids utilizing field cores were also determined. Statistical analysis indicated that the variations within the wet and dry APA results were significant but the variations for APA results within sections, air voids results, or permeability results were insignificant.

The APA results show that 50 percent of the dry tested core specimens across the project sections of the coarse graded mix have exhibited satisfactory rutting resistance. And since the average APA rut depth was 0.28 inch (7.1 mm), which is slightly above the 0.276 inch (7.0 mm) failure specification, the overall assessment of the coarse graded mix under dry conditions can be put near satisfactory with room for improvement. But the effect of moisture takes its toll on the coarse-graded mix's ability to resist rutting. All but one of the 18 wet tested specimens has failed the APA rut depth specification. An average of 8.7 mm APA rut depth is deemed unacceptable. Examination of the APA results across sections showed mixed trends.

The average permeability coefficient was 4.15×10^{-5} cm/sec. The core specimen air void results were generally on the low side of the 6 to 8 percent in-place air voids target. The permeability results were ranging between very low to totally impermeable. A designation of "practically impermeable" would be a fair

characterization of the overall permeability of tested coarse graded pavement sections. Air voids and permeability results did not show obvious trends across the different sections. Comparing the air voids and permeability coefficient values with the APA rut results, the lower the air voids or permeability coefficient in a section the higher the rutting under the APA was observed. This observation is consistent with the conventional wisdom regarding the relationship between air voids and rutting.

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