A PRELIMINARY EVALUATION OF SUPERPAVE LEVEL ONE MIX DESIGN PROCEDURE

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Disclaimer

Preface

This report describes a study conducted at the University of Wyoming by Dr. Khaled Ksaibati, Associate Professor of Civil Engineering, and Jason Stephen, graduate student of Civil Engineering. This study was coordinated with George Huntington of the Wyoming Department of Transportation. In this study, the researchers evaluated the performance of asphalt mixes prepared using the Marshall mix design method and the Superpave level one mix design method. The Georgia Loaded Wheel Tester and the Thermal Stress Restrained Specimen Tester were used to test the rut-resistance and low-temperature cracking of asphalt mixes. This evaluation will assist in implementing the Superpave level one mix design method in Wyoming.

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CHAPTER 1

INTRODUCTION

Background

The purpose of an asphalt mix design method is to determine the optimum proportions of aggregate and asphalt cement to use in an asphalt pavement. Highway agencies around the country commonly use two empirical mix designs, Marshall and Hveem. A newer mix design developed by the Strategic Highway Research Program (SHRP), Superpave, is being considered for full implementation as a design method by highway agencies in the near future. The main advantage of Superpave over currently used mix design methods is that it is performance-based, which implies a direct relationship between laboratory analysis and field performance after construction [1]. Other design methods are empirical and therefore cannot accurately predict how a pavement will perform after construction [2].

The purpose of developing Superpave was to improve the field performance of asphalt pavements. There are several modes of failure that an asphalt pavement may experience the two most common are rutting and low-temperature cracking. Repeated, heavy traffic loads permanently deform an asphalt pavement causing rutting. This occurs during the warmer months due to a decrease in asphalt viscosity. Low-temperature cracking occurs at sub-freezing temperatures when the viscosity of asphalt is high and is caused by the tensile stress that develops as a result of shrinkage [2]. For a pavement to resist rutting and low-temperature cracking, it must perform well under a wide range of environmental conditions.

Objectives

Several highway agencies currently are experimenting with the Superpave mix design method to determine its effectiveness. The Wyoming Department of Transportation (WYDOT) has obtained the necessary equipment to perform the Superpave testing. The objective of this study was to compare the Superpave mix design to the Marshall mix design on a typical aggregate source in Wyoming. The comparison concentrated on the resistance to rutting and low-temperature cracking of asphalt mixes prepared using the two design methods.

Report Organization

Chapter 2 of this report contains a literature review related to the Marshall and Hveem mix design methods in addition to the newer Superpave level one mix design method. Chapter 3 describes the design of the experiment including information about the materials used in the study, the Marshall and Superpave level one mix deigns, and the accelerated testing devices used in the study. Results from the Marshall and Superpave mix designs are summarized in chapter 4. Chapter 5 contains the Georgia Loaded Wheel Tester and Thermal Stress Restrained Specimen Tester accelerated testing results on the Marshall and Superpave samples. Finally, conclusions and recommendations based on the study are presented in chapter 6.

CHAPTER 2

LITERATURE REVIEW

For approximately the past 50 years, engineers have designed asphalt mixtures using the Marshall or Hveem mix design methods. Over this period, different highway agencies have modified the two design procedures to better fit their particular needs. Both methods have proven to be satisfactorily effective in aiding the design of highways and interstates, but some problems exist. The primary problem is that both the Marshall and Hveem design methods are empirical — they do not produce samples that share the properties or performance of the finished product. This makes it difficult to accurately predict how a particular mix will perform in the field [2].

Congress initiated SHRP in 1987 as a five-year, $150 million program designed primarily to improve the performance and safety of roads in the United States. The Superpave (Superior Performing Asphalt Pavements) mix design method, is a product of SHRP and still is being evaluated for implementation into federal, state, and local specifications of asphalt mix design [1].

The Superpave mix design method is divided into three levels. Level one mix design is used for low-volume roads, while levels two and three are used for intermediate-volume and high-volume roads, respectively. Each level becomes more rigorous than the one before it and provides more information on the mixture's performance. This report concentrates on level one mix design because levels two and three still are being refined at the national level.

The Superpave mix design method differs from the Marshall and Hveem mix design methods by using performance-based and performance-related criteria to design the proper asphalt mix. This allows a direct relationship to be drawn between the lab and field performance of the asphalt mix [1]. The remainder of this chapter briefly reviews current material selection procedures, the Marshall and Hveem mix design procedures, and the Superpave material selection and level one mix design procedure.

Current Design Methods

Marshall is the design method most commonly used by highway agencies. Hveem is used less because of its complexity [2]. WYDOT currently uses the Marshall design method to design all of its Hot Mix Asphalt (HMA) for highways and interstates. The following two sections of this report describe the material-selection process used for current mix design methods.

Asphalt Cement

Before a good asphalt mix can be designed by Marshall or Hveem, designers must select the proper asphalt cement grade and determine its properties. They decide on a proper asphalt cement grade by examining the type of asphalt mix being designed and the geographical location of its use. After the asphalt cement is selected, designers may determine its viscosity and whether the asphalt meets specifications of flash point, penetration, ductility, and solubility. Once they conclude an asphalt cement is acceptable, they find its specific gravity and create a temperature-viscosity plot to determine its appropriate mixing and compaction temperatures [2].

Aggregate

For a mix design to be successful, the appropriate aggregate also must be selected. Designers may perform several tests to determine if an aggregate is acceptable for an asphalt mix. The tests include the Los Angeles abrasion, sulfate soundness, sand equivalent, deleterious substances, polishing, crushed face count, and flat-elongated particle count. When designers accept a particular aggregate, they test its gradation, specific gravity, and absorption. They determine the final combination of aggregate for the mix design using local gradation specifications and a Federal Highway Administration (FHWA) 0.45 power gradation chart [2].

It should be noted there are no universal procedures or specifications when determining the specific aggregate and the aggregate gradation to use in a mix design. Each highway agency determines the tests and specifications that will be used.

Marshall Design Method

Bruce Marshall developed the Marshall design method at the Mississippi Highway Department around 1939. In 1943, the Corps of Engineers Waterways Experiment Station (WES) began to study Marshall's mix design procedures in an attempt to develop a method for designing asphalt mixtures for airfield pavements. The corps' study involved a series of laboratory and field experiments designed to find a laboratory compaction procedure that produced the same densities found in the field during construction and aircraft loading [2]. Based on the results of the study, a standard compaction procedure was adopted using a sliding hammer with a 98.4 mm (3.88 in.) diameter head weighing 4.54 kg (10.0 lb.) to deliver 50 blows per side to the sample. The WES then established stability, flow, density, and void criteria based on the standard compaction procedure [2]. The compacted test specimens are 63.5 mm (2.5 in.) high and 102 mm (4.0 in.) in diameter [3].

In the 1950s, WES further refined its specifications with a special set of criteria for high tire pressure. The agency's test procedure included a compactive force generated by 75 blows per side. WES also increased the Marshall stability criteria to control the use of natural sands which tend to cause rutting [2].

To determine the optimum asphalt cement content, three test specimens are prepared at five different asphalt contents. The asphalt contents are 0.5 percent apart from each other and include an estimated optimum asphalt content, two above the estimated optimum asphalt content, and two below the estimated optimum asphalt content. The estimated optimum asphalt content can be determined using specifications or experience.

A test specimen is prepared by first heating the asphalt cement and aggregate to mixture temperature, then mixing and allowing them to reach compaction temperature. Test specimens are compacted by applying 50 or 75 blows per side with the compaction hammer. The number of blows is determined by the expected traffic level of the pavement section [2].

Once the Marshall samples have been prepared, the designers use them to determine the average of several asphalt mix properties for each asphalt cement content. They use a density voids analysis to determine the unit weight, percent air voids, percent voids in mineral aggregate (VMA), and percent voids filled with asphalt (VFA). Designers use the Marshal test machine to measure stability and flow of the specimens. Stability is a value for the load under which the specimen fails. Flow is the amount of deformation that occurs when the specimen fails. If a sample has a low stability and a high flow value, the mixture will tend to rut and deform under a load. If the sample has a high stability and a low flow value, the mix will tend to be brittle and crack under a load [4].

Six plots help determine the optimum asphalt cement content. They are unit weight, percent air voids, VMA, VFA, stability, and flow versus the asphalt contents. Designers find the optimum asphalt content by using the plots to determine the average asphalt content at the maximum unit weight, maximum stability, and at 4 percent air voids. They then check this percentage of asphalt cement to insure that it is within the limiting criteria for flow, stability, percent air voids, VMA, and VFA [4].

Table 2.1 contains the current Marshall mix design criteria as given by the Asphalt Institute. Table 2.2. can be used to determine the limiting VMA [5].

Table 2.1. Marshall Mix Design Criteria [5].

Design Criteria Property	50 Blows		75 Blows	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Stability N (lb)	5338 (1200)	N/A	8006 (1800)	N/A
Flow 0.025 mm (0.01 in.)	8	16	8	14
Percent Air Voids	3	5	3	5
Percent VFA	65	78	65	75

Table 2.2. Marshall Mix Design Minimum Percent VMA Criteria [5].

Nominal Maximum Aggregate Size	Minimum Percent VMA For Design Percent Air Voids		
mm (in.)	**3.0**	**4.0**	**5.0**
1.18 (No. 16)	21.5	22.5	23.5
2.36 (No. 8)	19.0	20.0	21.0
4.75 (No. 4)	16.0	17.0	18.0
9.50 (3/8)	14.0	15.0	16.0
12.5 (1/2)	13.0	14.0	15.0
19.0 (3/4)	12.0	13.0	14.0
25.0 (1.0)	11.0	12.0	13.0
37.5 (1.5)	10.0	11.0	12.0
50.0 (2.0)	9.5	10.5	11.5
63.0 (2.5)	9.0	10.0	11.0

Hveem Design Method

Francis Hveem, a resident engineer in California, developed the Hveem design method. In the late 1920's, Hveem began working on oil mixes, a combination of fairly good-quality aggregate and slow-curing asphalt. At that time, many different agencies were using oil mixes in California as an intermediate-type surface for use under moderate traffic conditions.

As time went on, Hveem noticed a relationship between the gradation of the aggregate and the amount of oil it took to maintain a consistent appearance in an asphalt mix. This eventually led to the development of the kerosene equivalent test by Hveem. This test takes into account oil requirement differences as the absorption and surface area of the aggregate change. Hveem then developed another test to evaluate the stability of an asphalt mixture with the Hveem stableometer. The stableometer measures the horizontal transfer of a vertical load on an asphalt sample. Hveem also developed a test to determine the cohesive properties of a mix using a cohesionmeter. However, because HMA has replaced oil mixes and has cohesion values large enough to prevent raveling of the pavement, the cohesionmeter is rarely used anymore. The Hveem method evolved into its final form by 1959. Approximately 25 percent of the state highway departments, most in western states, have adopted this method [2].

Superpave Design Method

The level one mix design incorporates performance-based asphalt binder specifications with performance-related aggregate specifications and empirical volumetric criteria. This mix design method produces a mix design for low-traffic roads without using the performance-based testing required by levels two and three mix designs [6]. This makes the level one mix design simple to use, yet it still produces adequate performing asphalt pavements.

Asphalt Cement Grading

Asphalt selection for the Superpave mix design is performance-based and dependent on climate and traffic conditions. The high and low temperature requirement of the binder differentiates among the various grades of binders. For example, an asphalt binder grade of PG 58-28 means that the asphalt must meet high temperature requirements of 58^{o}C (136.4^{o}F) and low temperature requirements of -28^{o} C (-18.4^{o} F). Once a designer selects a binder grade based on temperature, the grade may be adjusted for different loading conditions [1].

Aggregate Selection

Aggregate selection for Superpave is based on two categories of aggregate properties: consensus aggregate properties and source aggregate properties. Consensus properties include coarse aggregate angularity, fine aggregate angularity, flat-elongated particles, and clay content. Source properties include toughness, soundness, and deleterious materials. Superpave provides criteria for these properties, but they also can be determined by local highway agencies.

Designers determine aggregate gradations using the 0.45 power gradation chart. If the aggregate meets the suggested Superpave or highway agency criteria, it is suitable for use in asphalt mixes [1].

Level One Mix Design Method

The Superpave level one mix design can accommodate an aggregate size as large as 50.0 mm (1.97 in.) and can be applied to virgin, recycled, dense-graded, and HMA with or without modification. This mix design can be used when constructing new surfaces, binder layers, base layers, and overlays [6].

The level one mix design method requires three basic steps. First, designers must select the proper aggregate and asphalt cement. Next, they select the design aggregate structure and estimated optimum asphalt cement content by preparing test specimens using trial aggregate gradations and a trial asphalt content. A design aggregate structure and estimated optimum asphalt content are selected by estimating a trial mix’s VMA, VFA, and percent of maximum density at the initial and maximum compaction levels at 4 percent air voids and determining if they meet limiting criteria. Compaction levels are measured in terms of the gyratory compactor. Finally, designers must determine the optimum asphalt cement content for the design aggregate structure by compacting two test specimens at four different asphalt cement contents. The asphalt contents are 0.5 percent above and below, 1.0 percent above, and one at the estimated optimum asphalt cement content. The design optimum asphalt cement content then is selected by determining which asphalt cement content satisfactorily conforms with the requirements for air voids, VMA, VFA, and dust proportions at the design compaction level. Percentage of maximum density criteria at the initial and maximum compaction levels is also used. Designers may evaluate the moisture sensitivity of the design mixture at an air void content of 7 percent [6]. Designers determine the Superpave criteria for material selection and the compactive effort required for the test samples using the design Equivalent Single Axle Loads (ESALs) for the project.

Chapter Summary

This chapter provided a brief history and description of currently used Marshall and Hveem mix design methods. In addition, a brief description of Superpave mix design method was included. All highway agencies have already received the necessary equipment for the Superpave level one mix design method. Some highway agencies have started experimenting with the three levels of design.

CHAPTER 3

EXPERIMENT DESIGN

In this research, the Marshall and Superpave level one mix design methods were performed on the same source of aggregate and asphalt cement. At the time the asphalt cement and aggregate were selected, they also were being used in a Wyoming construction project (Interstate 80, Cheyenne Marginal, project number NHI-80-6(163)362). These materials were used so the laboratory and field performance could be compared at a later time.

The performance of asphalt samples based on the Marshall and the Superpave level one mix design methods were compared through laboratory accelerated performance testing. The results of the tests were analyzed for differences in performance. Figure 3.1 summarizes the data collection strategies used in this research project.

Material Characteristics

Frontier Oil Refinery of Cheyenne, Wyoming, manufactured the asphalt cement used in this study. The properties of the asphalt cement determined by the Wyoming Department of Transportation (WYDOT) are shown in Table 3.1.

Star Aggregates, Inc. of Cheyenne, Wyo., supplied the 100 percent virgin aggregate used in this study. The aggregate was crushed and sieved into coarse and fine piles. The coarse pile contained material retained on a 4.75 mm (No. 4) sieve, the fine pile contained material which passed a 4.75 mm (No. 4) sieve, as verified in a WYDOT sieve analysis. The sieve analysis results are shown in Table 3.2.

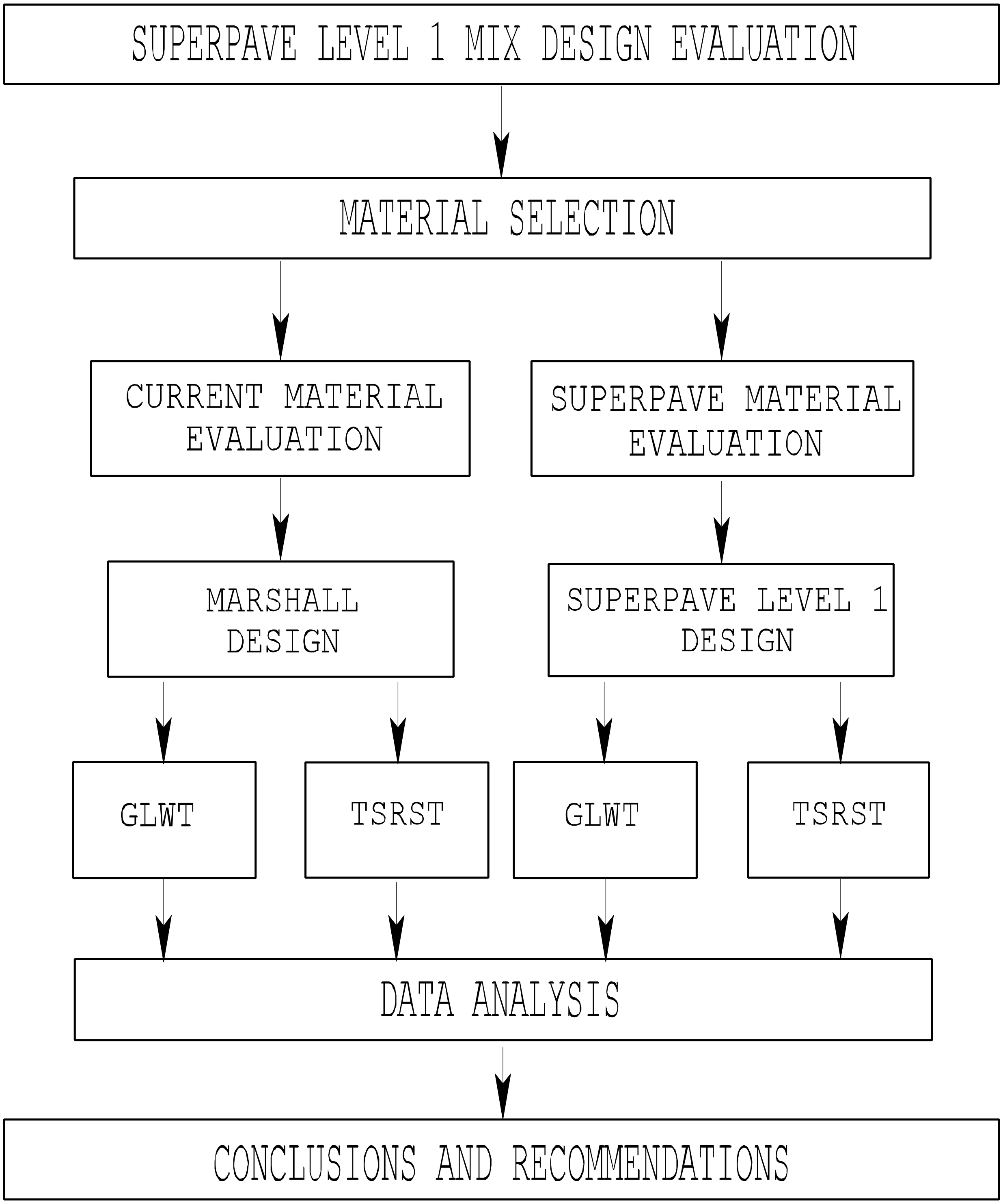

Figure 3.1. Overview of Data Collection Strategies.

Table 3.1. Asphalt Cement Properties.

Property	Result
Penetration Grade	40-50
Viscosity Grade	AC-20
Mix Temperature	146ºC (295ºF)
Lay down Temperature	143ºC (290ºF)
Specific Gravity	1.034

Table 3.2. Sieve Analysis of Coarse and Fine Star Aggregate.

Sieve Size	Coarse (% Passing)	Fine (% Passing)
25.0 mm (1 in.)	100.0	100.0
19.0 mm (3/4 in.)	95.0	100.0
12.5 mm (½ in.)	43.0	100.0
12.5 mm (3/8 in.)	25.4	100.0
4.75 mm (#4)	1.3	89.7
2.36 mm (#8)	0.8	60.3
1.18 mm (#16)	0.6	39.7
600 mm (#30)	0.5	25.9
300 mm (#50)	0.4	15.5
150 mm (#100)	0.3	8.5
75.0 mm (#200)	0.2	4.4

Mix Design Methods

For this study, WYDOT performed the Marshall mix design and the University of Wyoming (UW) performed the Superpave level one mix design. Both mix designs used the same aggregate and asphalt cement described in the previous section, but the materials were subjected to different tests and combined differently in each case, as per mix design specifications.

Accelerated Performance Testing

After the Marshall and Superpave mix designs were completed, accelerated testing was used to analyze the rutting and cold temperature cracking resistance of each design. To accomplish the accelerated testing, the Georgia Loaded Wheel Tester (GLWT) and the Thermal Stress Restrained Specimen Tester (TSRST) were used. Descriptions of the tests follow.

Georgia Loaded Wheel Tester

The GLWT was developed by the Georgia Department of Transportation to test the rut-resistance of asphalt mixes. The original asphalt specimens used in the GLWT were rectangular and measured 76.2 x 76.2 x 381 mm (3 x 3 x 15 in.). Because this size specimen is difficult to prepare, UW began using smaller, round specimens. Due to the change in their size, asphalt samples were placed between two concrete spacers before being secured in the machine [7].

The gyratory compactor was used to prepare a 152 mm (6.0 in.) round and 76.2 mm (3.0 in.) tall asphalt specimen for testing in the GLWT. Once an asphalt specimen was made, it was confined in the GLWT and a rubber hose pressurized to 0.69 MPa (100 psi) was placed in the mounting brackets just above the top of the sample. A steel wheel loaded with 45.4 kg (100 lb) was placed on top of the hose. A motor then repeatedly rolled the loaded wheel back-and-forth over the hose, producing a contact pressure of approximately 0.69 MPa (100 psi) between the hose and the sample. Each back-and-forth motion of the wheel counted as one cycle [7].

Once a specified number of loadings cycles had been achieved by the GLWT, the rut depth was measured with an aluminum dowel containing three dial indicators. This device constructed to accommodate the round specimens was placed in the rubber hose mounting brackets inside the GLWT, above a sample. It measured the rut depth of the asphalt sample in the center and 50.8 mm (2 in.) off center in each direction. The measurements were averaged to find a final rut depth for a particular number of cycles [7].

Thermal Stress Restrained Specimen Tester

The TSRST tests an asphalt mix's resistance to cold temperature cracking, by cooling an asphalt sample in an environmental cabinet with liquid nitrogen while restraining it from contracting. The cooling creates a tensile stress in the specimen, and when the tensile stress equals the tensile strength of the specimen, the specimen fractures. The temperature and the pressure continuously are recorded by a computer until the sample fails [8].

The specimens tested in the TSRST had a diameter of 50.8 mm (2.00 in.) and were approximately 229 mm (9.00 in.) tall. Each specimen was constructed by compacting a rectangular sample 76.2 x 76.2 x 381 mm (3 x 3 x 15 in.), and coring it using a drill press to produce a 50.8 mm (2.00 in.) cylinder. The cylindrical sample was then trimmed to the appropriate length.

The compaction process consisted of placing the asphalt mix in a steel mold in three even lifts, each being tamped 20 times. The mix was compacted by the application of three, 356 kN (80,000 lb) static loads with a hydraulic press, the first two were immediately released; the third was sustained for five minutes. On completion of compaction, samples were removed from the mold, cored, and trimmed to size, as described earlier.

CHAPTER 4

MIX DESIGNS

The following sections describe results of the Marshall and Superpave level one mix designs.

Marshall

The aggregate used in the Marshall mix design consisted of 43.0 percent coarse and 57.0 percent fine aggregate. The combined gradation and job mix formula limits used for the Cheyenne marginal project are shown in Table 4.1. The aggregate was tested by the Wyoming Department of Transportation (WYDOT) and the University of Wyoming (UW) for coarse aggregate angularity, fine aggregate angularity, thin elongated particles, and sand equivalency. It was determined by WYDOT that the aggregate was acceptable for use in the Cheyenne marginal project. The results from the aggregate tests are shown in Table 4.2. WYDOT also determined the specific gravities of the coarse, fine, and combined aggregate, which are shown in Table 4.3. The FHWA 0.45 power gradation chart for the combined aggregate is displayed in Figure 4.1. The asphalt cement used to construct the asphalt mix was AC-20. This is the standard asphalt cement grade used in this region.

WYDOT completed the Marshall mix design with a compaction effort of 75 blows from the Marshall compaction hammer. The optimum asphalt content was determined to be 5.50 percent. The stability, flow, unit weight, percent air voids, percent VFA, and percent VMA versus asphalt cement content plots used to determine the optimum asphalt content are shown in Figure 4.2. The properties of the asphalt mix at 5.50 percent asphalt cement content pass the criteria shown in Table 2.1 and Table 2.2.

Table 4.1. Sieve Analysis of Aggregate for Marshall Mix Design.

Sieve Size	Combined	JMF Limits
37.5 mm (1 1/2 in.)	100.0	-
25.0 mm (1 in.)	100.0	100
19.0 mm (3/4 in.)	97.9	90-100
12.5 mm (1/2 in.)	75.5	66-80
12.5 mm (3/8 in.)	67.9	-
4.75 mm (#4)	51.7	46-60
2.36 mm (#8)	34.7	31-41
1.18 mm (#16)	22.9	-
600 mm (#30)	15.0	12-22
300 mm (#50)	9.0	-
150 mm (#100)	5.0	-
75.0 mm (#200)	2.6	2-7

Table 4.2. Aggregate Test Results.

Aggregate Test	Result
Coarse Aggregate Angularity	100/100
Fine Aggregate Angularity	50.3
Thin Elongated Particles	0%
Sand Equivalency Test	64

Table 4.3. Specific Gravities of Aggregate.

Specific Gravity	Coarse (43%)	Fine (57%)	Combined
Bulk	2.607	2.582	2.593

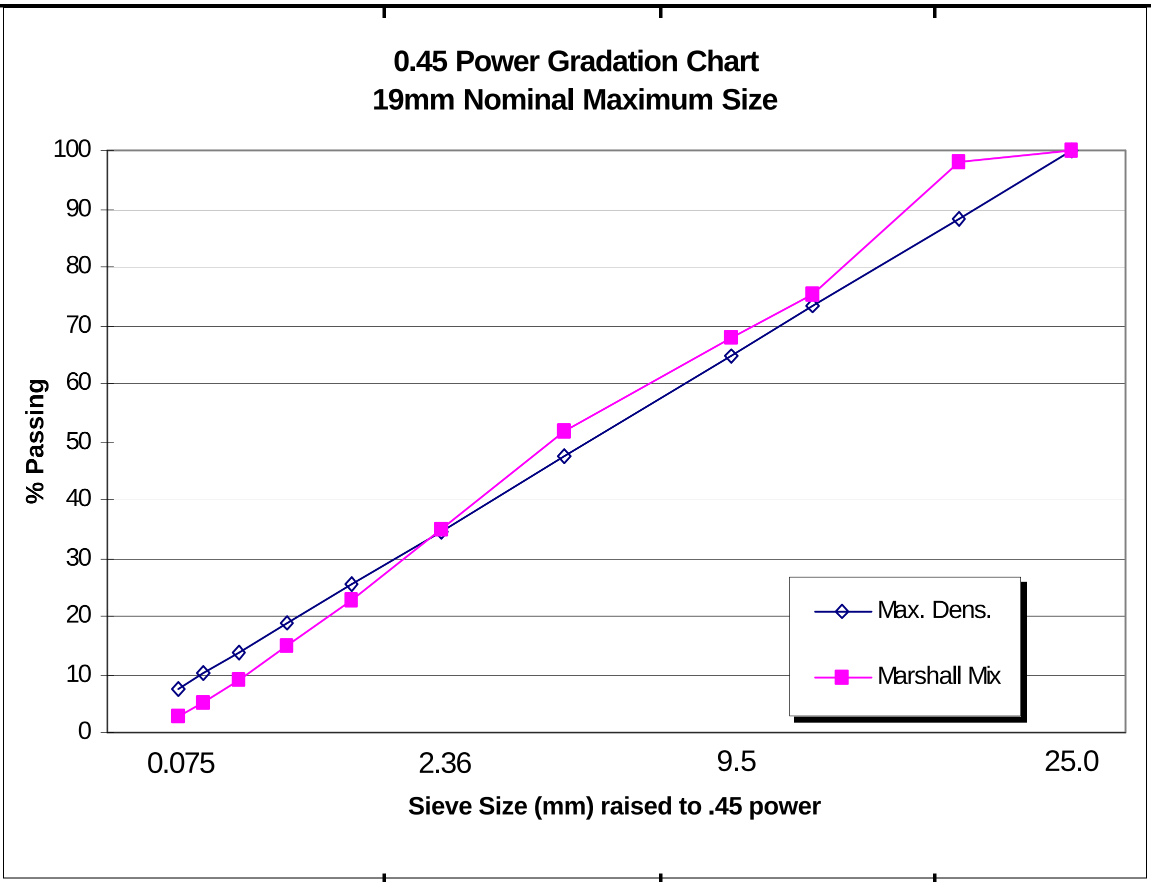

Figure 4.1. 0.45 Power Gradation Chart for Marshall Mix Design.

Apparent	2.663	2.659	2.661
Absolute	0.810	1.112	2.647

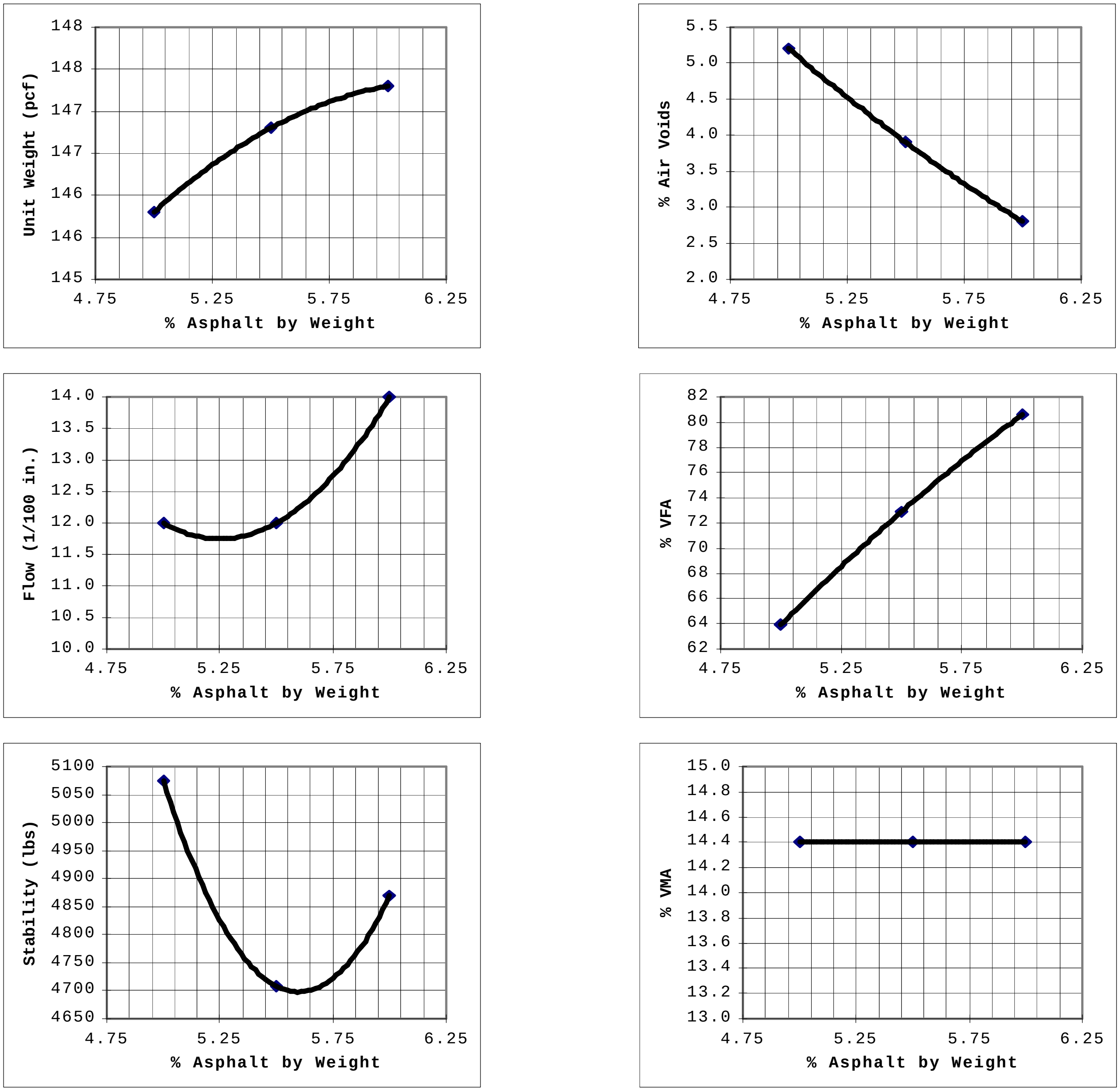

Figure 4.2. Marshall Mix Design Plots.

Superpave

The aggregate and asphalt cement used for the Superpave level one mix design were the same materials used in the Marshall mix design, but in this case, the Superpave mix design used several different trial blends of the coarse and fine aggregates. The trial blends are shown in Table 4.4. The trial blends were chosen to cover a wide range of aggregate gradations. The fifth aggregate combination was chosen the same as the Marshall mix design aggregate combination in an effort to determine if this combination would be acceptable based on Superpave criteria. The combined sieve analysis for all five blends are shown in Table 4.5.

A 0.45 power gradation chart containing each trial blend is displayed Figure 4.3, which includes the Superpave mix design criteria. The criteria were determined based on a 19 mm (0.75 in.) nominal aggregate size. Note that trial blends number four and number five crossed into the "restricted zone" of the 0.45 power gradation chart. This implies that the two gradations contained too much fine sand and may cause the asphalt mix to not compact properly, making them insufficient. For this reason, the last two blends were not tested further.

According to the Superpave mix design method, several tests may be performed on the aggregate to determine its consensus and source properties, which help determine if the aggregate is suitable for use in an asphalt pavement. In this study, only the consensus properties were determined. Table 4.6 shows the Superpave criteria and consensus properties, which included coarse and fine aggregate angularity, sand equivalent of fine aggregate, and thin elongated particles. The criteria was based on a design load for the Cheyenne marginal project of 10 million ESALs.

Table 4.4. Aggregate Blending for Trial Blends.

Trial Blend Number	Percentage of Total Aggregate Mix	
	Coarse	Fine
1	45	55
2	50	50
3	55	45
4	20	80
5	43	57

Table 4.5. Combined Sieve Analysis for Superpave Trial Blends.

Sieve Size	Blend #1	Blend #2	Blend #3	Blend #4	Blend #5
37.5 mm (1 1/2 in.)	100.0	100.0	100.0	100.0	100.0
25.0 mm (1 in.)	100.0	100.0	100.0	100.0	100.0
19.0 mm (3/4 in.)	97.8	97.5	97.3	99.0	97.9
12.5 mm (1/2 in.)	74.4	71.5	68.7	88.6	75.5
12.5 mm (3/8 in.)	66.4	62.7	59.0	85.1	67.9
4.75 mm (#4)	49.9	45.5	41.1	72.0	51.7
2.36 mm (#8)	33.5	30.6	27.6	48.4	34.7
1.18 mm (#16)	22.1	20.2	18.2	31.9	22.9
600 mm (#30)	14.5	13.2	11.9	20.8	15.0
300 mm (#50)	8.7	8.0	7.2	12.5	9.0
150 mm (#100)	4.8	4.4	4.0	4.3	5.0
75.0 mm (#200)	2.5	2.3	2.1	3.6	2.6

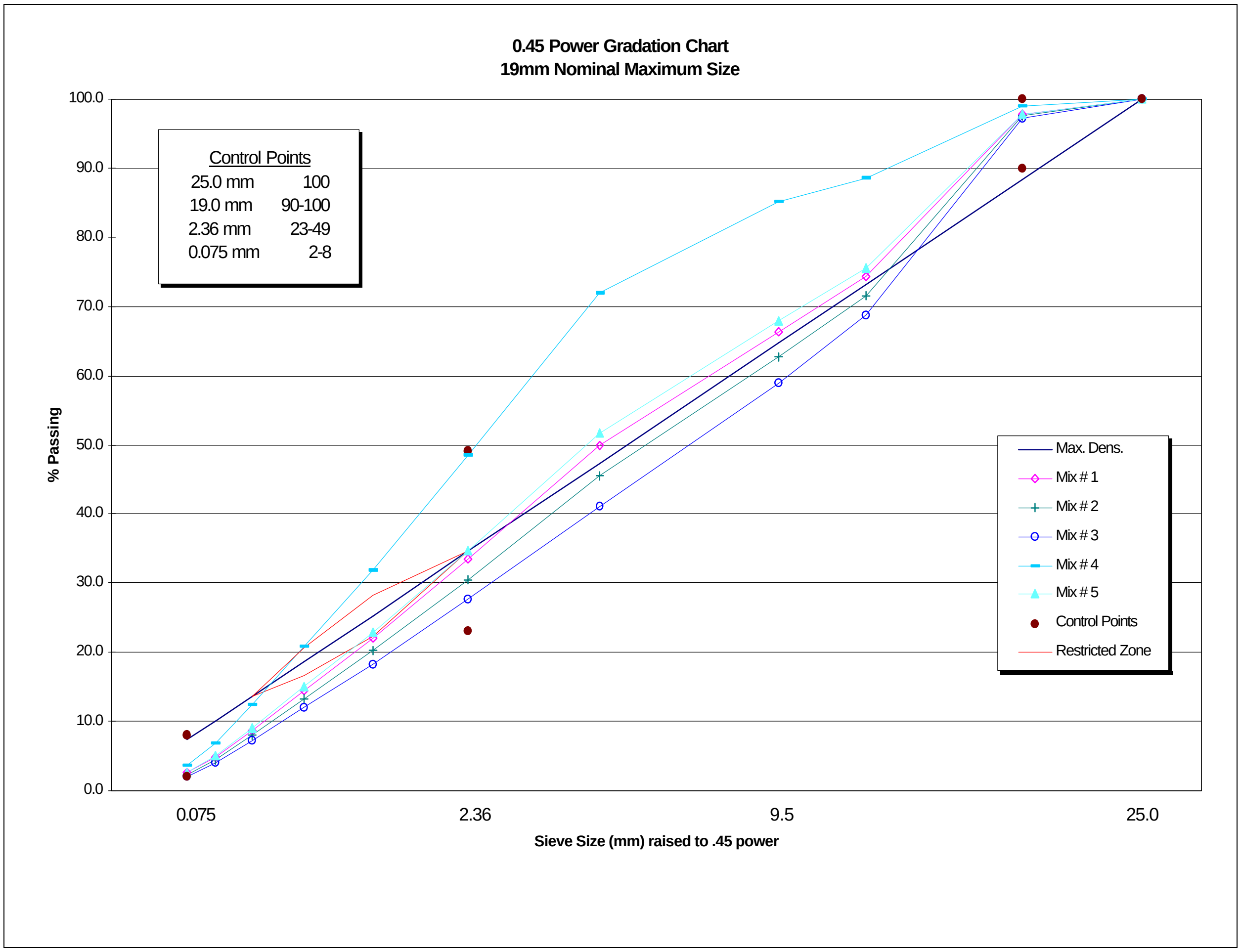

Figure 4.3. 0.45 Power Gradation Chart for Superpave Trial Aggregate Blends.

Table 4.6. Consensus Aggregate Properties and Superpave Criteria [1].

Property	Aggregate	Criteria
Coarse Aggregate Angularity	100/100	85/80
Fine Aggregate Angularity	50.3	45
Sand Equivalent of Fine Aggregate	64	45
Thin Elongated Particles	0	10

WYDOT tested the Frontier AC-20 asphalt cement used in this study to determine its performance grade based on the criteria set by Superpave and analyzed two different asphalt cement samples. The tests used to determined the asphalt cement grade were, dynamic shear rheometer (DSR), rotational viscometer (RV), bending beam rheometer (BBR), and direct tension tester (DTT). Results from the tests are shown in Appendix A. WYDOT determined the grade of the asphalt cement to be PG 58-22. This grade provides an actual reliability against failure of 99.9 percent at the high temperature and 94.8 percent at the low temperature in Cheyenne Wyoming [1].

At UW, trial blends one, two, and three were evaluated by compacting two asphalt samples and using volumetric properties to analyze them. The initial trial asphalt content was determined to be 4.7 percent for each of the three blends. The gyratory compaction effort was $N_{initial} = 8$, $N_{design} = 96$, $N_{maximum} = 152$ gyrations, based on the design specification of 10 million ESALs. The maximum specific gravity of the asphalt mixes (G_{mm}), determined using AASHTO T 209, with the average percent of G_{mm} of each trial blend at N_{ini}, N_{des}, and N_{max}, are shown in Table 4.7. The estimated volumetric properties of the samples and the criteria used to select the appropriate aggregate blend are listed in Table 4.8. These criteria also were determined based on the 10 million design ESALs.

In the end, the only mix to pass all of the Superpave level one criteria was trial blend number one, which was selected as the best possible aggregate blend. Trial blend number two and three failed to meet the Superpave criteria for dust proportion.

Table 4.7. G_{mm} and Percent G_{mm} for Compacted Trial Blends at N_{ini}, N_{des}, and N_{max}.

Blend #	**Max. Specific Gravity (G_{mm})**	**% Of Maximum Density or Specific Gravity**		
		N_{ini} 8 Gyrations	**N_{des} 96 Gyrations**	**N_{max} 152 Gyrations**
1	2.431	86.7	94.5	95.6
2	2.452	86.3	94.2	95.4
3	2.453	86.0	94.2	95.5

Table 4.8. Estimated 4.0 Percent Air Voids Properties @ N_{des} [1].

Property	**Blend #**			**Criteria**
	1	**2**	**3**	
% Air Voids of Sample	4.0	4.0	4.0	4.0
Estimated AC Content	5.3	5.4	5.4	-
Estimated % VMA	15.3	14.9	14.8	13.0% Min
Estimated % VFA	73.9	73.1	73.0	65% - 75%
Estimated % G_{mm} @ N_{ini}	88.2	88.0	87.7	89% Max
Estimated % G_{mm} @ N_{max}	97.2	97.2	97.2	98% Max
Dust Proportion	0.6	**0.5**	**0.4**	0.6 - 1.2

The estimated volumetric properties found in Table 4.8 for the asphalt mix containing aggregate blend number one at 4.0 percent air voids was used to estimate the optimum asphalt cement content, determined to be 5.3 percent. To determine the actual optimum asphalt cement content, two samples were made at the estimated optimum asphalt cement content and at 4.8 percent, 5.8 percent, and 6.3 percent, asphalt cement contents. For the samples, the G_{mm} and the average percent of G_{mm} at N_{ini}, N_{des}, and N_{max} are shown in Table 4.9. The volumetric properties of the compacted specimens used to determine the optimum asphalt content are shown in Table 4.10. Plots showing the properties versus percent asphalt cement content, at an N_{des} of 96 gyrations, are shown in Figure 4.4. Based on the volumetric analysis, the optimum asphalt cement content was established at 4.0 percent air voids and was determined to be 5.55 percent. The other volumetric properties were checked to determine if the Superpave criteria were met. The estimated properties of the asphalt mix at 5.55 percent asphalt cement content and the criteria are shown Table 4.11. As before, the criteria were based on a design of 10 million ESALs. The optimum asphalt cement content of 5.55 percent passed all of the criteria in the Superpave manual except dust proportion, which was slightly lower than that specified in the criteria.

Table 4.9. G_{mm} and Percent G_{mm} for Trial Mixes of Blend #1 at N_{ini}, N_{des}, and N_{max}.

Percent AC	Max. Specific Gravity G_{mm}	Percent G_{mm}		
		N_{ini} 8 Gyrations	N_{des} 96 Gyrations	N_{max} 152 Gyrations
4.8	2.451	85.5	93.7	94.9
5.3	2.425	87.2	95.5	96.9
5.8	2.409	87.0	96.6	97.7
6.3	2.387	88.9	98.2	99.5

Table 4.10. Volumetric Properties at N_{des} for Blend #1 Samples.

Property	Percent AC Content			
	4.8	5.3	5.8	6.3
% Air Voids	6.3	4.5	3.2	1.8
% VMA	15.7	14.4	15.3	15.3
% VFA	59.7	71.0	78.9	88.2

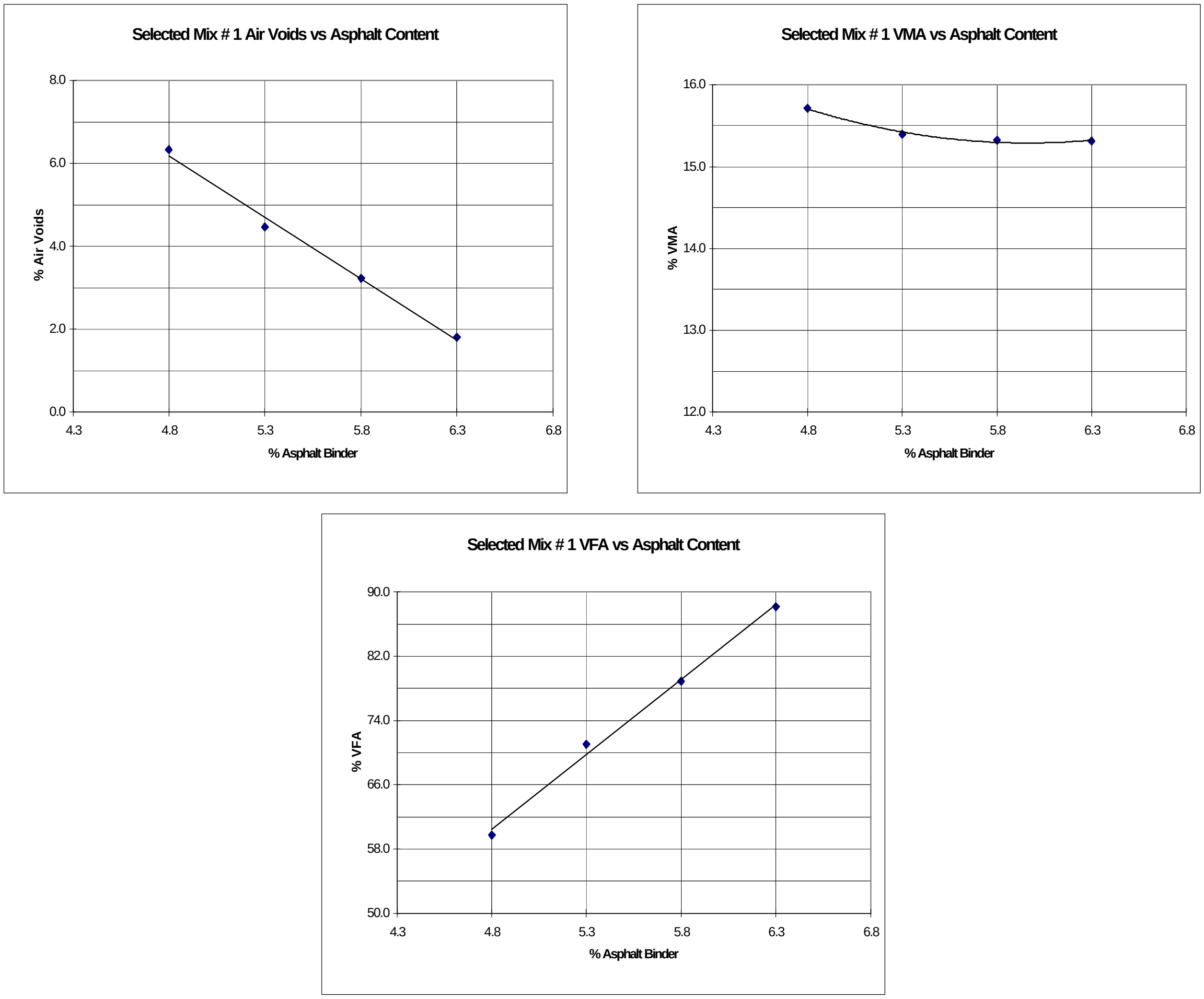

Figure 4.4. Volumetric Properties Versus Asphalt Cement Content for Level One Mix Design.

Table 4.11. Estimated Properties at 5.55 Percent Asphalt Cement Content and Superpave Criteria [1].

Property	5.5 % AC Content	Criteria
% Air Voids @ N_{des}	4.0	4.0 %
% VMA @ N_{des}	15.3	13.0% Min.
% VFA @ N_{des}	73.9	65% - 75%
% Gmm @ $_{Nini}$	87.6	89% Max
% Gmm @ N_{max}	97.3	98% Max
Dust Proportion	0.52	0.6 - 1.2

CHAPTER 5

ACCELERATED PERFORMANCE TESTING

The Georgia Loaded Wheel Test (GLWT) and the Thermal Restrained Specimen Tester (TSRST) were used to determine the temperature susceptibility of the asphalt mixtures constructed using the Marshall and Superpave level one mix designs. The GLWT tested the high-temperature susceptibility. The TSRST tested the low-temperature susceptibility of the asphalt mixes. The following sections describe the results of the tests.

Georgia Loaded Wheel Test

Two samples based on the Marshall mix design and two samples based on the Superpave mix design were prepared and tested in the GLWT. The samples were compacted to densities similar to those found in the field using the gyratory compactor, then tested at 46.1^{o}c (115^{o}F) for a total of 8,000 cycles with a pressure in the rubber hose of 0.69 MPa (100 psi). Rut depth measurements were taken at 2,000, 4,000, and 8,000 cycles in each case. Tables 5.1 and 5.2 show the rut depths that were achieved during testing of the Marshall and Superpave samples.

The maximum acceptable rut depth in the GLWT is 7.62 mm (0.30 in.) after 8,000 cycles. In this case, both the Superpave and the Marshall samples showed excellent rut resistance. The Superpave showed slightly more rut depth than the Marshall samples due to the slight increase in asphalt content.

Table 5.1. GLWT Results for Marshall Samples.

Number of cycles	Rut Depth (mm)		
	Sample #1	Sample #2	Average
1,000	0.46	0.71	0.58
4,000	0.51	0.81	0.66
8,000	0.66	0.86	0.76

Table 5.2. GLWT Results for Superpave Samples.

Number of cycles	Rut Depth (mm)		
	Sample #1	Sample #2	Average
1,000	1.27	1.04	1.16
4,000	1.50	1.57	1.54
8,000	1.68	1.96	1.82

Thermal Stress Restrained Specimen Test

Two samples from each of the two mix designs also were prepared for the TSRST. The samples were cored to a 50.8 mm (2 in.) diameter and were trimmed to 229 mm (9 in.) long. During the TSRST testing process, a computer recorded the temperature and pressure in two-minute intervals until the samples fractured.

Tables 5.3 and 5.4 show the TSRST results, which include the fracture temperatures, pressures, and time it took for the Marshall and Superpave samples to fail. The tables also contain the slope of the linear portion of the stress versus temperature curve. Actual test results are shown in Appendix B. It is clear from Table 5.3 and 5.4 that the Superpave samples will offer slightly better resistance to low temperature cracking.

Table 5.3. TSRST Results for Marshall Samples.

Result	Sample #1	Sample #2	Average
Fracture Temperature (^{o}C)	-28.3	-26.9	-27.6
Fracture Pressure (ka)	1722.0	1875.0	1799.0
Time To Fracture (min.)	204.0	190.0	197.0
Slope ds/DT	95.9	105.6	100.8

Table 5.4. TSRST Results for Superpave Samples.

Result	Sample #1	Sample #2	Average
Fracture Temperature (°C)	-28.6	-29.5	-29.1
Fracture Pressure (kPa)	1893.0	1919.0	1906.0
Time To Fracture (min.)	196.0	216.0	206.0
Slope δS/δT	130.0	120.6	125.3

Chapter Summary

In this chapter, accelerated testing was performed on the Marshall and Superpave samples. Because both mix designs procedures resulted in similar mixes, the results from the accelerated testing were close. WYDOT has performed the Marshall and Superpave design procedures on other sources of aggregates. As shown in Figure 5.1, for some aggregate sources the two mix design procedures resulted in identical optimum asphalt contents, while for others the resulting asphalt contents were significantly different. Future studies will concentrate on the aggregate sources with different optimum asphalt contents.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

In this study, samples made using the Marshall mix design method and the Superpave mix design method were compared using accelerated testing. The following conclusions and recommendations are based on the data analysis of the results this study produced.

Conclusions

The aggregate gradation used for the Superpave mix design was close to the gradation used for the Marshall mix design, but the 0.45 power gradation plot of the aggregate used for the Marshall mix design crossed into the restricted zone established by Superpave. This made the aggregate gradation used in the Marshall mix design unacceptable for use in the Superpave mix design. However, the performance of the Marshall samples did not appear to be significantly affected by the gradation.

The asphalt cement used in the Marshall mix design was determined to be an acceptable grade for use in the Superpave mix design, with a high reliability of not failing. Based on this, currently used AC-20 asphalt cements may be acceptable for use with the Superpave mix design on projects in the same region.

The optimum asphalt cement content determined by the Marshall and the Superpave mix designs were similar. This shows that in some cases Marshall and Superpave produce nearly identical mix designs when the same materials are used and the aggregate gradations are similar in both designs.

The Superpave samples tested in the GLWT rutted slightly more than the Marshall samples, though both mix designs produced samples that did not come close to failure at a rut depth of more than 7.62 mm (0.30 in.) after 8,000 cycles.

The Superpave samples tested in the TSRST fractured at a slightly higher pressure and lower temperature than the Marshall samples.

WYDOT mix design testing on other sours of aggregate indicates that Superpave and Marshall will result in similar optimum asphalt contents in some cases and significantly different asphalt contents in other cases. It is recommended that additional testing be performed on other aggregate sources to determine if Superpave will produce mixes with better performance.

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