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Superpave Mix Designs for Arkansas

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16. Abstract

Superpave, an asphalt concrete mixture design procedure developed under the Strategic Highway Research Program (SHRP), is to be implemented state-wide in Arkansas in 1998. The Arkansas State Highway and Transportation Department (AHTD) sponsored TRC-9604, *Superpave Mix Designs for Arkansas*, to investigate potential impacts of Superpave implementation on current mix design practice. Aggregates currently used in Arkansas for hot-mix asphalt concrete (HMAC) appear to be acceptable for use in Superpave. It is recommended that AHTD retain (and slightly refine) existing specifications for aggregate source properties, and adopt Superpave specifications for aggregate consensus properties. Recommended adoption of Superpave gradation specifications may result in significant reductions in the use of sand-sized aggregates in HMAC, particularly natural (rounded) sands. HMAC volumetric analysis in Superpave is similar to current AHTD methods, with two notable differences -- the method for calculating voids in the mineral aggregate (VMA), and the definition of the dust proportion ("fines to asphalt ratio"). It is recommended that AHTD adopt Superpave specifications in both instances. It is also recommended that AHTD refine its method for estimating the moisture sensitivity of an HMAC mixture (where it currently uses the Marshall stability test) to reflect current Superpave methodology -- the use of the split-tensile strength to determine the effect of moisture on the mix. Overall, the transition from traditional Marshall based mix design to Superpave is certainly feasible, and can be accomplished using current Arkansas aggregates.

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FINAL REPORT

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Superpave Mix Designs for Arkansas

by

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conducted by

Department of Civil Engineering
University of Arkansas

in cooperation with

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This report is based on the findings of Project TRC-9604, Superpave Mix Designs for Arkansas.

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

SI CONVERSION FACTORS

1 inch = 25.4 mm

1 foot = 0.305 m

1 lb/ft^3 = 16 kg/m^2

1 psi = 6.9 kN/m^2

1 lb = 4.45 N

EXECUTIVE SUMMARY

Superpave (***Su***perior ***Per***forming Asphalt ***Pave***ments) is an asphalt-aggregate mixture design procedure developed through the Strategic Highway Research Program (SHRP), conducted from 1988 through 1993. The Arkansas State Highway and Transportation Department (AHTD) is currently implementing the Superpave design procedure into routine practice. AHTD sponsored research project TRC-9604 to investigate potential impacts of Superpave implementation on the asphalt and aggregate industries in Arkansas.

Aggregates currently used in Arkansas for hot-mix asphalt concrete (HMAC) were sampled and tested for compliance with Superpave aggregate criteria. It is recommended that AHTD retain existing specifications with minor refinements for aggregate "source" properties (toughness, soundness, deleterious materials), and adopt Superpave test methods and criteria for aggregate "consensus" properties (coarse aggregate angularity, fine aggregate angularity, clay content, flat & elongated particles). It is further recommended that HMAC aggregate gradation curves pass below the Superpave "restricted zone"; this recommendation represents a significant change to current Arkansas specifications and practices. The use of sand-sized particles, in particular relatively fine sands, will decrease as mixes become increasingly coarse.

Superpave mixture volumetric analysis will not represent a major change from current AHTD practices. However, Superpave methods for determining the Voids in Mineral Aggregate (VMA) for a mix should be adopted by AHTD. Superpave uses the bulk specific gravity of the aggregate (G_{sb}) in VMA calculations, while current AHTD methods use the effective specific gravity (G_{se}) of the aggregate. This recommended change could result in differences in calculated VMA of about one to one-and-a-half percent, depending on the absorption capacity of the aggregate used. It is observed that mixtures containing a combination of crushed stone and crushed gravel tend to be more successful in meeting Superpave criteria than mixtures containing either aggregate type exclusively. In addition, AHTD should adopt Superpave specifications for determining the dust proportion ('fines to asphalt ratio') and for estimating the moisture sensitivity of a mix.

Based on the results obtained, it appears that current Arkansas aggregate sources can be used successfully to create Superpave mixes, and that Superpave implementation in 1998 is fully feasible.

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INTRODUCTION

1.1 Statement of the Problem

Arkansas has traditionally used the Marshall method for designing hot-mix asphalt concrete (HMAC) mixtures. However, a new method of mix design has been developed under the Strategic Highway Research Program (SHRP). This new method is called Superpave, which stands for **Su**perior **Per**forming Asphalt **Pave**ments. ***(1)*** Superpave is a performance-based design procedure, meaning that emphasis is placed on fundamental mixture properties rather than empirical laboratory relationships to predict how a pavement will perform in the field. Superpave test methods also include a binder specification, which is based on two fundamental properties, temperature and loading. ***(1)*** Therefore, a mix can be "tailor-made" for a particular project, in terms of expected traffic and climate.

Many of the procedures and criteria contained in Superpave volumetric design are very similar to the Marshall design method. However, Superpave has a more extensive procedure for aggregate selection, and includes aggregate properties as an integral part of the mix design process. Superpave also goes beyond volumetric design by including procedures and criteria for performance tests, which predict a pavement's response to factors causing major distresses such as permanent deformation (rutting), fatigue cracking, and low temperature cracking. ***(2)***

Superpave is important to Arkansas because many of its major roadways, including the interstate system, were built in the 1950's and 1960's and are in desperate need of repair.

(3) Though many of the pavements have been serviceable throughout their design lives, the typical 20 year design lives of these pavements have long since expired and billions of dollars are needed for repairs. Superpave will aid in predicting pavement performance so that even more reliable and long lasting pavements can be placed in the field. This will create a higher benefit - to - cost ratio, enabling tax dollars to be spent more wisely.

Superpave is to be implemented in Arkansas during the 1998 calendar year. ***(4)*** Changes in mix design could cause impacts to be felt by agencies, contractors, construction companies, (HMAC) producers, and aggregate producers. The Arkansas State Highway and Transportation Department (AHTD) sponsored research project TRC-9604, "Superpave Mix Designs for Arkansas", to investigate potential impacts to the paving industry arising from Superpave implementation. TRC-9604 was conducted by the Department of Civil Engineering at the University of Arkansas, Fayetteville. This report documents the findings from TRC-9604. A discussion of the Superpave mix design method as well as the results of the research done in order to determine the effects of Superpave implementation in Arkansas are included.

1.2 Project Objectives

The overall objective of the study is to facilitate the transition from the Marshall method of mix design to the Superpave design procedure. Specifically, the project sought to identify potential changes to traditional practice regarding such areas as aggregate selection and properties, laboratory procedures, and HMAC properties. Included in the consideration of the impacts of Superpave implementation were secondary issues such as laboratory facility and equipment needs, and personnel training requirements.

1.3 Background Information

The goal of any mix design is to produce a cost-effective blend of asphalt cement and aggregate which will provide a durable pavement with enough stability to withstand the demands of traffic loads. The pavement should contain enough air voids to allow for additional compaction under traffic loads and thermal expansion of the asphalt, but not so much as to make the pavement permeable to air and moisture, which could harm the pavement. Finally, the pavement should be workable for proper field placement, have a surface texture to prevent skidding, and be resistant to cracking at low temperatures. A balance of these properties will produce the best possible asphalt pavement. ***(5, 6)***

1.3.1 The Marshall Method

The Marshall and Hveem methods of asphalt mix design have probably been the most predominant methods used in the United States prior to Superpave. ***(5)*** The Marshall method, which is currently used in Arkansas, was created in 1939 by Bruce Marshall, a former Bituminous Engineer with the Mississippi State Highway Department. In the 1940's, the Army Corps of Engineers refined the method and it was then standardized by the American Society for Testing and Materials (ASTM) for laboratory design and field control of hot-mix asphalt. ***(5, 7)***

The two principal features of the Marshall method are a density-voids analysis and a stability-flow test of compacted specimens. The Marshall method employs impact compaction of laboratory test specimens by a free-fall "Marshall Hammer" from eighteen inches above the specimen with 35, 50, or 75 blows to each face, depending on the expected traffic levels for the mix. The cylindrical test specimens are four inches in diameter and approximately 2.5 inches in height. ***(5, 6)***

The mix design process begins with acceptance tests of aggregate and viscosity testing of the asphalt cement to be used in the mix. The viscosity of the asphalt cement is tested between 140° F and 275° F to determine proper mixing and compacting temperatures. ***(5)*** A temperature which corresponds with a viscosity of 0.17 ± 0.02 Pa•s is used as the mixing temperature, and a temperature which corresponds with a viscosity of 0.28 ± 0.03 Pa•s is the compaction temperature. Next, aggregates which are acceptable according to the standard tests for toughness, soundness, and deleterious materials are then tested for gradation, specific gravity, and absorption. ***(5, 8)*** Because aggregate interparticle contact provides nearly all of the shear strength in the mix, particle shape and size are important. Rounded particles, often found in natural sand, do not provide as much interlock as do angular fractured face particles. ***(9)*** Based on experience, most agencies agree that natural sand should be limited to approximately 15% of a blend. ***(7, 8)*** Next, a suitable combination of aggregates is determined and plotted according to the gradation chart. A suitable blend is one which falls within the specification band on the gradation chart, and provides sufficient void space in the mix for asphalt cement and air. Aggregate size is chosen based on whether the mix is a surface, binder, or base course. Surface mixtures use smaller aggregates than do binder or base courses. Various agencies have developed specification bands for their own use. A typical Arkansas gradation chart and specification band is given in Figure 1. ***(7)***

Next, the specimens are batched, mixed, and compacted. In a typical Marshall mix design, three specimens each are compacted at six different asphalt cement (AC) contents for a total of 18 specimens. Each specimen contains approximately 1180 grams of material. In addition, an uncompacted sample is prepared for determination of the theoretical maximum

Figure 1. Gradation Chart with Specification Band

density at each AC content. After the specimens are compacted with the Marshall Hammer and allowed to cool, the height of each specimen is determined, and bulk specific gravity tests are performed. Then, a Marshall stability/flow test is performed on each specimen. Upon completion of these tests, calculations determine the unit weight for each asphalt content, the percent of absorbed asphalt, air voids, percent voids in the mineral aggregate (VMA), and the voids filled with asphalt (VFA). When these values are calculated, then six graphs are prepared and studied. ***(5, 6, 7)*** They are:

- Stability vs. % AC
- Flow vs. % AC
- Unit Weight vs. % AC
- % Air Voids vs. % AC
- VFA vs. % AC
- VMA vs. % AC

Noted trends in these graphs are:

1. As AC content increases, stability increases to a maximum, then decreases.
2. Flow increases as AC increases.
3. Unit weight vs. %AC follows a trend like that of stability, but the peak typically occurs at a higher AC content.
4. As AC content increases, air voids decrease to a minimum.
5. VMA decreases to a minimum, then increases as AC content increases.
6. VFA increases as AC content increases.

These trends are shown in Figure 2.

Limits are set by the Marshall method for each level of compactive effort for determining an acceptable mix design. The optimum level of air voids is three to five percent, and is typically accepted as four percent. It should be noted that four percent is the level desired after several years of traffic. Mixes that consolidate to less than three percent can be

Figure 2. Trends in Marshall Mixture Design

expected to rut and shove after time. The AC content at 4 percent air voids may or may not be the chosen mix design unless all other criteria are met. There are two methods for choosing an optimum AC content. First the AC percent at 4 percent air voids is recorded and all other criteria are checked for that particular AC content. The other way is to chose an acceptable AC content from each of the criteria. ***(5)*** The average of these values is then verified as acceptable and then used for the mix design. VMA is the most difficult property to meet. The curve is usually a flat U-shape, such that the flatter the curve, the less sensitive the mix to AC content. VMA and air voids are very susceptible to compactive effort. ***(5, 6, 7)*** If the anticipated traffic on a site is greater than the correlating compactive effort in the laboratory, then the result may be a pavement that ruts. It is evident that the critical piece of the design is to adequately simulate field compaction in the laboratory. The Asphalt Institute recommends criteria based on mixture type. ***(7)*** If all of the criteria are met and the field conditions have been properly modeled, then the mix design is acceptable and may be used in the field.

Advantages of the Marshall method are that its equipment is relatively inexpensive and portable, making it applicable for quality control operations in the field. The disadvantages of the method are that the impact compaction method may not truly simulate compaction as it occurs in the field. Additionally, it is felt that the Marshall stability test does not adequately measure the shear strength of a pavement, making it very difficult to estimate a particular pavement's resistance to distress. ***(5, 10)*** A growing dissatisfaction with the Marshall method led to the development of the Superpave mixture design procedure.

1.3.2 Superpave

In the spring of 1987, the United States Congress passed legislation to provide five years of funding for the Strategic Highway Research Program (SHRP), which represents the single largest highway research effort in history. The primary focus of the research was asphalt pavement design in order to improve durability and performance of roadways in the U. S. ***(1, 10)*** One third of the $150 million research funding was used to create a performance based asphalt design specification to relate laboratory analysis directly to field performance. In 1991, the term Superpave was created to refer to the performance based specifications, test methods, equipment, testing protocols, and a mix design system. Superpave includes a binder specification in which binder grade is determined by various measures of binder stiffness at specific combinations of load duration and temperature. The binder grade refers to the temperature range at which these stiffness requirements are met. The binder grade should be chosen according to the design air temperatures in the particular geographic area, but a higher grade may be selected if the traffic conditions are to be extreme. Design pavement temperatures for various geographic areas have been determined based on the highest seven day average temperature and the lowest pavement temperature in a year. ***(1, 10)*** The grades of asphalt are termed accordingly. For example, an asphalt binder PG 64-16 is "performance graded" and would meet the specification for a design high pavement temperature of 64 degrees C and a design low temperature warmer than -16 degrees C.

The Marshall method was based on empirical relationships and not fundamental properties. ***(2, 5)*** Superpave measures fundamental properties such as stiffness modulus, fatigue resistance, and resistance to permanent deformation, and has developed a laboratory compaction method that better simulates compaction under rollers in the field. Therefore, potential pavement failures may be predicted and prevented before the pavements are constructed.

The goals of Superpave are accomplished through a three stage testing process in which the design is governed by *performance-based* properties that directly impact the response of the asphalt pavement under load. Other criteria are *performance-related*, which are properties that are indirectly related to pavement performance. The three levels of mix design represent the varying degrees to which a pavement is tested. A pavement designed for low volumes of traffic would only be tested at the first level, but a pavement that is designed for extremely high volumes of traffic would be worth the time and expense of testing at the second or third level. Table 1 lists the level of testing required for the various traffic conditions based on Equivalent Single Axle Loads (ESALs). ***(1)***

Superpave Design Level	Traffic, ESALs[1]	Testing Requirements[2]
1	ESALs < 10^6	Materials selection and volumetric proportioning
2	10^6 < ESALs < 10^7	Level 1 + performance prediction tests
3	ESALs > 10^7	Level 1 + enhanced performance prediction tests

[1]Default traffic ranges in Superpave. Can be adjusted as an agency option.
[2]In all cases, moisture susceptibility is evaluated using AASHTO T 283.

Table 1. Superpave Mix Design Levels

The first level of Superpave mix design is the volumetric design and is based on empirical performance related parameters of the aggregate (gradation, angularity, and clay content) and of the mix (air voids, VMA, and VFA). ***(1)*** This level is very much like the Marshall method of design, differing primarily in the use of the Superpave Gyratory Compactor.

Superpave requires that aggregates used in mixes meet certain criteria. The acceptance criteria is an integral part of the design process. Aggregates have both source and consensus properties. ***(1, 2, 10, 11)*** Source properties of aggregates are toughness, soundness, and deleterious materials. Toughness is an aggregate's resistance to fracture from impact, soundness is an aggregate's resistance to breakdown due to weathering action, and deleterious materials are considered contaminants in the aggregate that could prevent a strong bond between the binder and aggregate. ***(9)*** Source properties are site specific and vary based on the geographic conditions of the area. Each agency, therefore, must determine its own criteria which area aggregates must meet.

Consensus properties are those aggregate properties which experts believe are critical to hot mix asphalt performance. These properties are coarse aggregate angularity, fine aggregate angularity, flat and elongated particles, and clay content. ***(1)*** Coarse aggregate angularity is measured as the percentage of particles larger than 4.75 mm with one or more fractured faces, and fine aggregate angularity is measured as the percent air voids contained in loosely compacted fine aggregates (smaller than 2.36 mm). Flat and elongated particles are defined as those which have a maximum to minimum dimension ratio greater than five, making the particles more likely to fracture during compaction. Clay content is the percentage of clay material contained in the portion of aggregate smaller than 4.75 mm. A high clay content may allow a clay film to form on the aggregate surface, preventing strong adhesion to the binder. Required values for these properties vary according to expected traffic levels. Source and consensus properties along with the appropriate test methods are listed in Tables 2 and 3. ***(1, 12, 13)*** Superpave criteria for consensus properties are given in Tables 4 through 7. ***(1, 10)***

Source Property	ASTM Specification	AASHTO Specification
Toughness	ASTM C131 or C535	AASHTO T 96
Soundness	ASTM C88	AASHTO T 104
Deleterious Materials	ASTM C142	AASHTO T 112

Table 2. Aggregate Source Properties

Consensus Property	Superpave Specification
Coarse Aggregate Angularity	Penn DOT Test Method #621 "Determining the Percentage of Crushed Fragments in Gravel"
Fine Aggregate Angularity	AASHTO TP - 33 "Test Method for Uncompacted Void Content of Fine Aggregate (Method A)"
Flat and Elongated Particles	ASTM D 4791 "Flat of Elongated Particles in Coarse Aggregate"
Clay Content	AASHTO T 176 "Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test"

Table 3. Aggregate Consensus Properties

Traffic, million ESALs	Depth from Surface < 100 mm	Depth from Surface > 100 mm
< 0.3	55/-	-/-
< 1	65/-	-/-
< 3	75/-	50/-
< 10	85/80	60/-
< 30	95/90	80/75
< 100	100/100	95/90
≥ 100	100/100	100/100

Note: "85/80 denotes that 85% of the coarse aggregate has one or more fractured faces and 80% has two or more fractured faces.

Table 4. Superpave Coarse Aggregate Angularity Criteria

Traffic, million ESALs	Depth from Surface	
	< 100 mm	> 100 mm
< 0.3	-	-
< 1	40	-
< 3	40	40
< 10	45	40
< 30	45	40
< 100	45	45
≥ 100	45	45

Table 5. Superpave Fine Aggregate Angularity Criteria

Traffic, million ESALs	Maximum, Percent
< 0.3	-
< 1	-
< 3	10
< 10	10
< 30	10
< 100	10
≥ 100	10

Table 6. Superpave Flat and Elongated Particles Criteria

Traffic, million ESALs	Sand Equivalent Minimum, Percent
< 0.3	40
< 1	40
< 3	40
< 10	45
< 30	45
< 100	50
≥ 100	50

Table 7. Superpave Clay Content Criteria

The Superpave gradation criteria is a major departure from traditional AHTD and Marshall-type specifications. The "0.45 Power Chart" for aggregate gradation that has been used for years remains in Superpave. Arkansas has traditionally used a specification band within which blend gradations must fall. ***(8)*** In contrast, Superpave gradation specifications include the maximum density line, control points, and a restricted zone. The maximum density line is a straight line drawn between the maximum aggregate size and the origin, representing the densest possible aggregate gradation. The control points are located at the #200 (75 micron) sieve, the #8 (2.36 mm) sieve, and at the nominal maximum sieve size. The nominal maximum aggregate size is one sieve size larger than the first sieve which retains more than ten percent; the maximum aggregate size is one sieve size larger than the nominal maximum sieve size. Superpave gradation sizes are designated by the nominal maximum aggregate size. For example, Table 8 shows the gradation requirements for a 37.5 mm nominal size blend. The first sieve retaining more than 10% is the 25.0 mm sieve. Therefore, 37.5 mm is the nominal maximum aggregate size, and 50.0 mm is the maximum aggregate size. The gradation curve must pass between the control points, but should not pass through the restricted zone. ***(2, 10)*** The location of the restricted zone and control points are given in Tables 8 through 12 for each of the blend size designations.

Sieve, mm	Control Points		Restricted Zone Boundary Minimum	Restricted Zone Boundary Maximum
50.0	-	100.0	-	-
37.5	90.0	100.0	-	-
25.0	-	-	-	-
19.0	-	-	-	-
12.5	-	-	-	-
9.5	-	-	-	-
4.75	-	-	34.7	34.7
2.36	15.0	41.0	23.3	27.3
1.18	-	-	15.5	21.5
0.600	-	-	11.7	15.7
0.300	-	-	10.0	10.0
0.150	-	-	-	-
0.075	0.0	6.0	-	-

Table 8. Superpave Gradation Requirements for 37.5 mm Nominal Maximum Aggregate Size

Sieve, mm	Control Points		Restricted Zone Boundary Minimum	Restricted Zone Boundary Maximum
37.5	-	100.0	-	-
25.0	90.0	100.0	-	-
19.0	-	-	-	-
12.5	-	-	-	-
9.5	-	-	-	-
4.75	-	-	39.5	39.5
2.36	19.0	45.0	26.8	30.8
1.18	-	-	18.1	24.1
0.600	-	-	13.6	17.6
0.300	-	-	11.4	11.4
0.150	-	-	-	-
0.075	1.0	7.0	-	-

Table 9. Superpave Gradation Requirements for 25.0 mm Nominal Maximum Aggregate Size

Sieve, mm	Control Points		Restricted Zone Boundary Minimum	Maximum
25.0	-	100.0	-	-
19.0	90.0	100.0	-	-
12.5	-	-	-	-
9.5	-	-	-	-
4.75	-	-	-	-
2.36	23.0	49.0	34.6	34.6
1.18	-	-	22.3	28.3
0.600	-	-	16.7	20.7
0.300	-	-	13.7	13.7
0.150	-	-	-	-
0.075	2.0	8.0	-	-

Table 10. Superpave Gradation Requirements for 19.0 mm Nominal Maximum Aggregate Size

Sieve, mm	Control Points		Restricted Zone Boundary Minimum	Maximum
19.0	-	100.0	-	-
12.5	90.0	100.0	-	-
9.5	-	-	-	-
4.75	-	-	-	-
2.36	28.0	58.0	39.1	39.1
1.18	-	-	25.6	31.6
0.600	-	-	19.1	23.1
0.300	-	-	15.5	15.5
0.150	-	-	-	-
0.075	2.0	10.0	-	-

Table 11. Superpave Gradation Requirements for 12.5 mm Nominal Maximum Aggregate Size

Sieve, mm	Control Points		Restricted Zone Boundary Minimum	Maximum
12.5	-	100.0	-	-
9.5	90.0	100.0	-	-
4.75	-	-	-	-
2.36	32.0	67.0	47.2	47.2
1.18	-	-	31.6	37.6
0.600	-	-	23.5	27.5
0.300	-	-	18.7	18.7
0.150	-	-	-	-
0.075	2.0	10.0	-	-

Table 12. Superpave Gradation Requirements for 9.5 mm Nominal Maximum Aggregate Size

The intention of the restricted zone is to prevent a blend from being parallel to the maximum density line in the sand-sized sieves. Blends which pass through the restricted zone often exhibit a humped shape and typically contain too much fine sand in relation to total sand, making them more likely to fail by permanent deformation. An example of such a gradation is given in Figure 3. Gradations which pass through the restricted zone are also thought to be too dense to provide adequate VMA for the binder, causing the mix to be extremely sensitive to binder content. ***(1, 10)*** A Superpave gradation specification is shown in Figure 4 and is compared to a current AHTD gradation specification in Figure 5.

Figure 3. Typical “Humped” Gradation Curve

Figure 4. Superpave Gradation Chart

Figure 5. Superpave vs. AHTD Gradation Specification

After a blend is found which meets the Superpave gradation criteria, the aggregates are batched and mixed much like in the Marshall method. However, after mixing, the specimen is subjected to short-term aging in an oven at 135° C for two hours. The original test method required a four hour aging period, but this requirement has since been reduced to two hours. ***(14)*** The short-term aging is an effort to simulate aging of the material during the construction process. The specimen is then brought up to compaction temperature for approximately thirty minutes before compacting. ***(15)***

The compaction procedure is both an obvious and a profound difference between Superpave and Marshall. The Superpave Gyratory Compactor (SGC) was developed to better simulate field compacting conditions. The 150 mm diameter specimens are compacted while rotating at an angle of 1.25 degrees under 600 kPa of constant vertical pressure. ***(1, 11)*** A typical sample weighs about five kilograms. The height of the specimen is monitored and captured during compaction; and, estimated and corrected bulk specific gravities are calculated. The percent of theoretical maximum density (%G_{mm}) is then plotted against the log of the number of gyrations (log N). Criteria must be met for the %G_{mm} at specific numbers of gyrations, termed N initial (N_{ini}), N design (N_{des}), and N maximum (N_{max}). The N_{des} value is based on the level of traffic volume and the design temperature at the site of the actual project; N_{ini} and N_{max} are then calculated from N_{des}. Criteria for N_{ini}, N_{des}, and N_{max} are given in Table 13. ***(1, 11)***

Design ESALs (millions)	<39° C			39 - 40° C			41 - 42° C			43 - 44° C		
	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}
< 0.3	7	68	104	7	74	114	7	78	121	7	82	127
0.3 - 1	7	76	117	7	83	129	7	88	138	8	93	146
1 - 3	7	86	134	8	95	150	8	100	158	8	105	167
3 - 10	8	96	152	8	106	169	8	113	181	9	119	192
10 - 30	8	109	174	9	121	195	9	128	208	9	135	220
30 - 100	9	126	204	9	139	228	9	146	240	10	153	253
> 100	9	143	233	10	158	262	10	165	270	10	172	288

Average Design High Air Temperature

Table 13. Superpave Design Gyratory Compactive Effort

Two or three specimens are compacted for each blend at an initial estimated AC content. Values for air voids, VMA, VFA, %G_{mm} at N gyrations, and the dust proportion (DP) are then calculated. The dust proportion is a ratio of the percent passing the 75 micron sieve to the effective binder content, where the effective binder content is the quantity of binder which is not absorbed by the mineral aggregate. Criteria for these volumetric properties are given in Tables 14 through 18.

Nominal Maximum Aggregate Size	Air Voids % at N_{des}
37.5 mm	4.0
25.0 mm	4.0
19.0 mm	4.0
12.5 mm	4.0
9.5 mm	4.0

Table 14. Superpave Air Voids Criteria

Nominal Maximum Aggregate Size	Minimum VMA, percent
37.5 mm	11.0
25.0 mm	12.0
19.0 mm	13.0
12.5 mm	14.0
9.5 mm	15.0

Table 15. Superpave VMA Criteria

Traffic, million ESALs	Design VFA, percent
< 0.3	75 -80
< 1	65 - 78
< 3	65 - 78
< 10	65 - 75
< 30	65 - 75
< 100	65 - 75
≥ 100	65 - 75

Table 16. Superpave VFA Criteria

Nominal Maximum Aggregate Size	Dust Proportion, percent	
	Minimum	Maximum
37.5 mm	0.6	1.2
25.0 mm	0.6	1.2
19.0 mm	0.6	1.2
12.5 mm	0.6	1.2
9.5 mm	0.6	1.2

Table 17. Superpave Dust Proportion Criteria

Gyration Number	Required Density
N_{ini}	Maximum of 89% G_{mm}
N_{max}	Maximum of 98% G_{mm}

Table 18. Superpave Densification Criteria

Based on the results of compaction, criteria for these values at the specific aggregate size are studied and blends meeting the criteria may be studied further. This phase of design serves as a screening process and determines the acceptability of a particular aggregate structure of the mix before extensive testing is done. Next, the volumetric properties are used to predict a new AC content which will hopefully produce four percent air voids in the completed mix, as well as other acceptable characteristics. This aggregate structure is then tested using specimens prepared at four asphalt contents -- the new estimated AC content, estimated ± 0.5%, and estimated + 1.0%. The same criteria are checked and any mix which meets all the criteria is considered acceptable and the designer may proceed with other tests as desired.

The final step of the volumetric testing level is to evaluate the mixture's sensitivity to moisture. This step is accomplished by performing the moisture sensitivity test according to AASHTO T 283. ***(10, 12)*** In this test, six specimens are compacted to seven percent air voids. One subset of three specimens are considered the control set and the other three specimens are subjected to vacuum saturation and an optional freeze/thaw cycle. Both subsets are then tested to determine their indirect tensile strengths; the ratio of the tensile strength of the conditioned subset to the control subset is considered its moisture sensitivity. Superpave requires a minimum of 80 percent tensile strength ratio. ***(1)***

1.3.3. Performance Testing

A significant addition to design brought about by Superpave is the requirement of performance testing for pavements which will see heavier traffic. Sometimes referred to as level two and level three testing, these performance tests are used to help predict whether a mix will be susceptible to the major distresses of permanent deformation (rutting), fatigue cracking, and low temperature cracking. The higher the traffic level for a mix, the more rigorous the performance testing should be. "Level Two" testing predicts the probability of the survival of a mix for given traffic and environmental conditions. In effect it "screens" mixes from a standpoint of whether or not to use it for field placement. "Level Three" testing attempts to predict actual levels of rutting and fatigue cracking over a projected load history of the in-place pavement. ***(1)***

Two new pieces of equipment have been developed for the sole purpose of performance testing. They are the Superpave Shear Tester (SST) and the Indirect Tensile Tester (IDT). These two machines are used to model material properties, environmental effects, pavement response, and pavement distress. ***(1)*** Both machines have environmental control chambers and record and measure pavement response characteristics for a variety of temperature and loading conditions. The SST and IDT tests include repeated load shear, simple shear, and frequency sweep for fatigue and permanent deformation; indirect tensile strength for permanent deformation; and low temperature creep, low temperature fracture, and fatigue cracking analysis for low temperature cracking. Both pieces of equipment are quite expensive, making them accessible to a limited number of design institutions. They have also come under a significant amount of scrutiny regarding their ability to accurately model pavement performance. The equipment and models originally used for data analysis of materials and pavement structure are currently undergoing extensive revisions. For these reasons, proof testing has become a "surrogate" method for performance testing. ***(1,16)***

1.3.4. Proof Testing

Proof testing is a term used for tests which are used to "prove" that a mixture is resistant to a particular type of distress. One of the most popular of these is the wheel tracking test. Several variations have been built, but all use a loaded wheel that travels back and forth across a pavement sample. Deflections are recorded which give insight as to a pavement's resistance to rutting and/or stripping. Other proof tests include the flexural beam fatigue test and the thermal stress restrained specimen test. ***(16)***

Even though proof tests have the potential to give equal or more accurate predictions regarding pavement performance than performance testing, proof testing can only provide empirical data which is applicable to a single specific mixture. The SST and IDT give insight as to the actual fundamental properties of a mix, which can often lead to more substantial conclusions regarding the characteristics of a group of mixtures. Presently, the cost of proof testing is much lower than performance testing. This fact coupled with the fact the SST and IDT equipment and testing procedures are not yet firmly in place has caused proof testing to gain popularity across the country.

Chapter 2

PROJECT OBJECTIVE AND SCOPE

2.1 Project Objective

The objective of this research was to determine what impacts the implementation of Superpave would have on current hot-mix asphalt operations in Arkansas. Specifically, the goals were to determine whether or not existing aggregate stockpiles would be suitable for use in Superpave blends, and what changes would have to be made in order to successfully implement the Superpave mix design procedure. The Arkansas aggregates were used in the Superpave procedure in an attempt to create acceptable mixture designs. A baseline of information was created by testing a series of blends according to the Superpave criteria. Valuable information was gained concerning potential changes necessary for the Arkansas Highway and Transportation Department (AHTD) to implement Superpave in the state during 1998.

2.2 Project Scope

Arkansas aggregates from four sources were sampled and tested. The aggregates used were crushed stone, crushed gravel, manufactured sand (screenings), and natural sands. All of these types of aggregate are typical of those used in Arkansas. Sandstone is sometimes used, but was not available from the sources sampled. A total of thirty-three (33) blends were developed from these sources, and tests were performed according to the Superpave volumetric mix design and the appropriate specifications. Fine, medium, and coarse blends were developed and tested for both surface and binder courses ranging in size from 9.5 mm to 25.0 mm by Superpave designation. Typical fine, medium, and coarse gradations are shown in Figure 6. A binder meeting the specifications for a PG 64-22 classification was used, corresponding to the project design temperature of 38° C and a project design traffic level of 3-10 million ESALs. ***(1)***

Figure 6. Typical Fine, Medium, and Coarse Superpave Gradations

Chapter 3

EXPERIMENTAL PROCEDURES

3.1 Aggregate Testing

Aggregates were tested from four hot-mix asphalt plants in Arkansas. The sources were Delta Asphalt (Paragould), A.P.A.C., Inc. (West Memphis), L. J. Earnest Inc. (Texarkana,) and Granite Mountain / D.P.H., Inc. (Little Rock). A listing of sources and aggregates is given in Table 19. A map showing the approximate geographic location of each source is given in Figure 7. The specific gravity, absorption, and gradation was determined for each aggregate and fine aggregate angularity was determined for each of the fine aggregates. Also, fine aggregate angularity was determined for the fine portion of each blend of aggregates. The test methods and specifications used in aggregate testing are listed in Table 20. ***(12)***

Delta Asphalt	L.J. Earnest, Inc.
<u>Paragould, Arkansas</u>	<u>Texarkana, Arkansas</u>
28.5 mm crushed limestone	28.5 mm crushed limestone 19.0
mm crushed gravel	19.0 mm crushed limestone 12.5
mm crushed limestone	15.9 mm crushed limestone 6.35
mm crushed limestone	‘dirty’ limestone screenings
crushed (gravel) coarse sand	‘clean’ limestone screenings
field (pit) fine sand	field (pit) sand
	Donna Fill[1]
A.P.A.C., Inc.	Granite Mountain, Inc.
<u>West Memphis, Arkansas</u>	<u>Little Rock, Arkansas</u>
31.75 mm crushed limestone	19.0 mm‘dirty’ crushed limestone
25.0 mm crushed limestone	19.0 mm‘clean’crushed limestone
19.0 mm crushed gravel	limestone screenings 12.5
mm crushed gravel	coarse manufactured sand 12.5
mm crushed limestone	Donna Fill[1]
limestone screenings	river sand
field (pit) sand	[1] Donna Fill is an angular fine aggregate
Donna Fill[1]	(97% passing 0.6 mm) produced by 3-M Co.

Table 19. Aggregates Used in Superpave Mixture Design Research

<u>Specification</u>	<u>Specification Title</u>
AASHTO T 11	“Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing”
AASHTO T 27	“Sieve Analysis of Fine and Coarse Aggregates”
AASHTO T 84	“Specific Gravity and Absorption of Fine Aggregate”
AASHTO T 85	“Specific Gravity and Absorption of Coarse Aggregate”
AASHTO T 248	“Reducing Field Samples of Aggregate to Testing Size”
AASHTO TP 33	“Standard Test Method for Uncompacted Void Content of Fine Aggregate”

Table 20. Specifications Used in Aggregate Testing

Figure 7. Map of Aggregate Source Locations

3.2 Gradation

The Superpave gradation criteria is a major departure from traditional AHTD gradation specifications. Superpave gradation specifications do not promote blends as finely graded as traditional AHTD blends. An example of an AHTD gradation specification is given in Table 21. ***(8)*** Most AHTD blends would pass through or above the location of the restricted zone, but Superpave recommends that blends pass beneath the restricted zone, allowing fewer fines. Often, too many fines will cause a mix to have difficulty meeting the VMA criteria. ***(10)***

Sieve	Percent Passing	Tolerance
¾"	100	-
½"	85-100	±7
#4	55-80	±7
#10	35-60	±5
#20	22-45	±4
#40	15-35	±4
#80	8-22	±4

Table 21. AHTD Gradation Specification Sample

Fine, medium, and coarse blends were tested according to Superpave specifications. A fine blend according to Superpave gradation specifications most closely resembles the acceptable gradations for the AHTD. Fine blends passed above the restricted zone, the medium blends passed very close to yet beneath the restricted zone, and coarse blends passed well below the restricted zone.

3.3 Binder

The asphalt binder used for the project was a performance graded asphalt PG 64-22, meaning that it meets a high temperature requirement of 64° C and a low temperature requirement of -22° C. The binder was tested for viscosity by the Brookfield viscometer according to ASTM D 4402, "Standard Test Method for Viscosity Determinations of Unfilled Asphalts Using the Brookfield Thermosel Apparatus". ***(13)*** The viscosity curve was plotted on the graph to determine the temperatures to be used for mixing and compaction. The mixing temperature used for the project was 160° C and the compaction temperature was 147° C.

3.4 Mix Design

The design parameters for the project were a design temperature of less than 39° C, and a design traffic level of 3 to 10 million Equivalent Single Axle Loads (ESALs). Based on these parameters, all specimens in the study were compacted to a maximum number of gyrations equal to 152. The initial number of gyrations is 9 and the design number of gyrations is 96 (see Table 13). ***(1)***

All blends were batched to a total aggregate weight of 4700 grams. The appropriate weight of binder was then added to the heated aggregate for an approximate sample weight of 4900 to 5000 grams. This weight of material usually produced the required final specimen height of 115 mm ±5 mm. ***(14)*** All materials were heated to 160° C for mixing, and specimens were mixed according to AASHTO specification TP4, "Standard Method for Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the SHRP Gyratory Compactor". Next, each specimen was aged for four hours at 135° C and brought up to compaction temperature of 147° C. A four hour aging period was used for all specimens since most of the research was complete before it was learned that the aging criteria had been changed to two hours. The aging process was conducted according to AASHTO specification PP2, "Standard Practice for Short and Long Term Aging of Hot Mix Asphalt (HMA)". ***(12)*** A listing of specifications used in Superpave mixture design is given in Table 22.

Specification	Specification Title
ASTM 4402	"Standard Test Method for Viscosity Determinations of Unfilled Asphalts Using the Brookfield Thermosel Apparatus"
AASHTO T 166	"Bulk specific Gravity of compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens"
AASHTO T 209	"Maximum specific Gravity of Bituminous Paving Mixtures"
AASHTO T 245	"Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus"
AASHTO T 269	"Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures"
AASHTO T 275	"Bulk Specific Gravity of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens"
AASHTO T 283	"Resistance of Compacted Bituminous Mixture to Moisture Induced Damage"
AASHTO PP2	"Standard Practice for Short and Long Term Aging of Hot Mix Asphalt (HMA)"
AASHTO TP4	"Standard Method for Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the SHRP Gyratory Compactor"

Table 22. Specifications Used in Mix Design

Each specimen was compacted in the SGC to N_{max} = 152. After a short time for cooling, the 150 mm diameter specimens were extruded from the mold and allowed to cool to room temperature. After reaching room temperature, the specimens were each tested for bulk specific gravity (G_{mb}) according to AASHTO T 166, "Standard Method of Test for Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens". Also, sample mixtures were prepared for determining theoretical maximum specific gravity (G_{mm}) according to AASHTO T 209, "Standard Method of Test for Maximum Specific Gravity of Bituminous Paving Mixtures". These specimens contained approximately 2000 grams of aggregate plus the appropriate binder weight. ***(12)***

As each specimen was compacted, the SGC measured and recorded the height of the specimen at each gyration. The key values are the height of specimen at N_{ini}, N_{des}, and N_{max}. These values along with G_{mm}, G_{mb}, AC content, the bulk specific gravity of the aggregate blend (G_{sb}), and the percent of material in the blend passing the No. 200 sieve comprise the variables needed to perform the volumetric calculations and analysis. Equation (1) is used to determine G_{sb}.

(1) $$G_{sb} = \frac{P_1 + P_2 + P_N}{P_1/G_1 + P_2/G_2 + P_N/G_N}$$

where: G_{sb} = bulk specific gravity for the total aggregate
P_1, P_2, P_N = individual percentages by mass of aggregate
G_1, G_2, G_2 = individual bulk specific gravities of aggregate

First, specimen densification curves for each mix are prepared based on SGC height data. The measured heights are used to calculate a volume and estimated G_{mb} at each gyration height, assuming that the specimen is a smooth cylinder:

(2) $$G_{mb}\text{ (estimated)} = \frac{W_m/V_{mx}}{\gamma_w}$$

where:	G_{mb} (estimated)	= estimated bulk specific gravity of specimen during compaction,
	W_m	= mass of specimen, grams
	γ_w	= density of water = 1 g/cm^3
	V_{mx}	= volume of compaction mold (cm^3)

and: $$V_{mx} = \frac{\pi d^2 h_x}{4} * 0.001\text{cm}^3 / \text{mm}^3$$

where:	d	= diameter of mold (150 mm) and
	h	= height of specimen in mold during compaction (mm)

Because of the irregular surface texture, the assumption of a smooth cylinder is only an approximation. Thus a correction factor must be applied. ***(10)*** The correction factor is the measured G_{mb} of the specimen divided by the estimated G_{mb} at N_{max}.

(3) $$C = \frac{G_{mb}\text{ (measured)}}{G_{mb}\text{ (estimated)}}$$

where:	C	= correction factor
	G_{mb} (measured)	= measured bulk specific gravity after N_{max}
	G_{mb} (estimated)	= estimated bulk specific gravity at N_{max}

This correction factor is based on G_{mb} at N_{max} , then applied to each estimated G_{mb} to give a corrected G_{mb} at each N.

(4) $$G_{mb}\text{ (corrected)} = C * G_{mb}\text{ (estimated)}$$

where:	G_{mb} (corrected)	= corrected bulk specific gravity of the specimen at any gyration

C	= correction factor
G_{mb} (estimated)	= estimated bulk specific gravity at any gyration

Next, the percent G_{mm} at each gyration was calculated as the ratio of the corrected G_{mb} to the measured G_{mm}.

(5) $$\% G_{mm} = G_{mb} \text{ (corrected)} / G_{mm}$$

where:

$\% G_{mm}$	= percent of maximum theoretical specific gravity
G_{mb} (corrected)	= corrected bulk specific gravity of the specimen at any gyration
G_{mm}	= maximum theoretical specific gravity

Average values were used for companion specimens. The $\%G_{mm}$ was then plotted against the log of N to create the densification curve. Next, the percentage of air voids at N_{des} was calculated, as well as VMA, VFA, and dust proportion. Equations for these quantities are given in Figure 9.

(6) $$V_a = 100 * \frac{G_{mm} - G_{mb}}{G_{mm}}$$

where:

V_a	= air voids in compacted mixture, percent of total volume
G_{mm}	= maximum specific gravity of paving mixture
G_{mb}	= bulk specific gravity of compacted mixture

(7) $$VMA = 100 - \frac{G_{mb} * P_s}{G_{sb}}$$

where:

where:	VMA	= voids in mineral aggregate (% bulk volume)
	G_{sb}	= bulk specific gravity for the total aggregate
	G_{mb}	= bulk specific gravity of compacted mixture
	P_s	= aggregate content, % by total mass of mixture

(8) $$VFA = 100 * \frac{VMA - V_a}{VMA}$$

where:	VFA	= voids filled with asphalt, percent of VMA
	VMA	= voids in mineral aggregate (% bulk volume)
	V_a	= air voids in compacted mixture, percent of total volume

(9) $$DP = \frac{P_{0.075}}{P_{be}}$$

where:	DP	= Dust Proportion
	$P_{0.075}$	= aggregate content passing the 0.075 mm sieve, percent by mass of aggregate
	P_{be}	= effective asphalt content, percent by total mass of mixture, percent

An example problem with actual values follows.

Given:

	% in Blend	Individual Bulk Sp. Gr.
Aggregate A	72	2.573
Aggregate B	19	2.638
Aggregate C	9	2.597

% Passing the 75µm (#200) sieve	=	4.1 %
Binder Content	=	6.2%
G_{mm}	=	2.411
Wt. of Specimen	=	4985.0 g
Ht. @ N_{ini}	=	137.6 mm
Ht. @ N_{des}	=	124.6 mm
Ht. @ N_{max}	=	119.4 mm
G_{mb} (measured) @ N_{max}	=	2.341
P_{be}	=	5.293 %

$$G_{sb} = \frac{72 + 19 + 9}{72/2.573 + 19/2.638 + 9/2.597}$$

$$G_{sb} = 2.587$$

Then calculate an estimated G_{mb} at N_{max}.

$$V_{mx} = \frac{\pi\,(150)^2\,(119.4)}{4} * 0.001\text{cm}^3 / \text{mm}^3$$

$$V_{mx} = 2109.97 \text{ cm}^3$$

$$G_{mb} \text{ (estimated)} = \frac{4985.0 / 2109.97}{1}$$

$$G_{mb} \text{ (estimated) at } N_{max} = 2.363$$

Determine the correction factor.

$$C = \frac{2.341}{2.363} = 0.9907$$

Determine the estimated G_{mb} at N_{des}.

$$V_{mx} = \frac{\pi\,(150)^2\,(124.6)}{4} * 0.001\text{cm}^3/\text{mm}^3$$

$$V_{mx} = 2201.86 \text{ cm}^3$$

$$G_{mb}\text{ (estimated)} = \frac{4985.0 / 2201.86}{1}$$

$$G_{mb}\text{ (estimated) at } N_{des} = 2.264$$

Apply the correction factor.

$$G_{mb}\text{ (corrected)} = 0.9907 * 2.264 = 2.243$$

Next, calculate % G_{mm}, air voids, VMA, VFA, and DP.

$$\%\ G_{mm} = (\ 2.243 /\ 2.411\ ) = 93.0\%$$

$$V_a = 100 * \frac{2.411 - 2.243}{2.411} = 7.0\ \%$$

$$VMA = 100 - \frac{2.243 * 93.8}{2.587} = 18.7\ \%$$

$$VFA = 100 * \frac{18.7 - 7.0}{18.7} = 62.5\ \%$$

$$DP = \frac{4.1}{5.293} = 0.775\ \%$$

It is evident that this mixture does not meet all of the criteria for Superpave mixture design.

Once these values were calculated for a trial aggregate structure, estimated values were derived which would produce 4% air voids at N_{des}. These calculation procedures are outlined in Chapter 5 of the Asphalt Institute's Superpave Level I Mix Design Manual, SP-2. ***(1)*** After a new estimated binder content is calculated, estimated VMA and estimated VFA values are calculated, and so on. These estimations are then compared to Superpave criteria. If estimated properties met (or closely resembled) the criteria, then specimens were prepared using the new estimated binder content, ±0.5% the estimated binder content, and +1.0% the estimated binder content, and tested by the same compaction and evaluation method.

For the specimens with varying binder content, the same variables of air voids, VMA, VFA, $\%G_{mm}$, and dust proportion were calculated and compared to Superpave criteria. The binder content producing approximately 4.0% air voids which also met the other criteria (see Tables 14 - 18) was chosen as optimum. ***(1, 10)*** If there was no combination of values which met all criteria, then that particular aggregate structure and mix design was judged unacceptable and was discarded.

Various computer software packages are available which perform these mix design calculations according to Superpave methods. Pinepave Version 3.01™, which is marketed by the Pine Instrument Company, was used for most calculations in this research.

Superpave requires a test for the moisture sensitivity of a mix. This test, AASHTO T 283, measures the retained tensile strength of a conditioned specimen as compared to an unconditioned specimen. In this test, at least six specimens are compacted to approximately seven (7) percent air voids and then one half of the specimens are conditioned by placing them under water in a vacuum to achieve a saturation of 55 to 80 percent. The specimens are then subjected to indirect tensile strength testing. The retained tensile strength ratio (TSR) is the ratio of the average tensile strength of the conditioned specimens to the average tensile strength of the dry specimens. The minimum TSR allowed by Superpave is 80%. ***(1)***

CHAPTER 4

TEST RESULTS AND DISCUSSION

In order to implement the Superpave mix design method in Arkansas, several changes must be made, but the overall transition is feasible and should be relatively smooth. The significant findings of the research are included in the following sections.

4.1 Aggregates

Current Arkansas aggregates are capable of producing acceptable Superpave blends. This is possibly the most important conclusion of the research. In general, Superpave blends will be more coarse than traditional mixes. Coarser blends mean fewer fines, which could impact the aggregate industry.

Arkansas aggregates are currently tested for various properties. Source properties required in Arkansas are toughness, soundness, and deleterious materials. Test methods and criteria used by AHTD for these properties are listed in Table 23. ***(8)*** It is recommended that Arkansas retain these standards and acceptance criteria for use in HMAC.

Source Property	AHTD Specification	Specification Criteria
Toughness	AASHTO T 96	max. 40% loss
Soundness	AASHTO T 104	max. 12% loss
Deleterious Materials	AHTD 302 AASHTO T 113	"free of" deleterious materials max. 2% coal/lignite

Table 23. Aggregate Source Properties Required by AHTD

In terms of consensus properties, Arkansas currently evaluates coarse aggregate angularity by AHTD test method 304, “Method of Test for Crushed Particles in Aggregate”. The test procedure is very similar to the specification recommended by Superpave, but the acceptance criteria are not as stringent. It is recommended that AHTD adopt the Superpave test methods and criteria for this property. Concerning clay content, section 409 of the AHTD Specifications “Materials and Equipment for Asphalt Concrete Plant Mix Courses”, requires that the aggregate portion which passes the No. 40 sieve “shall have a plasticity index (PI) no greater than 4”. ***(8)*** It is recommended that AHTD adopt the Superpave criteria for this property as well. A test for flat and elongated particles has also been performed in the past as an “in-house” effort by AHTD. The Superpave criteria for this property should be enforced and adopted as an AHTD specification. Although the Superpave specifications for consensus properties are not currently a part of the AHTD specification, these tests are not new to Arkansas aggregates. The consensus property which is fairly new to HMAC in Arkansas is fine aggregate angularity. Relative to aggregate consensus properties, it is recommended that AHTD adopt Superpave test methods and acceptance criteria.

Fine aggregate angularity was tested for all fine aggregates used in the research. The tests were performed according to AASHTO TP33, and most aggregates did pass the minimum Superpave requirements. Some did not pass, but were not excluded from the mix design process based solely on this factor. Several states have experienced difficulty with aggregate not meeting the criteria. Some states, such as Texas, have suggested that each state develop its own guidelines for the minimum criteria, based on experience and knowledge of local aggregate performance. ***(17)*** Others have requested that the minimum requirements be reduced nationwide. A SHRP technical group responded to this by suggesting that rather than ease the criteria, reasons for aggregate failure should be investigated. ***(18)*** It has also been suggested that the fine aggregate angularity test does not detect natural sands, but in a study performed at the Kansas Department of Transportation, it was concluded that the test does differentiate between natural sand and crushed gravel samples. ***(19)***

In the research conducted for this project, the fine aggregate angularity test was tested for aggregate blends, as recommended by the Superpave criteria. In this case, a blend may have contained an individual aggregate that had failed the minimum criteria. However, when combined with other aggregates of a blend, the overall combination may have possessed properties that did meet the criteria. Therefore, it is recommended that fine aggregate angularity should be performed on the aggregate blend (as intended) rather than individual aggregates. Individual aggregate tests should only be used to identify specific "problem aggregates", not to accept or reject individual aggregates. An example comparison of individual and blend fine aggregate angularity results is given in Table 24. For a minimum required uncompatcted void content of 45%, the individual aggregates are not acceptable. However, the combination of aggregates in the 12.5 mm and 25.0 mm blends do have adequate uncompacted void content to meet the criteria.

Source	Aggregate I.D.	Uncompacted Void Content (%)
A.P.A.C. (West Memphis)	Limestone Screenings	44.3
	Field Sand	37.3
	River Sand	43.1
	Superpave 12.5 mm blend	46.1
	Superpave 19.0 mm blend	44.7
	Superpave 25.0 mm blend	47.1

Table 24. Example Fine Aggregate Angularity Results

The gradation specifications as dictated by Superpave criteria are a major change to the traditional Arkansas design process. The AHTD specifications are much more fine than what is allowed by Superpave. Traditional blends almost always pass above the restricted zone, and some are too fine to meet Superpave criteria at all. This is evident by the fact that of ten (10) acceptable Superpave blends found, only one possessed a gradation curve which passed above the restricted zone. This fact also supports the Superpave recommendation that aggregate blends pass below the restricted zone. To meet the Superpave criteria , aggregate blends will now be more coarse. The nine blends passing below the restricted zone were considered to be medium and coarse blends; three of the nine were considered coarse.

Because the blends are more coarse, it is reasonable to conclude that fewer sand-sized particles will be needed for Superpave blends. The marked decrease in the use of sand-sized particles poses a significant impact on producers of such materials, unless alternative uses for such products are found. An even greater impact may be felt by producers of natural sands due to the fact that manufactured sands are highly preferred over natural sands. Manufactured sands are much more angular in nature and increase the potential for voids in the mineral aggregate (VMA) of a mix. Blends with too much sand, especially those containing too much fine sand in relation to total sand, are known as “tender” mixes, and have a high probability of failure by permanent deformation. ***(10)***

The most difficult of the volumetric criteria to comply with appears to be VMA. This is because adequate open spaces must be provided in the mix, but such space must be provided without sacrificing the strength of the aggregate structure. ***(20)*** The research suggests that the requirements for VMA (which vary based on nominal maximum aggregate size) are more likely to be met when the blend of aggregates contains a limited amount of sand, preferably angular or manufactured sand. Aggregate shape and surface texture play an important role in VMA, as do gradation and binder content. ***(20)*** A mix which does not contain enough void space may be prone to failure by permanent deformation, but a mix with too many voids may be more susceptible to stripping and/or permeability problems.

Another quality that could make a mix susceptible to permanent deformation is a gradation curve that lies parallel to the maximum density line. A curve parallel to the maximum density line also will be very densely compacted, with very low VMA. ***(10)*** Relative to this, a gradation curve that is S-shaped in nature can provide VMA as well as a strong aggregate skeleton. Other research has been completed which supports this conclusion. ***(21)*** An effort has been made to develop a relationship between VMA and the sum of the distances from the maximum density line. In “Evaluation and Selection of Aggregate Gradations for Asphalt Mixtures Using Superpave”, Anderson and Bahia conclude that “statistically, no good correlations exist relating VMA in an asphalt mixture to: sum of distances from the Superpave maximum density line; sum of distances from the restricted zone, and SGC compaction slope.” While statistically sound relationships were not found, they did conclude that using the sum of distances from the maximum density line and creating S-shaped gradation curves may still increase the chances that a mix will meet VMA criteria. ***(21)***

Additional observation verified by AHTD suggests that a combination of crushed stone and crushed gravel can also be helpful in creating a blend which meets Superpave specifications.

Another issue exists in the method of VMA calculation. the AHTD method of VMA calculation uses the effective specific gravity of the aggregate (G_{se}). ***(8)*** Superpave calculations use the bulk specific gravity of the aggregate (G_{sb}). It is recommended that the AHTD method be changed to reflect the method recommended by Superpave so that calculation will be consistent with the criteria. This could change the resulting VMA values by 1.0 % or more, depending on the asphalt absorption capacity of the aggregate blend.

4.2 Superpave Mix Design

Arkansas should not experience major difficulty in implementing Superpave. The first level of Superpave mix design is essentially the same volumetric analysis procedure which has been used for decades by AHTD. Blends will be compacted differently and have a more coarse appearance, but the underlying volumetric principles will remain intact.

Of thirty-three mixes tested, ten were considered acceptable by Superpave criteria. Thus, a typical success rate of about one-third (1/3) can be expected until further research can document a set of acceptable designs. This success rate has been verified by other research efforts currently taking place within the AHTD and elsewhere. By observation, Superpave mixes appear to be more "rich" than traditional Marshall mixes. Also, because of the more coarse aggregate structure, they also appear to be more porous.

The most obvious change required is the use of the Superpave Gyratory Compactor (SGC) for compacting specimens. The 1.25 degree gyration angle is felt to simulate the kneading action that takes place in field compaction more accurately (and more quietly) than did the Marshall impact hammer. By more accurately imitating the actual field compaction process, results from tests conducted on laboratory specimens should provide more realistic expectations for field hot-mix asphalt concrete (HMAC) mixes. The SGC possesses a much more sophisticated method of data collection in which the height of specimen is recorded for each gyration. The characteristics of the sample at N_{ini}, N_{des}, and N_{max} are key to mixture evaluation. The volumetric analysis procedure is relatively unchanged. ***(11)*** The same basic concepts of determining air voids, VMA, VFA, and DP properties evaluated are very similar to those previously evaluated in the Marshall method, but SGC compaction data has also been incorporated into this phase of mix design.

Ten acceptable blends were developed from the Arkansas aggregate sources. Four acceptable blends were developed using A.P.A.C. materials. They were coarse and medium 12.5 mm blends, a medium 19.0 mm blend, and a medium 25.0 mm blend. Two acceptable blends were developed using aggregates from Delta Asphalt. They were a 19.0 mm medium blend and a 25.0 mm coarse blend. From the L.J. Earnest materials, three blends were acceptable. They were a 19.0 mm medium blend, a 25.0 mm medium blend, and a 25.0 mm coarse blend. From the Granite Mountain materials, only one acceptable blend was found. The materials from this source were very fine and only 9.5 mm and 12.5 mm fine blends could be created which met the gradation specifications. The blend which met all of the Superpave criteria was a 12.5 mm fine blend. This blend was the only acceptable blend found which possessed a gradation curve that passed above the restricted zone. A complete summary of the acceptable mixes, corresponding volumetric property values, and required volumetric property values can be found in Table 25. Some volumetric property values varied slightly from the specification. These values are noted in the table. These blends were not discarded because it was felt that minor design changes to the blend should create an acceptable mixture.

Blend I.D.	Opt. AC %	VTM	VMA	VFA	DP	% G_{mm} @ N_{ini}	N_{max}	G_{mm}	TSR
<u>12.5 mm Mixes</u>									
Specification Values		*4.0*	*14.0*	*65-75*	*0.6-1.2*	*<89*	*<98*		
APAC Medium	5.5	4.0	13.9[1]	72.9	1.5[1]	85.7	97.7	2.444	N/A
APAC Coarse	6.7	4.5	17.4	74.2	0.9	84.7	96.9	2.394	99.3
Gr. Mtn. Fine	5.9	4.1	15.2	73.0	1.0	87.7	97.2	2.413	N/A
<u>19 mm Mixes</u>									
Specification Values		*4.0*	*13.0*	*65-75*	*0.6-1.2*	*<89*	*<98*		
Delta Medium	6.2	4.0	16.0	74.8	0.8	86.9	97.1	2.411	65.8
APAC Medium	5.6	4.0	14.4	73.6	1.0	85.8	97.6	2.447	82.6
L.J. Earnest Med.	5.4	4.0	13.8	71.9	0.6	87.8	97.3	2.436	90.4
<u>25 mm Mixes</u>									
Specification Values		*4.0*	*12.0*	*65-75*	*0.6-1.2*	*<89*	*<98*		
Delta Coarse	6.0	4.0	15.6	74.4	0.5[1]	86.0	97.5	2.493	75.6
APAC Medium	4.8	4.0	13.5	70.7	1.2	84.1	97.8	2.489	N/A
L.J. Earnest Med.	5.1	4.0	13.9	72.0	0.6	87.5	97.3	2.411	N/A
L.J. Earnest Coarse	5.3	4.0	14.3	72.5	0.7	86.7	97.4	2.402	N/A

[1]values slightly out-of-spec; additional design work should enable mixture acceptance

Table 25. Acceptable Superpave Blends Using Arkansas Aggregates

No conclusions were drawn from this research regarding a change in asphalt content when transitioning from Marshall to Superpave. However, in a comparison of Marshall and Superpave, Hafez and Witczak concluded that for warm design temperatures (43 -44° C), asphalt contents are similar, and as the design temperature drops, Superpave requires up to 1.0% more AC content than does Marshall. ***(22)***

Two acceptable Marshall mixes were tested in the SGC by Superpave criteria, each at compactive efforts of N_{max} = 152 and N_{max} = 174. The differences in optimum AC content by Marshall showed no trend. Superpave criteria recommended a decrease in AC content for both blends tested, but only one blend was found acceptable at N_{max} = 152. Therefore further study would be necessary to make such conclusions for Arkansas mixtures.

4.3 Moisture Damage

Moisture damage testing was performed according to AASHTO T 283 for acceptable blends from Delta Asphalt, A.P.A.C., and L. J. Earnest sources. Not all acceptable blends were tested due to lack of materials. The moisture damage test should detect the likelihood of stripping, which is largely a function of aggregate type and texture. Therefore, moisture damage test results should be similar for different blends which contain similar combinations of aggregates.

One of the challenges of performing the moisture damage test is to create a set of specimens which have been compacted to 7 ±1.0% air voids. ***(12)*** This can be a tedious trial and error process, though several valid calculation methods exist. The most efficient way found during this research was to estimate a number of gyrations necessary to create this density based on the densification curves developed from previous testing of that blend.

The current criteria suggested by Superpave is a minimum tensile strength ratio of 80%. Both A.P.A.C. blends tested met the criteria, as did the blend tested from the L. J. Earnest source. However, both Delta blends tested failed this criteria. This suggests that further study should be conducted to determine which aggregates from this source could be especially susceptible to stripping.

Arkansas currently performs a similar test on compacted mixtures, except that instead of determining retained tensile strength, retained Marshall stability is determined. It is recommended that AHTD adopt AASHTO T 283 for moisture sensitivity testing in order to be consistent with Superpave recommendations. The specification may need to be revised to reflect the testing of a 150 mm diameter specimen.

A more complete summary of acceptable mix designs and aggregate properties used in this research is contained in the Appendix.

CHAPTER 5

RECOMMENDATIONS FOR FUTURE RESEARCH

Additional research is suggested to examine the moisture sensitivity test as given by AASHTO T 283. Visual inspection of specimens following the split tensile test suggest that for tightly compacted specimens, the minimum allowable 55 percent saturation level may not allow moisture to reach the most internal areas of the specimen. It speculated that this could be partly due to the fact that sample specimens are now 150 mm in diameter, but the specification is clearly assuming a 100 mm diameter sample specimen. Additional study is recommended to explore the possible advantages of raising the minimum allowable saturation level to more accurately model HMAC sensitivity to moisture.

Performance testing was not performed as a part of this research. However, higher volume mixture designs will require such testing, and Arkansas agencies have not yet invested in equipment for such testing. It is recommended that various forms of proof testing be examined to serve this purpose. The Evaluator of Rutting and Stripping in Asphalt (ERSA) at the University of Arkansas is an example of such a test. Additional research should be performed on Arkansas Superpave mixtures regarding such tests.

CHAPTER 6

CONCLUSION

Based on the results of this study, it is reasonable to conclude that current Arkansas aggregates will be acceptable for use in Superpave blends. Most aggregates should be acceptable based on source and consensus property criteria, but note that consensus properties should be tested on aggregate blends rather than individual aggregates. The gradation specifications could cause a major change in combinations of aggregates. Use of sand-sized materials, especially natural sands, will be very limited. This will impact producers of such materials.

Superpave mixtures will appear more coarse and “richer” than mixtures used in the past. Aggregate blend gradations should pass below the restricted zone, especially for mixes with larger nominal maximum aggregate sizes (19.0 mm and larger). A success rate of about one-third can be expected for achieving acceptable Superpave mixtures from trial aggregate blends. An “S”-shaped gradation curve and/or a combination of crushed stone and crushed gravel may improve chances of creating an acceptable mix.

VMA calculations should be performed using the bulk specific gravity of the aggregate blend rather than the effective specific gravity of the blend. Although calculated VMA values will decrease for absorptive aggregates, calculated volumetric properties will be consistent with methods used to establish Superpave VMA requirements.

The current Marshall stability test should be replaced by AASHTO T 283 for moisture sensitivity testing. Proper air voids for these test specimens may be achieved by estimating the necessary number of gyrations from the densification curve for that blend. A trial and error process may also be needed to accomplish this. Another impact of implementing this standard is that the purchase of additional equipment may be required.

Further research should be conducted regarding the test method for the moisture sensitivity analysis in terms of sample size and level of saturation. Future work should also be done relative to performance testing and/or proof testing. Specifically, research should be performed using the ERSA wheel tracking machine, located at the University of Arkansas. Issues such as minimum criteria for rutting, temperature sensitivity, and moisture sensitivity should be addressed. A standard test method for the ERSA tester should be developed and used by the AHTD until more knowledge is gained concerning Superpave performance testing equipment.

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APPENDIX