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Department of Civil Engineering
University of North Dakota
Grand Forks, ND 58202

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North Dakota DOT
Materials and Research Division
300 Airport Road
Bismarck ND 58504-6005

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1. Abstract

Purpose and Need

Due to the dwindling sources of aggregate supplies and the need for durable and rut-resistant HMA for use in thin-lift pavement layers, the full or partial use of fine aggregate screenings such as the No. 4 mixes could be beneficial for HMA producers, aggregate producers, and transportation agencies.

Objective

The main objectives of this research study are:

1. To evaluate the rutting resistance performance of the No. 4 NMAS mixtures using the asphalt pavement analyzer.
2. To evaluate the benefits and impacts associated with employing the No. 4 NMAS mixtures as thin overlays or as maintenance applications for low to medium volume highways.
3. To show that the No. 4 NMAS mixtures are useful in providing utility for fine aggregate stockpiles in local gyratory mixes for thin-lift HMA applications

Scope

In this research project, rut-resistance performance and analysis were conducted on the local gyratory HMA mixtures. The performances of the various mixes were evaluated based on their deformation under the wheel load of the asphalt pavement analyzer. A 9.5 mm (3/8 inch) deformation under the wheel load of the APA has been considered the minimum criterion for rutting failure. The relative performances of the mixes are examined based on comparing their APA deformation values.

Summary

The results indicate that the mixes with higher crushed fines (i.e. 50:50 blend) performed better than the mixes with lower crushed fines (i.e. 60:40 blend). For the same blend percentage of natural to crushed fines where only the PG grade is the variable, the results were not conclusive. Comparing the rut depths of the 64 (50:50) and the 58 (50:50) mixes, one can see that the rut depth value for the 58 (50:50) mix is slightly lower than the rut depth value for the 64 (50:50) mix. Also the AC contents for the mixes containing the PG 58-28 and the PG 64-28 binders were 7.0% and 7.1%, respectively. Since the AC contents for the two cases were virtually equal and that the two mixes were tested at different temperatures, the rut depth values for the two mixes can not be compared directly, but they do indicate how the mixes would perform with different binders and temperatures The natural fines used for this study were of marginal quality. The FAA value of 36 was very low and the percent absorption value of 2.9 was relatively high. Needless to say that higher quality natural fines aggregates would help the performance of the No. 4 mixes. Since marginal quality natural aggregates worked very well in blends with relatively equal percentages of crushed fines, higher quality natural fines may allow the use of higher proportions of natural fines in No. 4 mixes and still be successful.

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UNIVERSITY OF NORTH DAKOTA
Grand Forks

Evaluation of North Dakota's 4.75 mm Local Gyratory HMA Mixtures for Thin Overlay Applications

Final Report

March 2009

SCHOOL OF ENGINEERING AND MINES

RCS HHO-30-19

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT	EXPERIMENTAL PROJECT NO. 1 STATE: UND, YEAR: 2008 - NUMBER: 01, SURF:	CONSTRUCTION PROJ NO 8	LOCATION Grand Forks 28
	EVALUATION FUNDING 1 X HP&R; 2 CONSTRUCTION; 3 DEMONSTRATION; 4 IMPLEMENTATION 48	NEEP NO. 49	PROPRIETARY FEATURE? Yes 51 X No

SHORT TITLE	TITLE 52 Evaluation of North Dakota's 4.75 mm Local Gyratory HMA Mixtures for Thin Overlay Applications
THIS FORM	DATE 140 MO. 3 -- YR. 09 REPORTING: 1 INITIAL 2 ANNUAL 3 FINAL X

KEY WORDS		
	KEY WORD 1 145 ASPHALT	KEY WORD 2 167 PAVEMENT
	KEY WORD 3 189 AGGREGATE	KEY WORD 4 211 BINDER
	UNIQUE WORD 233 SUPERPAVE	PROPRIETARY FEATURE NAME 255

CHRONOLOGY	Date Work Plan Approved	Date Feature Constructed:	Evaluation Scheduled Until:	Evaluation Extended Until:	Date Evaluation Terminated:
	07-2004 277	281	285	289	12-2005 293

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

AVAILABLE EVALUATION REPORTS	-CONSTRUCTION	-PERFORMANCE	FINAL
	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 The results indicate that the mixes with higher crushed fines (i.e. 50:50 blend) performed better than the mixes with lower crushed fines (i.e. 60:40 blend). The natural fines used for this study were of marginal quality. The FAA value of 36 was very low and the percent absorption value of 2.9 was relatively high. Needless to say that higher quality natural fines aggregates would help the performance of the No. 4 mixes. Since marginal quality natural aggregates worked very well in blends with relatively equal percentages of crushed fines, higher quality natural fines may allow the use of higher proportions of natural fines in No. 4 mixes and still be successful. 700

Form FHWA 1461

University of North Dakota
Department of Civil Engineering

Evaluation of North Dakota's 4.75 mm Local Gyratory HMA Mixtures for Thin Overlay Applications

Final Report Submitted to the

North Dakota Department of Transportation
Bismarck, ND

By:

Dr. Nabil Suleiman, Principal Investigator

March 2009

Disclaimer

ACKNOWLEDGMENT

The Principal investigator (PI) wishes to express his appreciation for the financial support provided by the NDDOT and the assistance received from the Materials and Research Division staff. Thanks are also extended to the Dakota Asphalt Pavement Association for providing the Asphalt Pavement Analyzer that made this research study possible. Finally, the author hopes that NDDOT will continue its research partnership with the Civil Engineering department at UND and do more research studies in the future.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

BACKGROUND

Thin-lift hot mix asphalt (HMA) layers are utilized in almost every maintenance and rehabilitation application (1). These mix types require smaller maximum particle sizes than most conventional HMA surface layers (1, 2). Until recently, the Superpave asphalt mix design specification did not include the 4.75 mm (No. 4) Nominal maximum aggregate size (NMAS) (3, 4). Such fine mixes have the potential to create a smooth riding surface, extend pavement life, improve ride quality, improve safety characteristics, enhance appearance, increase durability, reduce permeability, and reduce road-tire noise (1, 2, 3, 4). Also, because of the ability to place these mixes in thin lifts, they can be used to correct surface defects, decrease construction time, decrease construction costs, and extend maintenance dollars (3, 4, 5).

Past performance experience with thin hot mix asphalt (HMA) overlays has been positive. In Maryland (5), these mixes are used as part of a preventive maintenance program and have shown excellent rutting and cracking resistance. Due to the increased asphalt content provided by these mixes some degree of crack healing has been observed. Maryland's No. 4 mixes generally contain about 65% manufactured screenings and 35 percent natural sand. Typical lift thicknesses are between 19 and 25 mm (3/4 inch to 1 inch).

The Georgia DOT (6) has used No. 4 mixes for 30 years on low volume roads and for leveling purposes. Good performance has been provided by the mix, provided it is placed in thin lifts (approximately 1 inch max.). The fine Georgia mixes have been primarily comprised of screenings with a small amount of No. 89 stone resulting in approximately 60 to 65 percent passing the No. 8 sieve and an average of 8 percent dust. The Georgia No. 4 mix is currently designed using the Superpave gyratory compactor with Ndesign of 50 gyrations. Typical design air voids range between 4 and 7 percent. With these mixes, a higher design air void content is sometimes used to allow lower asphalt content for economic considerations without reducing the mixture durability; since the mixes are not as open to water and air at the same air void level as other larger NMAS mixes.

In the Arkansas study (7), three aggregate sources (limestone, sandstone, and syenite) were used to develop No. 4 NMAS mixtures. From each source, six mixtures were designed at varying design air void contents and design compaction levels. Two air void levels (4.5 and 6.0 percent) and three compaction levels (Ndes = 50, 75, and 100) were evaluated in order to determine the most advantageous design parameters with respect to rutting, stripping, and permeability. Also, the use of natural sand was investigated.

The results of the Arkansas study indicate that No. 4 mixes can be successfully designed using existing aggregate sources. In some cases, minor modifications to existing stockpile gradations improved design success. Design air voids and compaction level were both important to the performance of the mixes. The greatest resistance to rutting and stripping was provided for low and medium volume mixes when designed at 6.0 percent air voids, and for high volume mixes when designed at 4.5 percent air voids.

Research has been conducted at NCAT (3, 4, 8, 9) to evaluate the effectiveness of using 100 percent aggregate screenings for HMA mixes. Granite and limestone screenings were designed in NCAT's research using the Superpave gyratory compactor at an Ndesign of 100 gyrations for 4, 5, and 6 percent air voids. Both of the mixes were No. 4 nominal maximum size mixes, with the granite mix being considerably finer than the limestone. The volumetric properties and rut testing results for these screening mixes indicate that granite mixes had significantly higher asphalt contents than the limestone mixes, primarily due to the increased fineness and rougher surface texture of the granite. Based on rut testing, it generally appeared that the screening mixes have the potential to provide good rut resistance (10, 11).

Generally, the reviewed studies (12, 13, 14, 15) have shown that different design air void levels were recommended for different applications. Some aggregate sources were able to tolerate the addition of natural sand. In general, rutting and stripping potential increased as the natural sand content increased. When compared to mixes with larger NMAS, the No. 4

mixes exhibited rutting and stripping resistance similar to, and sometimes greater than, that of typical 12.5 mm (½ inch) surface mixes. The permeability of the No. 4 mixes was determined to be very low, and thus there is excellent potential for using these mixes to seal surfaces that may be prone to permeability problems.

PURPOSE AND NEED

Due to the dwindling sources of aggregate supplies and the need for durable and rut-resistant HMA for use in thin-lift pavement layers, the full or partial use of fine aggregate screenings such as the No. 4 mixes could be beneficial for HMA producers, aggregate producers, and transportation agencies.

Although the main functions of thin overlays produced from No. 4 mixes are to correct surface defects (leveling), create a smooth riding surface, extend pavement life, improve ride quality, increase skid resistance, increase durability, reduce permeability, reduce road-tire noise, decrease construction time, and decrease construction costs; these mixes may also provide a use for screened manufactured stockpiles, and provide some structural improvement to pavements with low and medium traffic volumes.

The primary focus of this study is to develop and evaluate local Superpave gyratory mixes, namely the No. 4 NMAS mixes, which could utilize excess amounts of fine aggregates to use as thin overlays for non-interstate highways and for maintenance applications. The Asphalt Pavement Analyzer (APA) has been used to examine the rut resistance of the No. 4 mixes.

OBJECTIVES AND SCOPE

The main objectives of this research study are:

1. To evaluate the rutting resistance performance of the No. 4 NMAS mixtures using the asphalt pavement analyzer.

2. To evaluate the benefits and impacts associated with employing the No. 4 NMAS mixtures as thin overlays or as maintenance applications for low to medium volume highways.
3. To show that the No. 4 NMAS mixtures are useful in providing utility for fine aggregate stockpiles in local gyratory mixes for thin-lift HMA applications.

In this research study, local gyratory HMA mix designs were prepared using North Dakota's locally available aggregates that contained two different percentages of crushed fines. The first aggregate blend contained 60% natural fines and 40% crushed fines. The second aggregate blend contained 50% natural fines and 50% crushed fines. The aggregates were taken from Northwood project NH-8-018(040)124 and were conforming to the ASTM specification limits for No. 4 mixes.

Gradations for the No. 4 mix were controlled on the 4.75 mm (No. 4), 1.18 mm (No. 16), 0.6 mm (No. 30), and 0.075 mm (No. 200) sieves. The control points on the No. 16 sieve were 40% and 80%, for No. 30 were 25% and 65%, and for the No. 200 sieve were 2% and 10%. Two asphalt binder grades, PG 64-28 and PG 58-28, were used in this study. The design compactive effort (Ndesign) of 75 gyrations corresponding to an equivalent single axle load (ESAL) range of 0.3 to 3 million under current Superpave specifications was adopted in this study. The percent air voids were designed at 6.0%.

In this research project, rut-resistance performance and analysis were conducted on the local gyratory HMA mixtures. The performances of the various mixes were evaluated based on their deformation under the wheel load of the asphalt pavement analyzer. A 9.5 mm (3/8 inch) deformation under the wheel load of the APA has been considered the minimum criterion for rutting failure. The relative performances of the mixes are examined based on comparing their APA deformation values.

MATERIAL SELECTION, PROPERTIES, AND GRADATIONS

MATERIAL SELECTION

Two different grade asphalt binders, PG 58-28 and PG 64-28 were chosen for this study. All of the binders were supplied by one asphalt producer. Both aggregates adopted for this study, natural fines (NF) and crushed fines (CF), were from one source [Northwood's project NH-8-018(040)124]. The selected aggregates had gradations that were consistent with No. 4 nominal maximum aggregate sizes.

The properties of the selected binders were provided by the NDDOT asphalt laboratory. The consensus and source properties of aggregates were obtained from tests conducted at UND and NDDOT laboratories. The test results will be reported in later 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 performed by the NDDOT asphalt laboratory. The properties meet NDDOT asphalt binder specifications.

The aggregate tests conducted for this study were: 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 (No. 8). The FAA property ensures a high degree of fine aggregate internal friction and rutting resistance.

Specific gravities for coarse and fine aggregates, water absorption, and consensus properties for individual stockpiles were conducted by the PI and the NDDOT laboratory. Table 1 displays the results of the aggregate properties for individual stockpiles of natural and crushed fines. Table 2 shows the consensus aggregate properties and Table 3 illustrates the aggregate blend properties.

Table 1 Aggregate Properties for Individual Stockpiles

	Agg #1 **Natural Fines**	**Agg #2** **Crushed Fines**
Bulk SpG (G_{sb})		
Coarse	2.503	2.559
Fine	2.503	2.559
Apparent SpG (G_{sa})		
Coarse	2.699	2.748
Fine	2.699	2.748
Water Absorption		
Coarse	2.900	2.690
Fine	2.900	2.690
Combined		
Bulk SpG (G_{sb})	2.503	2.559
Apparent SpG (G_{sa})	2.699	2.748
Water Absorption	2.900	2.690

Table 2 Consensus Aggregate Properties

Aggregate Properties	**Agg #1**	**Agg #2**	**Blends of (NF:CF) in %**		**Spec's**
	NF	**CF**	60:40	50:50	
Fine Agg. Angularity (% FAA)	36.0	47.4	40.5	41.7	40 Min
Clay Content (% Sand Equivalent)	57.0	71.0	62.6	64.0	40 Min
Coarse Agg. Angularity (%)	On Plus #4 Material		100		75 Min
Thin & Elongated Pieces			1.1		10 Max

Table 3 Aggregate Blend Properties

Blend Properties	Blends of (NF:CF) in %	
	60:40 Blend	50:50 Blend
Fine Aggregate Angularity (FAA)	40.5	41.7
Bulk SpG (G_{sb})	2.525	2.531
Apparent SpG (G_{sa})	2.718	2.723
Water Absorption (%)	2.812	2.791
Light Wt Particles (%)	1.1	1.1
Toughness (% Loss)	22.6	22.6

GRADATIONS

Gradations for this study were chosen based on the No. 4 mix requirements. The ASTM gradation limits (control points) were adopted for this study. Table 4 displays the individual gradations for the natural and crushed fine stockpiles used in this study. The ASTM control point limits are also shown.

Table 4 Individual Aggregate Gradations and Control Limits

	Agg #1	Agg #2	Control Points (ASTM Limits)	
Aggregate Description --->	Natural Fines	Crushed Fines	Lower Limit	Upper Limit
If Agg. is Crushed, Enter 1	0	1		
Sieve Size	% Passing	% Passing	% Passing	% Passing
5/8" (16mm)	100.0	100.0	100	100
1/2" (12.5mm)	100.0	100.0	100	100
3/8" (9.5mm)	100.0	99.0	100	100
#4 (4.75mm)	96.2	94.9	80	100
#8 (2.36mm)	86.1	71.8	65	100
#16 (1.18mm)	71.3	47.1	40	80
#30 (0.6mm)	50.7	31.0	25	65
#50 (0.3mm)	25.4	18.8	7	40
#100 (0.15mm)	8.5	11.9	3	20
#200 (0.075mm)	5.5	8.9	2	10

Tables 5 and 6 display the blend gradations for the 60:40 and 50:50 splits of NF to CF blend ratios, respectively.

Table 5 Aggregate Gradations for the 60:40 NF to CF Blend

Aggregate Description	Aggregate No.	Blend %	Sieve Size	60:40 Blend Gradation	Control Points Lower	Control Points Upper
Natural Fines	1	60	5/8"	100	100	100
Crushed Fines	2	40	1/2"	100	100	100
Sum of % =100			3/8"	99.6	100	100
			#4	95.7	80	100
			#8	80.4	65	100
			#16	61.6	40	80
			#30	42.8	25	65
Nominal Maximum Agg. Size = No. 4			#50	22.8	7	40
			#100	9.9	3	20
			#200	6.9	2	10

Table 6 Aggregate Gradations for the 50:50 NF to CF Blend

Aggregate Description	Aggregate No.	Blend %	Sieve Size	50:50 Blend Gradation	Control Points Lower	Control Points Upper
Natural Fines	1	50	5/8"	100	100	100
Crushed Fines	2	50	1/2"	100	100	100
Sum of % =100			3/8"	99.5	100	100
			#4	95.6	80	100
			#8	79.0	65	100
			#16	59.2	40	80
			#30	40.9	25	65
Nominal Maximum Agg. Size = No. 4			#50	22.1	7	40
			#100	10.2	3	20
			#200	7.2	2	10

Since the gradations involved significant amounts of fine materials, where segregation becomes a concern, a decision was made to split the aggregates on three sieve sizes for weight batching and blending. The aggregates were split into three categories, + No. 4, - No. 4 & + No. 30, and - No. 30. Figure 1 shows a photo of the batched aggregates.

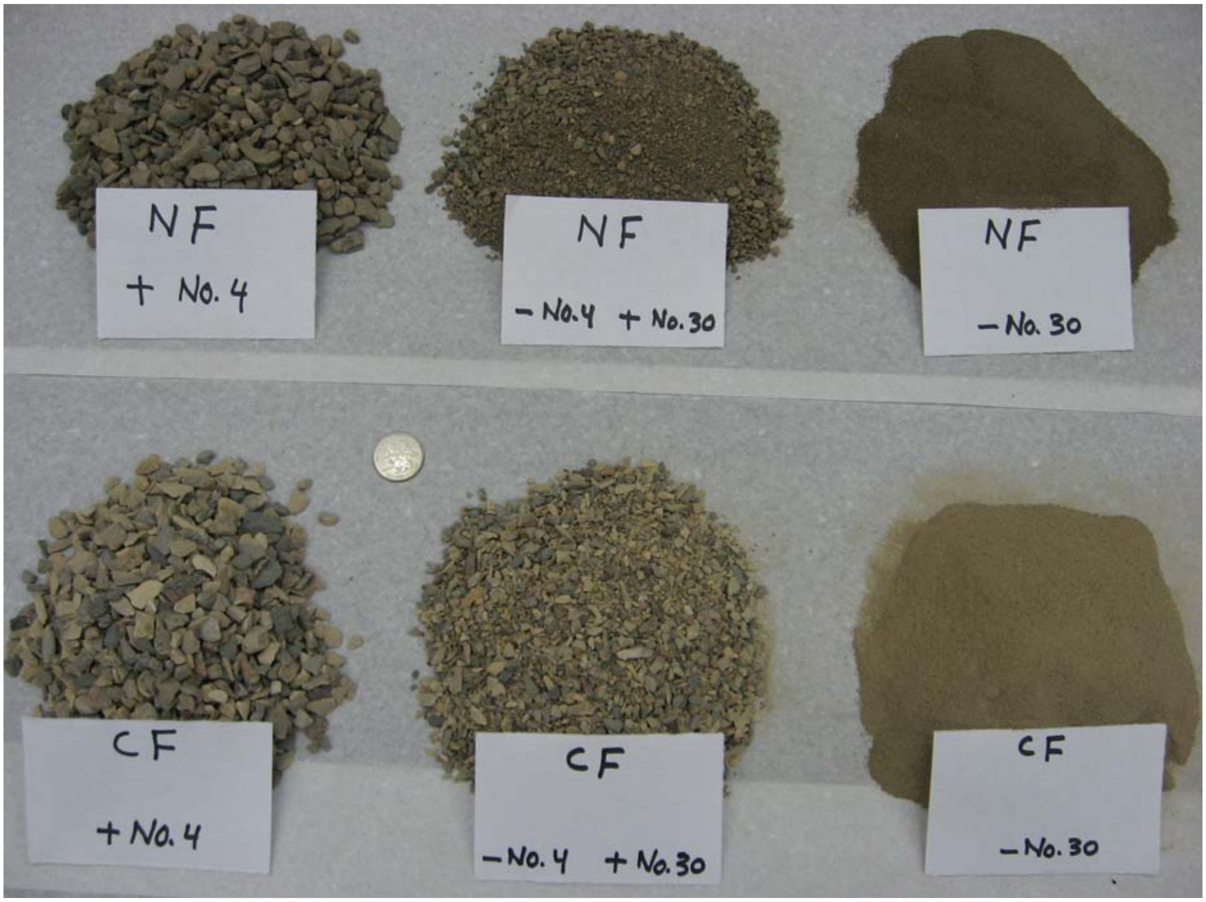

Figure 1 A Photograph of Batched Aggregates

LABORATORY MIX DESIGN AND ANALYSIS

BACKGROUND

This research study entailed mix designs involving two binders and two aggregate blends. The binders were PG 64-28 and PG 58-28 binder grades. And the two aggregates involved were 60:40 and 50:50 blends of natural fines to crushed fines. These two aggregate blends were adopted after initial testing ruled out blends with higher natural fines percentages. Blends with 80% and 100% natural fines produced mixes with excessive asphalt contents and produced severe rut depths under the APA.

DESIGN CONSIDERATIONS

After careful review of past research on No. 4 mixes, the following points were considered or adopted to ensure the success of the study: (1) the mixes were designed at 6 percent air voids to keep the asphalt contents within a reasonable range (below 8%); (2) the dust percentages in the blends that are passing the No. 200 sieve were kept in the 6% to 8% range to help reduce the required asphalt content and improve stability of the mix; (3) the voids in mineral aggregates (VMA) were designed between 16% and 18%; (4) the fine aggregate angularities (FAA) of the blends were kept above 40; (5) the dust to effective asphalt content was desired to be between 0.9 and 2.2; the volume of the effective asphalt was desired to be approximately at 12; and (6) the acceptable APA rut depth for these types of mixes typically used for roads with less than 300,000 ESALs and with low truck traffic is about 9.5 mm (3/8 inch).

The Superpave mix design procedures in the NDDOT Field Sampling and Testing Manual were adopted for this study with some modifications to account for the No. 4 mixes. Several measurements and calculations were performed to obtain the various mixtures' volumetric properties. The volumetric results and their specifications are presented later in this chapter.

MIX DESIGN RESULTS

A total of four mix design cases were conducted for this study; 64 (60:40), 64 (50:50), 58 (60:40), and 58 (50:50). The numbers 64 and 58 represent the binder grades PG 64-28 and PG 58-28, respectively. Also the 60:40 and 50:50 represented the NF to CF ratios that were used in the aggregate blends.

A Superpave gyratory compactor (SGC) was used to produce specimens that are 6-inch (150 mm) in diameter and approximately 4.6-inch (117 mm) in height. The 2 hour short term aging was adopted for this study to be consistent with the NDDOT Superpave mix procedures.

Tables 7 and 8 display the void analysis results for the two binder grades at different AC contents. Table 9 presents the mix properties at the design (optimal) AC contents of the mixes.

Table 7 Voids Analysis of PG 64-28 Mixes @ Ndes for Various Binder Contents

Study Mix Designs	**Properties @ Different AC Contents**				
AC Content (%)	**6.0**	**7.0**	**8.0**	**9.0**	**10.0**
PG 64-28 Binder with 60:40 Aggregate Blend					
Bulk Specific Gravity of the Mix (Gmb)	2.230	2.251	2.273	2.290	
Percent Aggregate	94	93	92	91	
Theor. Maximum SpG of Mix (Gmm)	2.431	2.406	2.370	2.342	
Air Voids, Va (%)	8.3	6.5	4.1	2.2	
Voids in Mineral Agg. (VMA)	17.7	17.8	17.9	18.1	
Voids in Mineral Agg. Filled (VFA)	53.2	63.7	76.9	87.8	
PG 64-28 Binder with 50:50 Aggregate Blend					
Bulk Specific Gravity of the Mix (Gmb)	2.229	2.261	2.287	2.288	
Percent Aggregate	94	93	92	91	
Theor. Maximum SpG of Mix (Gmm)	2.445	2.411	2.362	2.338	
Air Voids, Va (%)	8.8	6.2	3.2	2.2	
Voids in Mineral Agg. (VMA)	17.7	17.4	17.4	18.2	
Voids in Mineral Agg. Filled (VFA)	50.3	64.2	81.6	88.2	

Table 8 Voids Analysis of PG 58-28 Mixes @ Ndes for Various Binder Contents

Study Mix Designs	**Properties @ Different AC Contents**				
AC Content (%)	**6.0**	**7.0**	**8.0**	**9.0**	**10.0**
PG 58-28 Binder with 60:40 Aggregate Blend					
Bulk Specific Gravity of the Mix (Gmb)		2.259	2.279	2.286	2.267
Percent Aggregate		93	92	91	90
Theor. Maximum SpG of Mix (Gmm)		2.446	2.380	2.354	2.323
Air Voids, Va (%)		7.6	4.3	2.9	2.4
Voids in Mineral Agg. (VMA)		17.5	17.7	18.3	19.9
Voids in Mineral Agg. Filled (VFA)		56.3	75.9	84.1	87.8
PG 58-28 Binder with 50:50 Aggregate Blend					
Bulk Specific Gravity of the Mix (Gmb)	2.242	2.270	2.295	2.290	
Percent Aggregate	94	93	92	91	
Theor. Maximum SpG of Mix (Gmm)	2.446	2.411	2.380	2.348	
Air Voids, Va (%)	8.4	5.8	3.6	2.5	
Voids in Mineral Agg. (VMA)	17.2	17.1	17.1	18.2	
Voids in Mineral Agg. Filled (VFA)	51.5	65.9	79.1	86.4	

Table 9 No. 4 Mix Properties at Recommended Asphalt Contents

Mix Properties	**(64) 60:40**	**(64) 50:50**	**(58) 60:40**	**(58) 50:50**	**Spec's**
Optimum AC (%)	7.2	7.1	7.5	7.0	< 8 Desired
Density (pcf)	140.7	141.3	141.6	141.6	
Air Voids (%)	6.0	6.0	6.0	6.0	6.0
VMA (%)	17.8	17.4	17.6	17.1	16.0-18.0
VFA (%)	66.3	65.9	66.1	65.9	65.0-78.0
%Gmm @ Ninitial	86.2	86.3	86.5	86.2	89.0 Max
%Gmm @ Nmaximum	95.2	96.3	94.5	95.4	98.0 Max
AC Film Thickness (m)	6.3	6.2	6.2	5.9	
Dust/Effective AC Ratio	1.3	1.4	1.4	1.5	0.9-2.2
Asphalt Absorption (%)	2.25	2.18	2.69	2.33	
Maximum SpG @ Ndes	2.399	2.409	2.414	2.414	
Effective (Gme)	2.672	2.674	2.703	2.684	

The optimal AC content percentages ranged between 7.0% and 7.5% for the various mixes (below 8%) as desired. Even though the volumetric properties specifications of the HMA of the No. 4 mixes were modified from the Volumetric Mix Design (AASHTO M 323) Superpave specifications, most of those properties were within or close to the Superpave specifications.

Obviously, the design air voids (6.0%) for all the mix designs meet the specifications for percent air voids for No. 4 mixes in this study. 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. In this study, air voids were designed at 6.0% to help bring down the AC content and VMA to reasonable levels (< 8.0% AC and within 16.0% to 18 % VMA). In this study, Since the VMA is a function of the nominal maximum aggregate size (No. 4 in this study); a minimum of 16% and a maximum of 18.0% VMA are specified. The results indicate that all the design mixes have been within the specified range.

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 less than 300,000 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 No. 4 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.

Figure 2 presents an example with plots of unit weight, air voids, VMA, VFA, %Gmm @ Ninitial, and the theoretical maximum specific gravity versus %AC content for a No. 4 mix design with PG 64-28 binder and 50:50 aggregate blend.

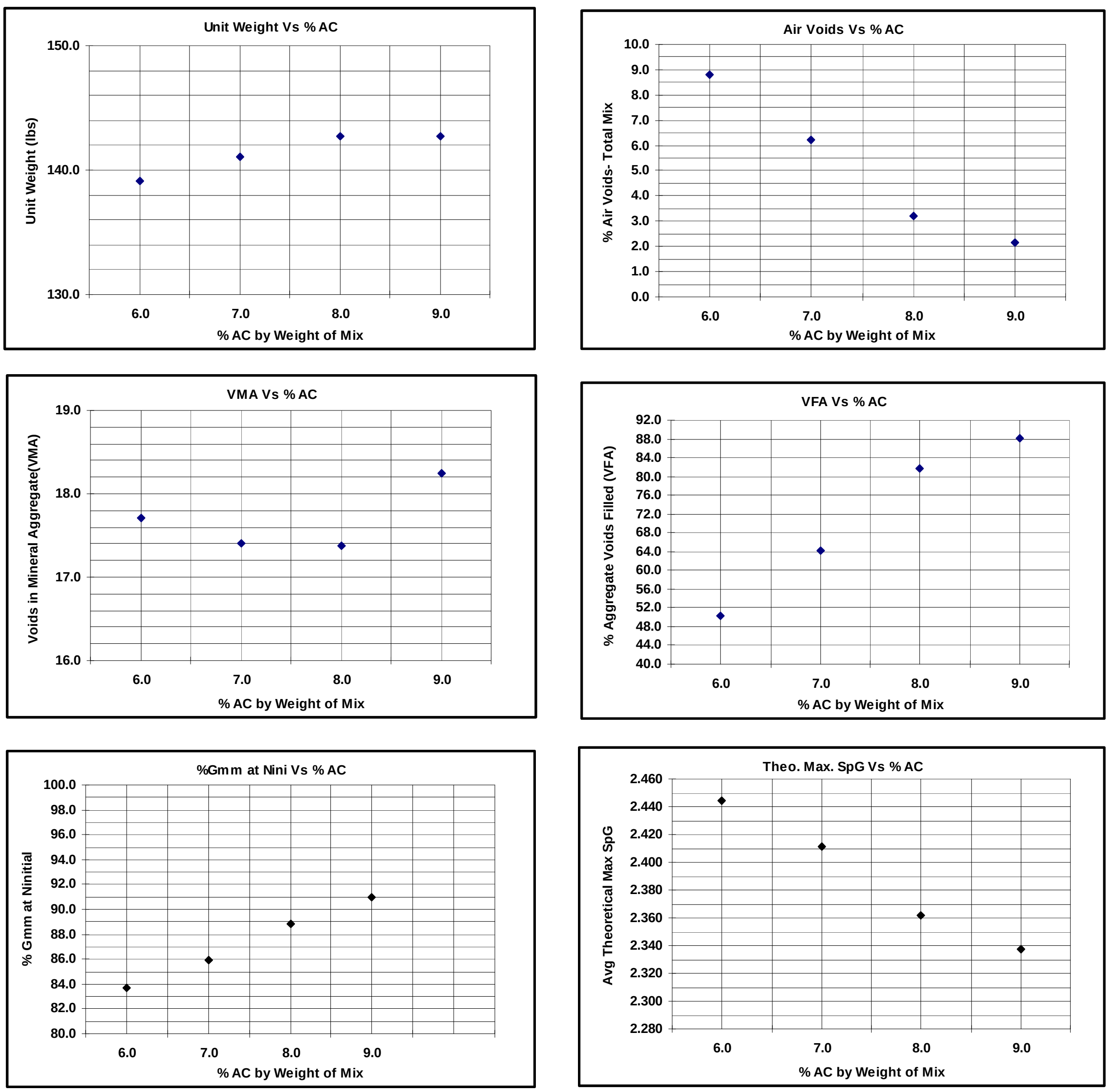

Figure 2 Mix Design Graphs for PG 64-28 Binder and 50:50 Aggregate Blend

LABORATORY PERFORMANCE TESTING AND ANALYSIS

BACKGROUND

The utilization of the Asphalt Pavement Analyzer to evaluate rutting resistance of HMA mixtures has gained momentum in recent years as more states found it to be fast, cost-effective, and practical to use. In this study, testing with the APA was conducted according to TP 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 (6 inches in diameter and 3 inches high) were produced at 7.0 ± 0.5% air voids to match actual densities of newly constructed pavements in the field. The specimens were heated for 6 hours either to 64^{o}C or 58^{o}C depending on the PG grade of the asphalt. The specified temperature was maintained for the duration of the test. All samples were tested dry and endured 8,000 cycles that lasted a little over 2 hours. Four samples for each mix design case were produced and tested in the APA for a total of 16 samples.

APA RESULTS AND ANALYSIS

The APA rut results[1] for the mix design cases are shown in Table 10 and Figure 3. Figures 4 and 5 also display rut depth comparisons via photographs.

Table 10 APA Rut Resistance Results for the No. 4 Mixes

Mix Design Cases	Left Side Depth (mm)		Right Side Depth (mm)		AVE (mm)
PG 64-28 & 60:40 Agg. Blend	*1*	*2*	*3*	*4*	7.1
	7.26	**6.97**	**7.60**	**6.57**	
PG 64-28 & 50:50 Agg. Blend	*5*	*6*	*7*	*8*	6.4
	6.20	**6.92**	**6.16**	**6.46**	
PG 58-28 & 60:40 Agg. Blend	*9*	*10*	*11*	*12*	7.9
	8.07	**7.89**	**7.56**	**8.04**	
PG 58-28 & 50:50 Agg. Blend	*13*	*14*	*15*	*16*	6.0
	6.49	**6.19**	**5.29**	**5.90**	

[1] One should be careful in comparing the rut depths for the two binders since they were tested at different temperatures.

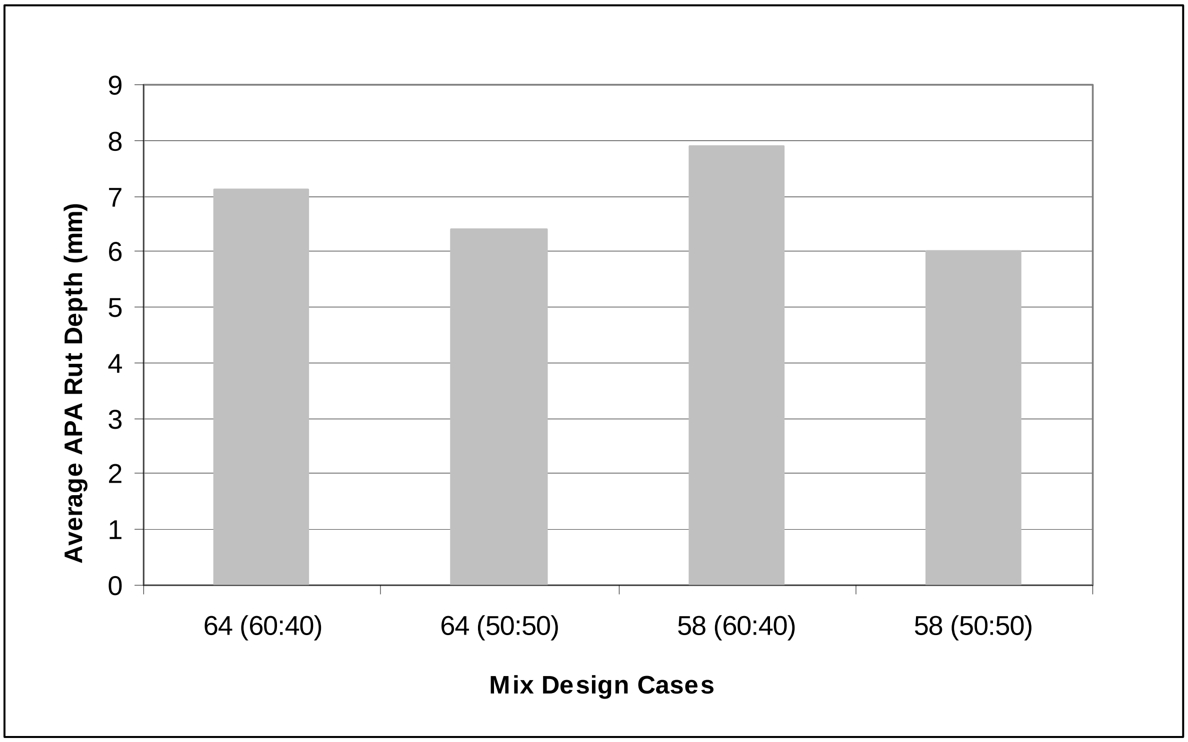

Figure 3 APA Average Performance Results for the No. 4 Mix Design Cases

Figure 4 Comparisons between 60:40 and 50:50 Blends in No. 4 Mix with PG 64-28 Binder

Figure 5 Comparisons between 60:40 and 50:50 Blends in No. 4 Mix with PG 58-28 Binder

The numbers 1 through 16 in Table 10 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.

In comparing the results, the APA performance specification adopted in this study is an average of 9.5 mm (3/8 inch) rut depth under the APA wheels (for traffic levels of < 300,000 design ESALs and low truck traffic).

The results indicate that the mixes with higher crushed fines (i.e. 50:50 blend) performed better than the mixes with lower crushed fines (i.e. 60:40 blend). For the same blend percentage of natural to crushed fines where only the PG grade is the variable, the results were not conclusive. Comparing the rut depths of the 64 (50:50) and the 58 (50:50) mixes, one can see that the rut depth value for the 58 (50:50) mix is slightly lower than the rut depth value for the 64 (50:50) mix. Also the AC contents for the mixes containing the PG 58-28 and the PG 64-28 binders were 7.0% and 7.1%, respectively. Since the AC contents for the two cases were virtually equal and that the two mixes were tested at different temperatures, the rut depth values for the two mixes can not be compared directly, but they do indicate how the mixes would perform with different binders and temperatures.

Comparing the rut depths of the 64 (60:40) and the 58 (60:40) mixes, it can be observed that the 58 (60:40) mix had higher rut depth value than the 64 (60:40) mix. Also one can see that the %AC content for the mix containing the PG 58-28 was 7.5% while it was 7.2% for the mix containing the PG 64-28 binder. Since the two mixes were tested at different temperatures, one should be careful in comparing the two results.

Even-though, some of the above results could not be compared due to testing at different temperatures, one can generally notice an increase in rut depth with higher AC contents. Due to the nature of the No. 4 mixes' gradations and small aggregates sizes, high AC contents can be easily produced, thus, extra care should be taken to ensure producing mixes with relatively lower values (< 8.0%) of optimal AC contents.

SUMMARY AND CONCLUSIONS

Due to the decline in aggregate supplies and the need for durable and rut-resistant HMA for use in thin-lift pavement layers, the use of surplus fine aggregate such as the No. 4 NMAS aggregates could be beneficial for HMA producers, aggregate producers, and transportation agencies.

Previous research has indicated that thin overlays produced from No. 4 mixes can be used to correct surface defects (leveling), create a smooth riding surface, extend pavement life, improve ride quality, increase skid resistance, increase durability, reduce permeability, reduce road-tire noise, decrease construction time, and decrease construction costs. They may also provide a use for surplus fine aggregate stockpiles and provide some structural improvement to pavements with low to medium traffic volumes.

The primary focus of this study was to develop and evaluate No. 4 mixes, which could utilize excess amounts of fine aggregates to use as thin overlays for non-interstate highways and for maintenance applications. The Asphalt Pavement Analyzer (APA) has been used to examine the rut resistance of the No. 4 mixes.

Due to the nature of the No. 4 mixes, several modifications were considered for this study: (1) the mixes were designed at 6 percent air voids to keep the asphalt contents within a reasonable range (below 8 percent); (2) the dust percentages in the blends that are passing the No. 200 sieve were kept in the 6 to 8 percent range to help reduce the required asphalt content and improve stability of the mix; (3) the voids in mineral aggregates (VMA) were designed between 16 and 18 percent; (4) the fine aggregate angularities (FAA) of the blends were kept above 40; (5) the dust to effective asphalt content was desired to be between 0.9 and 2.2; the volume of the effective asphalt was desired to be approximately at 12; and (6) the acceptable APA rut depth for these types of mixes typically used for roads with less than 300,000 ESALs and with low truck traffic is about 9.5 mm (3/8 inch).

This research study entailed mix designs involving two binders and two aggregate blends. The binders were PG 64-28 and PG 58-28 binder grades. And the two aggregates involved were 60:40 and 50:50 blends of natural fines to crushed fines. These two aggregate blends were adopted after initial testing ruled out blends with higher natural fines percentages. Blends with 80 and 100 percent natural fines produced mixes with excessive asphalt contents and produced severe rut depths under the APA. A total of four mix design cases were conducted for this study, 64 (60:40), 64 (50:50), 58 (60:40), and 58 (50:50). The numbers 64 and 58 represent the binder grades PG 64-28 and PG 58-28, respectively. Also the 60:40 and 50:50 represented the NF to CF ratios that were used in the aggregate blends.

Laboratory specimens (6 inches in diameter and 3 inches high) were produced at 7.0 ± 0.5% air voids to conform to actual densities of newly constructed pavements in the field. The specimens were heated either to 64^{o}C or 58^{o}C for 6 hours corresponding to the PG grade of the asphalt in the mix. The specified temperature was maintained for the duration of the test. All samples were tested dry and endured 8,000 cycles that lasted a little over 2 hours. Four samples for each mix design case were produced and tested in the APA for a total of 16 samples.

In comparing the results, the APA performance specification adopted in this study is an average of 9.5 mm (3/8 inch) rut depth under the APA wheels (for traffic levels of less than 300,000 design ESALs and low truck traffic).

The results indicate that the mixes with higher crushed fines (i.e. 50:50 blend) performed better than the mixes with lower crushed fines (i.e. 60:40 blend). For the same blend percentage of natural to crushed fines where only the PG grade is the variable, the results were not conclusive. Comparing the rut depths of the 64 (50:50) and the 58 (50:50) mixes, one can see that the rut depth value for the 58 (50:50) mix is slightly lower than the rut depth value for the 64 (50:50) mix. Also the AC contents for the mixes containing the PG 58-28 and the PG 64-28 binders were 7.0% and 7.1%, respectively. Since the AC contents for the two cases were virtually equal and that the two mixes were tested at different temperatures, the rut depth values for the two mixes can not be compared directly, but they do indicate how the mixes would perform with different binders and temperatures.

Comparing the rut depths of the 64 (60:40) and the 58 (60:40) mixes, it can be observed that the 58 (60:40) mix had higher rut depth value than the 64 (60:40) mix. Also one can see that the %AC content for the mix containing the PG 58-28 was 7.5% while it was 7.2% for the mix containing the PG 64-28 binder. Since the two mixes were tested at different temperatures, one should be careful in comparing the two results.

Even-though, some of the above results could not be compared due to testing at different temperatures, one can generally notice an increase in rut depth with higher AC contents. Due to the nature of the No. 4 mixes' gradations and small aggregates sizes, high AC contents can be easily produced, thus, extra care should be taken to ensure producing mixes with relatively lower values (< 8.0%) of optimal AC contents.

The design and performance testing of No. 4 mixes was a challenging research study. To ensure success, the special design considerations should be watched closely throughout the research study. For this study, the AC contents and VMA percentages were kept reasonably low by designing the air voids at 6% and by maintaining a high level of dust proportions. The fine aggregate angularities should also be above 40 all the time to improve stability.

The natural fines used for this study were of marginal quality. The FAA value of 36 was very low and the percent absorption value of 2.9 was relatively high. Needless to say that higher quality natural fines aggregates would help the performance of the No. 4 mixes. Since marginal quality natural aggregates worked very well in blends with relatively equal percentages of crushed fines, higher quality natural fines may allow the use of higher proportions of natural fines in No. 4 mixes and still be successful.

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APPENDIX

Mix Design Summary Sheets
No. 4 Mixes

Summary Sheet for 64 (60:40) Mix Design

HOT MIX DESIGN DATA - SUPERPAVE					
Department of Transportation, Materials and Research (Rev. 5-07)					
Lab. No.					
Location	UND		Project Specification		Section 410
Project	NDDOT		Type of AC (top lift)		PG 64-28
			Type of AC (bot lift)		PG 64-28
District			Letting Date		
County			Plus #4 (%)		4.3
Date			Minus #4 (%)		95.7
Pit Owner(s)					
			Gyratory Compactive Effort		
Pit #1 Location	Northwood, ND			Ninitial	7
Pit #2 Location				Ndesign	75
Pit #3 Location				Nmaximum	115
Mix Properties at Recommended Asphalt Content			**Summary of Aggregate**		
	Mix Design	Specification	**Characteristics from Mix Design**		
Optimum AC (%)	7.2				
Density (pcf)	140.7			Gradation (% passing)	
Air Voids (%)	6.0	3.0-5.0		5/8"	100.0
VMA (%)	17.8	14.0 Min		1/2"	100.0
VFA (%)	66.3	65-78		3/8"	99.6
%Gmm @ Ninitial	86.2	89 Max		#4	95.7
%Gmm @ Nmaximum	95.2	98Max		#8	80.4
AC Film Thickness (m)	6.3	7.5-13		#16	61.6
Dust/Effective AC Ratio	1.3	0.6-1.3		#30	42.8
Fine Agg Angularity (%)	40.5	45 Min		#50	22.8
Sand Equivalent (%)	62.6	40 Min		#100	9.9
Coarse Agg Angularity (%)	100.0	75 Min		#200	6.9
Flat/Elongated Pieces (%)	1.1	10 Max			
Maximum SpG @ Ndes	2.399		Asphalt Absorption (%)		2.25
			Water Absorption (%)		2.81
Frac. Faces Fine (%)	39.7		Light Wt Particles (%)		1.1
Frac. Faces Course (%)	47.2		Toughness (% Loss)		22.6
Final Aggregate Blend (%)			**Specific Gravity Information**		
60	Nat. Fines (NW)				
40	Crushed Fines		Bulk (Gsb)		2.525
			Apparent (Gsa)		2.718
			Effective (Gme)		2.672
			Effective (Vbe)		11.8
Remarks:					
60% NF - 40% CF Blend					
PG 64-28 Binder					
Distribution:					
Materials and Research					

Summary Sheet for 64 (50:50) Mix Design

HOT MIX DESIGN DATA - SUPERPAVE					
Department of Transportation, Materials and Research (Rev. 5-07)					
Lab. No.					
Location	UND		Project Specification		Section 410
Project	NDDOT		Type of AC (top lift)		PG 64-28
			Type of AC (bot lift)		PG 64-28
District			Letting Date		
County			Plus #4 (%)		4.4
Date			Minus #4 (%)		95.6
Pit Owner(s)					
			Gyratory Compactive Effort		
Pit #1 Location	Northwood, ND			Ninitial	7
Pit #2 Location				Ndesign	75
Pit #3 Location				Nmaximum	115
Mix Properties at Recommended Asphalt Content			**Summary of Aggregate**		
	Mix Design	Specification	**Characteristics from Mix Design**		
Optimum AC (%)	7.1				
Density (pcf)	141.3			Gradation (% passing)	
Air Voids (%)	6.0	3.0-5.0		5/8"	100.0
VMA (%)	17.4	14.0 Min		1/2"	100.0
VFA (%)	65.9	65-78		3/8"	99.5
%Gmm @ Ninitial	86.3	89 Max		#4	95.6
%Gmm @ Nmaximum	96.3	98Max		#8	79.0
AC Film Thickness (m)	6.2	7.5-13		#16	59.2
Dust/Effective AC Ratio	1.4	0.6-1.3		#30	40.9
Fine Agg Angularity (%)	41.7	45 Min		#50	22.1
Sand Equivalent (%)	64.0	40 Min		#100	10.2
Coarse Agg Angularity (%)	100.0	75 Min		#200	7.2
Flat/Elongated Pieces (%)	1.1	10 Max			
Maximum SpG @ Ndes	2.409		Asphalt Absorption (%)		2.18
			Water Absorption (%)		2.79
Frac. Faces Fine (%)	49.7		Light Wt Particles (%)		1.1
Frac. Faces Course (%)	57.3		Toughness (% Loss)		22.6
Final Aggregate Blend (%)			**Specific Gravity Information**		
50	Nat. Fines (NW)				
50	Crushed Fines		Bulk (Gsb)		2.531
			Apparent (Gsa)		2.723
			Effective (Gme)		2.674
			Effective (Vbe)		11.4
Remarks:					
50% NF - 50% CF Blend					
PG 64-28 Binder					
Distribution:					
Materials and Research					

Summary Sheet for 58 (60:40) Mix Design

HOT MIX DESIGN DATA - SUPERPAVE				
Department of Transportation, Materials and Research (Rev. 5-07)				
Lab. No.				
Location	UND		Project Specification	Section 410
Project	NDDOT		Type of AC (top lift)	PG 64-28
			Type of AC (bot lift)	PG 64-28
District			Letting Date	
County			Plus #4 (%)	4.3
Date			Minus #4 (%)	95.7
Pit Owner(s)				
			Gyratory Compactive Effort	
Pit #1 Location	Northwood, ND		Ninitial	7
Pit #2 Location			Ndesign	75
Pit #3 Location			Nmaximum	115
Mix Properties at Recommended Asphalt Content			**Summary of Aggregate**	
	Mix Design	Specification	**Characteristics from Mix Design**	
Optimum AC (%)	7.5			
Density (pcf)	141.6		Gradation (% passing)	
Air Voids (%)	6.0	3.0-5.0	5/8"	100.0
VMA (%)	17.6	14.0 Min	1/2"	100.0
VFA (%)	66.1	65-78	3/8"	99.6
%Gmm @ Ninitial	86.5	89 Max	#4	95.7
%Gmm @ Nmaximum	94.5	98Max	#8	80.4
AC Film Thickness (m)	6.2	7.5-13	#16	61.6
Dust/Effective AC Ratio	1.4	0.6-1.3	#30	42.8
Fine Agg Angularity (%)	40.5	45 Min	#50	22.8
Sand Equivalent (%)	62.6	40 Min	#100	9.9
Coarse Agg Angularity (%)	100.0	75 Min	#200	6.9
Flat/Elongated Pieces (%)	1.1	10 Max		
Maximum SpG @ Ndes	2.414		Asphalt Absorption (%)	2.69
			Water Absorption (%)	2.81
Frac. Faces Fine (%)	39.7		Light Wt Particles (%)	1.1
Frac. Faces Course (%)	47.2		Toughness (% Loss)	22.6
Final Aggregate Blend (%)			**Specific Gravity Information**	
60	Nat. Fines (NW)			
40	Crushed Fines		Bulk (Gsb)	2.525
			Apparent (Gsa)	2.718
			Effective (Gme)	2.703
			Effective (Vbe)	11.6
Remarks:				
60% NF - 40% CF Blend				
PG 58-28 Binder				
Distribution:				
Materials and Research				

Summary Sheet for 58 (50:50) Mix Design

HOT MIX DESIGN DATA - SUPERPAVE					
Department of Transportation, Materials and Research (Rev. 5-07)					
Lab. No.					
Location	UND		Project Specification		Section 410
Project	NDDOT		Type of AC (top lift)		PG 58-28
			Type of AC (bot lift)		PG 58-28
District			Letting Date		
County			Plus #4 (%)		4.4
Date			Minus #4 (%)		95.6
Pit Owner(s)					
			Gyratory Compactive Effort		
Pit #1 Location	Northwood, ND			Ninitial	7
Pit #2 Location				Ndesign	75
Pit #3 Location				Nmaximum	115
Mix Properties at Recommended Asphalt Content			**Summary of Aggregate**		
	Mix Design	Specification	**Characteristics from Mix Design**		
Optimum AC (%)	7.0				
Density (pcf)	141.6			Gradation (% passing)	
Air Voids (%)	6.0	3.0-5.0		5/8"	100.0
VMA (%)	17.1	14.0 Min		1/2"	100.0
VFA (%)	64.6	65-78		3/8"	99.5
%Gmm @ Ninitial	86.2	89 Max		#4	95.6
%Gmm @ Nmaximum	95.4	98Max		#8	79.0
AC Film Thickness (m)	5.9	7.5-13		#16	59.2
Dust/Effective AC Ratio	1.5	0.6-1.3		#30	40.9
Fine Agg Angularity (%)	41.7	45 Min		#50	22.1
Sand Equivalent (%)	64.0	40 Min		#100	10.2
Coarse Agg Angularity (%)	100.0	75 Min		#200	7.2
Flat/Elongated Pieces (%)	1.1	10 Max			
Maximum SpG @ Ndes	2.414		Asphalt Absorption (%)		2.33
			Water Absorption (%)		2.79
Frac. Faces Fine (%)	49.7		Light Wt Particles (%)		1.1
Frac. Faces Course (%)	57.3		Toughness (% Loss)		22.6
Final Aggregate Blend (%)			**Specific Gravity Information**		
50	Nat. Fines (NW)				
50	Crushed Fines		Bulk (Gsb)		2.531
			Apparent (Gsa)		2.723
			Effective (Gme)		2.684
			Effective (Vbe)		11.1
Remarks:					
50% NF - 50% CF Blend					
PG 58-28 Binder					
Distribution:					
Materials and Research					