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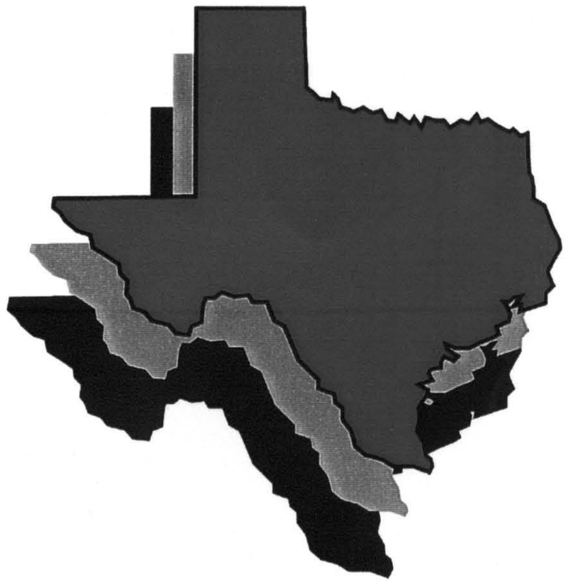
A Demonstration of Stone Matrix Asphalt Mix Designs Using High Polish Value Crushed Stone

DHT- 41



DEPARTMENTAL RESEARCH

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Technical Report Documentation Page

1. Report No. TX-97/DHT-41	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A DEMONSTRATION OF STONE MATRIX ASPHALT MIX DESIGNS USING HIGH POLISH VALUE CRUSHED STONE		5. Report Date October 1997
		6. Performing Organization Code
7. Author(s) George L. Thomas, Paul Shover, Ronald Kelly, and Phillip Brown		8. Performing Organization Report No. Research Report DHT-41
9. Performing Organization Name and Address Texas Department of Transportation Materials and Tests Division 39th and Jackson, BLDG 5 Austin, Texas 78731		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Section P. O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered In-house evaluation 1995 to 1997
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Historically, the Fort Worth District has used either lightweight aggregate or a crushed gravel from Reeves County, Texas, when a polish value of 35 minimum was required. It appeared to Fort Worth personnel that there was no competition among aggregate producers for this material in spite of the fact that there were listed in the "Rated Source Quality Catalog," at least seven or eight sources that met the requirements.

In order to increase awareness of alternate sources of high-polish aggregate among (hot mix) paving contractors, general contractors, aggregate producers, and hot-mix plants, the Fort Worth District Laboratory decided to design a few hot mixes using a variety of aggregate sources. A secondary objective was to demonstrate that special crusher runs generally are not required to achieve the required aggregate gradation for these mixes.

The Fort Worth District Lab also decided to introduce at the same time, a hot-mix asphalt concrete concept which was relatively new to Texas, stone matrix asphalt (SMA). This report documents some of the earliest SMA projects in Texas.

17. Key Words aggregate, stone matrix asphalt, SMA, asphalt mix design, polish value, aggregate gradation	18. Distribution Statement No restrictions. This document is available to the public through the Texas Department of Transportation Research Library, P.O. Box 5080, Austin, TX, 78763-5080.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	104	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

A DEMONSTRATION OF STONE MATRIX ASPHALT MIX DESIGNS USING HIGH POLISH VALUE CRUSHED STONE

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19 December 1996

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A DEMONSTRATION OF STONE MATRIX ASPHALT MIX DESIGNS USING HIGH POLISH VALUE CRUSHED STONE

Introduction

Historically, the Fort Worth District has used either lightweight aggregate or a crushed gravel from Reeves County, Texas, when a polish value of 35 minimum was required for a hot mix design under Item 3000, "Quality Control, Quality Assurance of Hot Mix Asphalt," or its progenitors. It appeared to us that there was no competition among aggregate producers for this material in spite of the fact that there are listed in the "Rated Source Quality Catalog," at least seven or eight sources that not only meet the required minimum polish value of 35, but also meet our requirements for LA Abrasion and $MgSO_4$ Soundness tests. Two of these sources are in the gravel category, and the remaining are crushed stone in the categories of igneous, sandstone, and limestone/dolomite. Please refer to the revised "Aggregate Quality Monitoring Program and the Rated Source Quality Catalog," effective 1 December 1996.

In order to increase awareness of alternate sources of high-polish aggregate among (hot mix) paving contractors, general contractors, aggregate producers, and hot-mix plants, the Fort Worth District Laboratory decided to design a few hot mixes using a variety of aggregate sources. A secondary objective is to demonstrate that special crusher runs generally are not required to achieve the required aggregate gradation for these mixes.

The Fort Worth District Lab also decided to introduce at the same time, a hot-mix asphalt concrete concept which is relatively new to Texas. This concept is the STONE MATRIX ASPHALT. Stone matrix asphalt (SMA) was developed in Germany about 16 years ago. In the United States, it has been used recently in Georgia, Maryland and a number of midwestern states with a high degree of success. In fact, both Georgia and Maryland have adopted SMA as their only hot mix for use on Interstate Highways. The first SMA in Texas was designed by the Fort Worth District Lab and placed in 1992. The Fort Worth District Lab started work on more SMA mixes in December 1995 and have now reached a point where these mixes should be introduced to contractors, aggregate producers, and hot-mix plants.

What is SMA?

In Germany this mixture is called "stone mastic asphalt"; but in keeping with U.S. practice we will continue to call it "stone matrix asphalt." The techniques used in Germany for the design of SMA mixtures are not greatly different from those used in the United States for designing hot mix asphaltic concrete mixtures.

In Germany, the Marshall test method is used to prepare and compact the test specimens to be used in the evaluation of the mixture. This test method is the same one used by many United States agencies. However, for SMA mixtures, Marshall stabilities and flows are not used in the evaluation of the mix design because those values are less meaningful than with dense-graded mixtures. Instead, properties such as aggregate gradation, asphalt grade and content, air void content, voids in the mineral aggregate, voids filled with asphalt, and asphalt draindown are analyzed and specified.

SMA mixtures consist basically of one or more coarse aggregates, fine aggregates, and mineral fillers blended in a combined aggregate mix in which intermediate sizes are absent or greatly reduced and that contain a fairly high quantity of filler. A small amount of cellulose fiber is added to the mixture in order to enable the mixture to hold a high asphalt content. This combination results in a mixture with a high percentage of voids in the mineral aggregate (VMA) and a high percentage of voids filled with asphalt (VFA).

The high content of coarse aggregate creates a stone skeleton to resist deformation and to provide good wear resistance and surface texture. The rich mortar (aggregates passing the 4.75 mm sieve, plus mineral filler and asphalt) provides improved low temperature properties, long-term durability, and a thick asphalt film on the aggregate to resist moisture damage.

SMA Mix Designs

We have written a Special Specification Item 8888, "Stone Matrix Asphalt (SMA) Concrete Pavement."

CAUTION: THE VERSION OF THIS SPECIFICATION ENCLOSED WITH THIS PAPER IS STILL UNDERGOING INTERNAL REVIEW, NOR HAS IT BEEN SEEN (as of this writing) BY THE SPECIFICATION COMMITTEE. IN ITS PRESENT FORM, THIS SPECIFICATION IS FOR INFORMATION ONLY — IT IS NOT TO BE USED FOR DESIGN, CONSTRUCTION OR BID ESTIMATES.

In spite of the above cautionary note, we felt it worthwhile to include it with this paper so that the readers may gain some insight into SMAs in general.

In this specification we have included Types A, B, C, D, and E that specify aggregate gradations of 19.0, 15.9, 12.7, 9.5 mm and "As Shown on Plans," respectively. We then selected the 15.9 mm (5/8 inch) gradation as a vehicle for the enclosed mix designs. In accordance with FHWA recommendations, we have excluded from use in these designs all material with rounded or partly rounded surfaces. Consequently, we are using "products of crushing" for all coarse and fine aggregate and mineral filler. This provision effectively excludes gravel and crushed gravel, field sand, agricultural lime, and baghouse fines from these designs. We have also restricted ourselves to using only standard crushed aggregate products from each pit in order to demonstrate that you don't have to order special crushings, or special blends from aggregate producers in order to meet these SMA gradations. The purpose of this self-imposed restriction is to keep prices down. For example, so far we have been able to meet the combined gradation using only a producer's standard aggregate gradations and screenings. Coarse and fine aggregate and screenings are from the same pit and rock type; however, there was one case where we used granite screenings with a sandstone coarse and fine aggregate. We did this because the granite screenings were much less expensive compared to screenings from the same parent rock of the coarse and fine aggregate.

For mineral filler we used a dolomitic dust from a crushing operation which passed the gradation requirements. The filler we used is a commercial product from the Unimin Corp., which is labeled as "Granusil SMA," from Mill Creek, OK. We used both Lion Oil AC-30 and Asphalt Materials, Inc., multigrade MG 20-40; but the asphalt used in these six SMA mix designs is the multigrade MG 20-40. The results with these two asphalts were nearly identical. Table 1, which follows, lists the aggregates used in these mix designs along with their principal quality characteristics.

TABLE 1: Sources for Coarse and Fine Aggregate

Producer	Pit	Location	Type of Stone	PV	LA Abrasion	$MgSO_4$ Soundness
Western R	Pedernal 0050309	NM	Ryolite	37	14	3
Capital Ag (Delta)	Brownlea 1402704	Burnett County	Sandstone w/ Calcite Cement	40	26	15
Meridian	Sawyer 0050437	Apple, OK	*Sandstone w/ Calcite Cement	38	31	14
Dolese	Cyril 0050411	Cyril, OK	Sandstone w/ Calcite Cement	42	33	27
Western R	Davis 0050439	Davis, OK	Ryolite	39	16	5
Smith Cr	Bullard 0914708	Limestone County	Siliceous Limestone	39	31	10

Contacts and Acknowledgements

We wish to acknowledge the kind assistance given by various individuals and organizations in obtaining the aggregates, mineral filler, cellulose fibers, and asphalt. Without their assistance this demonstration project would not have been possible. We also wish to acknowledge the technical guidance and loan of equipment provided by James N. Anagnos, Sr., Consultant (Hot Mix and Materials Specialist). We used a lot of ideas from "Mixture Design for Stone Matrix Asphalt," The Heritage Research Group, Indianapolis, IN. See Table 2 for details.

TABLE 2: Contacts

Company	Pit or Location	Name	Title	Phone
Western Rock	Corp. Offices	Neil Young	Sales Manager	(817) 381-2400
Western Rock	Pedernal	Adan Encinias	Sales Manager	(505) 584-2840
Western Rock	Davis	Don Jackson Butch Vores	Sales Manager Plant Manager	(405) 329-0504 (405) 369-3773
Capital (Delta)	San Antonio (Brownlea)	Mike Haas	Sales Manager	(800) 292-5315
Meridian	Dallas Office (Sawyer)	John Maurer	Sales Manager	(972) 556-1999
Dolese Bros.	Cyril	Bill Derby	Plant Manager	(405) 464-3168
Smith Cr Stone	Bullard	Steve Stone	Plant Manager	(214) 562-9060
Lion Oil AC-30	El Dorado	Tommy Cox Kim Plumle	Manager Sales Manager	(501) 864-1332 (501) 864-1331
Asphalt Mat'ls Inc. MG 2440	Gilbert Pit west of Weatherford	Bill Wilkins	Regional Manager	(817) 431-3442
Unimin Corp Mineral Filler	Arlington	Amy Schuchmann	Sales Manager	(817) 640-6622
Cron Chemical (Interfibe Corp)	Houston	Karl Knight	Sales person	(800) 683-2766
James N. Anagnos, Sr.	Georgetown	James N. Anagnos, Sr.	SMA Consultant	(512) 930-3924
UniChem Prod No 8162	Hobbs, NM	Terry Jacobs	Western Region Manager	(505) 393-7751

Disclaimer

The use or mention of a company or a product in this report is neither an endorsement nor a recommendation by the Texas Department of Transportation.

Commentary

There are no calculations to make to determine the optimum percent asphalt in designing SMA mixes. After plotting various factors against percent asphalt in the mix, you choose a target air void content (say 4%) for the laboratory molded samples, and then you verify that the other critical factors are within the bounds stated in Table 3, which is taken from the "Marshall Mix Design Method" in the appendix. These factors are density, VMA, and VFA. If all factors are within the required limits at the percent asphalt chosen with regard to air voids, then that is the mix's optimum percent asphalt. The optimum percent asphalt itself should fall between 6.0 % and 7.5 %. If it does not fall within this range (or very close to it), other design factors such as gradations, aggregate and mix specific gravities, differences in specific gravity between coarse and fine aggregate, etc., should be reexamined.

TABLE 3: SMA Specifications

ITEM	SPECIFICATION
Marshall Compaction	50 blows/Side
Asphalt Cement	PG 76-22 or PG 76-28
Asphalt Content, %	6.0 to 7.5
Air Void Content, %	3.5 to 4.5
Aggregate Absorption, %	2.0 Maximum
VMA, %	17 Minimum
VFA, %	75 to 84
Stripping, %	None Allowed
Draindown, %	0.3 Maximum
Cellulose Fiber, %	0.3

In order to prove to our own satisfaction that 0.3% fibers are needed in the SMA, we molded two sets (three per set) using the Pedernal mix which had an optimum asphalt of 6.8 % at 96 % density. One set was molded at 6.8 % asphalt with fibers; another set was molded at 6.5 % asphalt without fibers. The latter set without fibers fell apart when extruded from the mold and placed on a metal pan to cool. To us, this indicates that the addition of fibers is necessary to reach the optimum asphalt content of 6.5 %.

We also observed with the Pedernal mix at optimum asphalt content and without antistrip agent, that the aggregate stripped on samples without fibers, but did not strip on samples with fibers. This tendency seems to indicate that the presence of fibers in the mix may deter stripping. Further study on this phenomenon is needed, however.

We induced one other failure of the same type (i.e., slumping after removal from the mold) by using a gradation in the Davis mix, which was within the specified gradation envelope, but formed a curved gradation at the 4.75 mm sieve (i.e., from 9.5 mm to 2.00 mm) instead of a sharp dogleg at the 4.75 mm sieve composed of two nearly straight line segments meeting at the 4.75 mm sieve size. We remolded this mix with a gradation entering and leaving the dogleg with more nearly straight line segments and had no trouble with it.

These two experimental "failures" illustrate some of the sensitivities of the SMA mix that must be prevented in the lab and during plant production.

Another anomaly with the Davis mix is that on the first set of molded samples (5.5 to 7.5% asphalt), none reached 96.0 % density. We remolded another set of samples from 6.0 to 8.3 % asphalt and achieved an optimum density of 96.0 % at 7.9 or 8.0 % ^yphalt, as interpolated from the plotted data. Normally one doesn't want an asphalt content this high. This mix required a high asphalt content because the VMA was very high (23%).

A more economical mix at around 6.5% asphalt could be achieved if the gradation(s) of one or more cold feeds were altered slightly so as to yield a lower VMA. VMA depends almost entirely on gradation and particle shape.

Included with these brief notes are the following documents:

Special Specification Item 8888, "SMA Concrete Pavement" (Preliminary)

Special Specification Item 9999, "Cellulose Fibers for Bituminous Mixtures" (Preliminary)

Suggested Plan Notes and Designers' Discussion

Suggested Reference Items

Laboratory Design of Stone Matrix Asphalt (SMA) Mixtures with Fibers Using the Marshall Mix Design Method

Six SMA mix designs using the aggregates listed in Table 1, with various graphs of gradations and VMA, VFA, density, air voids plotted against percent asphalt, with optimum percent asphalt indicated on the graphs. Also included is a table of various factors at optimum percent asphalt for each aggregate source. As a matter of convenience, these mix designs will be referred to by their respective pit names as shown in the second column of Table 1.

These documents are contained in the appendices.

APPENDIX A: SPECIAL SPECIFICATIONS

SPECIAL SPECIFICATION

ITEM 3026

STONE MATRIX ASPHALTIC (SMA) CONCRETE PAVEMENT

1. Description. This Item shall govern for the construction of a base course, a level-up course, a surface course or a combination of these courses as shown on the plans, being composed of a compacted mixture of aggregate and asphalt cement with or without additives such as latex, antistripping agent and/or cellulose fibers mixed hot in a mixing plant, in accordance with the details shown on the plans and the requirements herein.

2. Materials. The Contractor shall furnish materials to the project meeting the following requirements prior to mixing. Additional requirements affecting the quality of individual materials or the paving mixture shall be required when indicated on the plans.

(1) Aggregate. The aggregate shall be composed of coarse aggregate, fine aggregate, and mineral filler. All coarse and fine aggregate and mineral filler shall be the products of a crushing operation. Unless allowed otherwise by the Engineer, coarse and fine aggregate shall be from the same source (pit). Samples of each aggregate and mineral filler shall be submitted for approval in accordance with Item 6, "Control of Materials".

Aggregate from each stockpile shall meet the quality requirements of Table 1 and other requirements as specified herein. Material handling procedures shall be used which avoid or reduce aggregate segregation.

Coarse and fine aggregate shall be located on a well-drained site, and shall be maintained at a moisture content of 6% or less. This may require that stockpiles be covered in wet weather. Mineral filler shall be stockpiled in a silo or other protected storage.

Once a stockpile has been sampled, tested and approved, additional aggregates shall not be added to it. When additional aggregates or mineral fillers are delivered to the hot mix plant, they shall be added to a stockpile which has not been sampled, tested and approved, or shall start a new stockpile.

Transfers of aggregates and mineral filler from one tested and approved stockpile to another tested and approved stockpile of the same gradation are acceptable on approval by the Engineer.

(a) Coarse Aggregate. Coarse aggregate is defined as that part of the aggregate retained on a 4.75 mm sieve for all types except Type A. The aggregate shall be natural and of uniform quality. Gravel and crushed gravel shall not be used.

Type A gradation of Table 2 uses the 6.3 mm instead of the 4.75 mm sieve to define coarse/fine aggregate.

Lightweight aggregate shall not be used. Lightweight aggregate is defined as expanded shale, clay or slate produced by the rotary kiln method.

The polish value for the coarse aggregate used in the surface or finish course shall not be less than the value shown on the plans, when tested in accordance with Test Method Tex-438-A. Unless otherwise shown on the plans, the polish value requirement will apply only to surface mix used on travel lanes. For rated sources, the Division of Materials and Tests' Rated Source Polish Value (RSPV) catalog will be used to determine polish value compliance.

Coarse aggregate shall not be blended to meet the polish value requirement.

At least one stockpile shall be provided for each cold feed aggregate and mineral filler required in the mix design as determined in Article 3., "Paving Mixtures". The Engineer may require additional stockpiles to maintain control of the mixture.

(b) Fine Aggregate. The fine aggregate is defined as that part of the aggregate passing the 4.75 mm sieve for all types except Type A and shall be of uniform quality throughout. Screenings and fine aggregate shall be products of stone crushing operations, and 100% shall pass the 4.75 mm sieve. No field sand or other uncrushed fine aggregate shall be used. Crushed gravel screenings shall not be used.

Screenings and fine aggregate shall be supplied from sources whose coarse aggregate meets the requirements shown in Table 1, unless otherwise shown on the plans.

(c) Mineral Filler. Mineral filler shall consist of thoroughly dried stone dust resulting from crushing operations. The mineral filler shall be free from foreign matter. The mineral filler must be kept dry and free flowing. Bag house fines and other materials with rounded particles shall not be used as mineral filler. The use of fly ash will not be permitted. Ag lime (processed limestone) is allowed as mineral filler.

When tested in accordance with Test Method Tex-200-F (Part II), the mineral filler shall meet the following gradation requirements, unless otherwise shown on the plans.

	Percent by Mass or Volume
Passing the 0.600 mm sieve	100
Passing the 0.180 mm sieve, not less than	75
Passing the 0.075 mm sieve, not less than	60

(d) The several aggregate fractions and mineral filler shall be sized, graded, and combined in such proportions that the resulting composite blend conforms to Table 2 for the grading type(s) selected for the project and shown on the plans.

TABLE 1
AGGREGATE
QUALITY REQUIREMENTS *

Requirement	Test Method	Natural Aggregate
FINE AND COARSE AGGREGATE **		
24 Hour Water Absorption, Percent, maximum	Tex-433-A	2.0
Flakiness Index, maximum	Tex-224-F	17
Deleterious Material, percent, maximum	Tex-217-F Part I	1.5
Decantation, percent, maximum	Tex-217-F Part II	1.5
Los Angeles Abrasion, percent, maximum	Tex-410-A	25
Magnesium Sulfate Soundness Loss, 5 cycle, percent, maximum	Tex-411-A	20
FINE AGGREGATE		
Linear Shrinkage, maximum	Tex-107-E Part II	3

* Sampled during delivery to the plant or from the stockpile, unless otherwise shown on the plans.

** Coarse aggregate shall meet Polish Value requirement for surface course of driving lanes only, as shown on the plans.

(2) Asphaltic Material.

(a) Paving Mixture. A polymer-modified, performance-graded asphalt cement for the paving mixture shall be selected from those listed below and shown on the plans, and as approved for the mix design and shall meet the requirements of Item 300, "Asphalts, Oils and Emulsions" and Special Provision (300---025). The Contractor shall notify the Engineer of the source of the asphaltic material prior to design of the asphaltic mixture. This source shall not be changed during the course of the project without the authorization of the Engineer.

PG 76-22
PG 76-28

(b) Tack Coat. Asphaltic materials, SS-1, SS-1h, CSS-1h, or similar as shown on the plans or approved by the Engineer, shall meet the requirements of Item 300, "Asphalts, Oils and Emulsions".

(3) Additives. Additives to facilitate mixing and/or improve the quality of the paving mixture shall be used when noted on the plans or may be used with the authorization of the Engineer. The following additives may be used except as prohibited: Anti-Stripping agent and Cellulose Fiber.

Antistrip Agent. Unless otherwise shown on the plans, the Engineer may choose to use either lime or a liquid antistripping agent to reduce the moisture susceptibility of the aggregate. The evaluation and addition of antistripping agents will be in accordance with Item 301, "Asphalt Antistripping Agents", and Test Method TEX-530-C. The maximum stripping allowed is zero percent.

Cellulose Fiber. Cellulose fiber shall be used to control asphalt drainage. The cellulose fiber shall be of the type shown on the plans and shall meet the requirements of Special Specification, "Cellulose Fiber for Bituminous Mixtures", Type A or B. Normally, drainage is controlled with the mineral filler and fiber content. Cellulose fibers shall be added at 0.3 % by mass of the mixture. The test procedure for drainage is TEX-235-F, "Determination of Draindown Characteristics in Bituminous Materials". A draindown of 0.3% max in one hour is allowed. A separate dry storage area or silo shall be required for the cellulose fiber.

3. Paving Mixtures. The paving mixtures shall consist of a uniform mixture of aggregate, asphalt cement, and additives as allowed or required.

The design of a paving mixture is a laboratory process which includes the determination of the quality and quantity of asphalt, additives and the individual aggregates, and the testing of the combined mixture. The design of the paving mixture is the responsibility of the District Laboratory. The final result of this process is called a Job-Mix Formula (JMF).

(1) Mixture Design. The Contractor shall furnish the Engineer with representative samples of the materials to be used in production. Using these materials, the mix shall be designed in accordance with the 50-blow Marshall Compaction Method (ASTM D 1559) and the "Laboratory Design of Stone Matrix Asphalt (SMA) Mixtures with Fibers Using the Marshall Mix Design Method", to comform with the requirements herein. Unless otherwise shown on the plans, the Engineer will furnish the mix design (JMF1). The Engineer may accept a design from the Contractor which was derived using these design procedures.

The second and subsequent mixture designs, or partial designs, for each type of paving mixture which are necessitated by changes in the material or at the request of the Contractor will be charged to the Contractor when a rate is shown on the plans.

The mixture shall be designed to produce an acceptable mixture at an optimum laboratory density of 96.0 percent, when tested in accordance with Test Method Tex-207-F and Test Method Tex-227-F. The operating range for control of laboratory density during production shall be optimum density plus 0.5 or minus 0.5 percent.

The bulk specific gravity will be determined for each aggregate to be used in the mixture design. If the determined values vary by 0.300 or more, the Volumetric Method, Test Method Tex-204-F, Part II, will be used.

When properly proportioned for the type specified, the blend of aggregates shall produce an aggregate gradation which will conform to the limits of the master grading shown in Table 2. Unless otherwise shown on the plans, the gradation of the aggregate will be determined in accordance with Test Method Tex-200-F, Part II (Washed Sieve Analysis), to develop the job-mix formula.

The voids in the mineral aggregate (VMA) will be determined in accordance with Test Method TEX-207-F. The VMA shall meet the requirement shown in Table 2.

Unless otherwise shown on the plans, the mixture of aggregate, asphalt, and additives proposed for use will be evaluated in the design stage for moisture susceptibility in accordance with Item 301, "Asphalt Antistripping Agents" using Test Method TEX-530-C. When tested according to the procedure specified, zero percent stripping is required.

To verify the design, a plant trial mixture (JMF2) shall be produced by the contractor and tested by the District Lab using all of the proposed project materials and equipment prior to any placement. JMF2 shall comply with Table 3 for tolerances.

(2) Job-Mix Formula Field Adjustments. The Contractor shall produce a mixture (JMF3) of uniform composition closely conforming to the approved job-mix formula (JMF1) and Table 3.

Laboratory density is a mixture design and process control parameter. If the laboratory density of the mixture produced has a value outside the range specified above, the Contractor shall investigate the cause and take corrective action. If two (2) consecutive test results fall outside the specified range, production shall cease unless test results or other information indicate, to the satisfaction of the Engineer, that the next mixture to be produced will be within the specified range.

If, during initial days of production, the Engineer determines that adjustments to the mixture design job-mix formula (JMF3) are necessary, the Engineer may allow adjustment of the mixture design job-mix formula within the following limits without a laboratory redesign of the mixture. The adjusted job-mix formula shall not exceed the limits of the master grading for the type of mixture specified, nor shall the adjustments exceed 5 percent on any one sieve 9.5 mm size and larger, or 3 percent on the sieve sizes below the 9.5 mm sieve.

When the considered adjustments exceed either the 5 or 3 percent limits of Table 3, and the Engineer determines that the impact of these changes may adversely affect pavement performance, a new laboratory mixture design will be required. Note that the field adjusted gradations shall remain within the limits established in Table 2 and 3 for all Job-Mix Formulas (JMF1, JMF2 and JMF3).

The asphalt content and cellulose fiber content may be adjusted as deemed necessary by the Engineer.

(3) Types. The aggregate gradation of the job-mix formula shall conform to the master grading limits shown in Table 2 for the type mix specified on the plans.

TABLE 2
Master Grading *
Percent Passing by Mass

Sieve Size	Type				
	A	B	C	D	E
25.0 mm	100				As Shown on the Plans
22.4 mm		100			
19.0 mm	80-100		100		
16.0 mm		80-100		100	
12.5 mm	45-70		80-100		
9.5 mm	20-28	53-70	55-75	80-100	
6.4 mm				45-70	
4.75 mm	15-23	20-28	20-28	20-28	
2.36 mm	13-21	13-21	13-21	13-21	
0.600 mm	10-17	10-17	10-17	10-17	
0.300 mm					
0.075 mm	9-15	9-15	9-15	9-15	
VMA, % (min)	17	17	17	17	

* Test Method Tex-200-F, Part II, (Washed Sieve Analysis) shall be used.

(4) Tolerances. The gradation of the aggregate and the asphalt cement content of the produced mixture (JMF3) shall not vary from the original job-mix formula (JMF1) by more than the tolerances allowed in Table 3.

Table 3
Stockpile and Job-Mix Formula Tolerances

COMPONENT	TOLERANCES (Note 1)			
	Original Design JMF1	Plant Trial Batch JMF2	Plant Production JMF3	All (2) Stockpiles JMF1, JMF2 JMF3
Aggregate Gradation:				
Passing 25.0 mm, retained on 9.5 mm Sieve	Limits of Table 2 +/- 1%	JMF1 +/- 5%(1)	JMF1 +/-5%(1)	See Note (3) +/- 5%
Passing 9.5 mm thru 0.075 mm Sieve	Must remain within Master Gradation Limits of Table 2			See Note (3) +/- 3%
Asphalt, mass	NA	JMF1 +/- 0.2%		
Asphalt, volume	NA	JMF1 +/- 0.5%		
Cellulose Fiber, mass	NA	JMF1 +/- 0.1%		

Notes:

(1) When a tolerance of +/- 5% is applied to the gradation of JMF1, the resulting gradation may fall outside the gradation limits of Table 2.

(2) Includes stockpiles for mineral filler.

(3) The basis for these tolerances (for stockpiles) shall be the gradations for each cold feed used in the approved JMF1.

The mixture will be tested in accordance with Test Method Tex-210-F, or Test Method Tex-228-F will be used in conjunction with combined cold feed belt samples tested in accordance with Test Method Tex-229-F. Other methods of proven accuracy may be used. The methods of test will be determined by the Engineer. However, mixtures produced by weigh-batch plants will be tested for gradation in accordance with Test Method Tex-210-F. If two consecutive tests indicate that the material produced exceeds the tolerances of Table 3 on any individual sieve, or if any single test indicate that the asphalt content tolerance or cellulose fiber content tolerance is exceeded, production shall stop and not resume until test results or other information indicate, to the satisfaction of the Engineer, that the next mixture to be produced will be within the above tolerances.

When disagreements concerning determination of specification compliance occur between allowed sampling and testing procedures, extracted aggregate testing shall take precedence over cold feed belt testing.

When cold feed belt samples (TEX-229-F) are used for job control, the Engineer will select the sieve analysis method that corresponds with the one used to determine the mixture design gradation.

4. Equipment.

(1) General. All equipment for the handling of all materials, mixing, placing and compacting of the mixture shall be maintained in good repair and operating condition and subject to the approval of the Engineer. Any equipment found to be defective and potentially having a negative effect on the quality of the paving mixture or ride quality will not be allowed.

(2) Mixing Plants. Mixing plants may be the weigh-batch type, the modified weigh-batch type or the drum-mix type. All plants shall be equipped with satisfactory conveyors, power units, mixing equipment, aggregate handling equipment, bins and dust collectors.

Scalping screens shall be required after cold feeds and ahead of the combined aggregate belt scales.

Automatic proportioning devices are required for all plants and shall be in accordance with Item 520, "Weighing and Measuring Equipment".

Mineral filler shall be porportioned into the mix by weight. A hopper or other acceptable storage system shall be required to maintain a constant supply of free-flowing mineral filler to the measuring system. A cold feed bin shall not be used.

The measuring device for adding mineral filler shall be tied into the automatic plant controls so that the supply of mineral filler will be automatically adjusted to plant production and provide a consistent percentage to the mixture. The measuring device for adding mineral filler shall have controls in the plant control room which will allow manual adjustment of feed rates to match plant production rate adjustments.

It shall be the Contractor's responsibility to provide safe and accurate means to enable inspection forces to take all required samples, to provide permanent means for checking the output of any specified metering device, and to perform calibration and mass checks as required by the Engineer. When cold feed belt sampling is to be used for gradation testing, occasional stoppage of the belt may be neccessary unless other means of sampling are approved by the Engineer.

Regardless of the burner fuel used, the burner or combination of burners and types of fuel used shall provide a complete burn of the fuel and not leave any fuel residue that will adhere to the heated aggregate or become mixed with the asphalt.

If latex is required by the approved JMF, it shall be introduced into the asphalt and thoroughly blended before being mixed with the hot aggregate. A bin or silo shall be provided for mineral filler which shall be dry and loose when metered.

Cellulose fiber will not be allowed in the hot bins.

The dryer shall continually agitate the aggregate during heating. The temperature shall be controlled so that the aggregate will not be damaged in the drying and heating operations. The dryer shall be of sufficient size to keep the plant in continuous operation. The drying temperature shall be 155 C min.

Asphaltic Material Measuring System. If an asphaltic material bucket and scales are used, they shall be of sufficient capacity to hold and weigh the necessary asphaltic material for one batch. The bucket and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment".

If a pressure type flow meter is used to measure the asphaltic material, the requirements of Item 520, "Weighing and Measuring Equipment", shall apply. This system shall include an automatic temperature compensation device to insure a constant percent by mass of asphaltic material in the mixture.

Provisions of a permanent nature shall be made for checking the accuracy of the asphaltic material measuring device. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material.

Surge-Storage System and Scales. A surge-storage system shall be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge-storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

Scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, "Weighing and Measuring Equipment". If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require weight checks by truck scales for the basis of approval of the equipment.

Recording Device and Record Printer. Automatic recording devices and automatic digital record printers shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day in accordance with Item 520, "Weighing and Measuring Equipment", unless otherwise shown on the plans.

(3) Asphaltic Material Heating Equipment. Asphaltic material heating equipment shall be adequate to heat the required amount of asphaltic material to the desired temperature. The heating apparatus shall be equipped with a continuously recording thermometer with a 24-hour chart that will record the temperature of the asphaltic material at the location of highest temperature.

(4) Spreading and Finishing Machine. The spreading and finishing machine shall be approved by the Engineer and shall meet the requirements indicated below.

(a) Screed Unit. The spreading and finishing machine shall be equipped with a heated compacting screed. It shall produce a finished surface meeting the requirements of the typical cross sections and the surface tests.

Extensions added to the screed shall be provided with the same compacting action and heating capability as the main screed unit, except for use on variable depth tapered areas and/or as approved by the Engineer.

The spreading and finishing machine shall be equipped with an approved automatic dual longitudinal screed control system and automatic transverse screed control system. The longitudinal controls shall be capable of operating from any longitudinal grade reference including a stringline, ski, mobile stringline, or matching shoe.

The Contractor shall furnish all equipment required for grade reference. It shall be maintained in good operating condition by personnel trained in the use of this type of equipment.

The grade reference used by the Contractor may be of any type approved by the Engineer. Control points, if required by the plans, shall be established for the finished profile in accordance with Item 5, "Control of the Work". These points shall be set at intervals not to exceed 15 meters. The Contractor shall set the grade reference from the control points. The grade reference shall have sufficient support so that the maximum deflection shall not exceed 1.6 mm between supports.

(b) Tractor Unit. The tractor unit shall be equipped with a hydraulic hitch sufficient in design and capacity to maintain contact between the rear wheels of the hauling equipment and the pusher rollers of the finishing machine while the mixture is being unloaded.

No portion of the mass of hauling equipment, other than the connection, shall be supported by the asphalt paver. No vibrations or other motions of the loading equipment, which could have a detrimental effect on the riding quality of the completed pavement, shall be transmitted to the paver.

The use of any vehicle which requires dumping directly into the finishing machine and which the finishing machine cannot push or propel to obtain the desired lines and grades without resorting to hand finishing will not be allowed.

(5) Material Transfer Equipment. Equipment to transfer mixture from the hauling units or the roadbed to the spreading and finishing machine will be allowed unless otherwise shown on the plans. A specific type of material transfer equipment shall be required when shown on the plans.

(a) Windrow Pick-Up Equipment. Windrow pick-up equipment shall be constructed in such a manner that substantially all the mixture deposited on the roadbed is picked up and loaded into the spreading and finishing machine. The mixture shall not be contaminated with foreign material. The loading equipment shall be designed so that it does not interfere with the spreading and finishing machine in obtaining the required line, grade and surface without resorting to hand finishing.

(b) Material Transfer System. Material transfer systems shall be designed to provide a continuous flow of uniform mixture to the spreading and finishing machine. When use of a material transfer system is required on the plans, it shall meet the storage capacity, remixing capability, or other requirements shown on the plans.

(6) Rollers. Steel wheel rollers shall be provided and shall meet the requirements for rollers in Item 340, "Hot Mix Asphaltic Concrete Pavement" as to type as follows:

(a) Two-Axle Tandem Roller. This roller shall be an acceptable self-propelled tandem roller weighing not less than 10.9 megagrams.

(b) Three-Wheel Roller. This roller shall be an acceptable self-propelled three wheel roller weighing not less than 10.9 megagrams.

(c) Three-Axle Tandem Roller. This roller shall be an acceptable self-propelled three axle roller weighing not less than 10.9 megagrams.

(d) Pneumatic Tire Roller. This roller shall not be used for compaction or finishing the SMA mat.

(e) Vibratory Rollers. Vibratory Steel Wheel roller shall not be used, unless directed otherwise by the Engineer.

(7) Straightedges and Templates. When directed by the Engineer, the Contractor shall provide acceptable 3.0 meter straightedges for surface testing. Satisfactory templates shall be provided as required by the Engineer.

(8) Alternate Equipment. When permitted by the Engineer, equipment other than that specified herein which will consistently produce satisfactory results may be used.

5. Stockpiling, Storage and Mixing.

(1) Stockpiling of Aggregates.

(a) All Plant Types. Prior to stockpiling of aggregates, the area shall be cleaned of trash, weeds, grass and shall be relatively smooth and well drained. The stockpiling shall be done in a manner that will minimize aggregate degradation, segregation, mixing of one stockpile with another, and will not allow contamination with foreign material.

The plant shall have at least a two-day supply of aggregates on hand before production can begin and at least a two-day supply shall be maintained through the course of the project, unless otherwise directed by the Engineer.

No stockpile shall contain aggregate from more than one source. There shall be one stockpile for each source aggregate identified in the approved JMF.

Additional material shall not be added to stockpiles that have previously been sampled for approval, unless authorized by the Engineer who will sample this additional material for testing and approval before adding to the stockpile.

Equipment of an acceptable size and type shall be furnished to work the stockpiles and prevent segregation and degradation of the aggregates.

If moisture content of any stockpile exceeds 6% in the lower 1/3 of the stockpile, production from this stockpile shall cease until such time that the moisture content tests 6% or less.

(b) Drum-Mix Plant. When a drum-mix plant is used, the following stockpiling requirements for coarse aggregates shall apply in addition to the aggregate stockpiling requirements listed under Subarticle 2.(1) and Section 5.(1)(a).

Once a job-mix formula has been established in accordance with Article 3., "Paving Mixtures", the coarse aggregates delivered to the stockpiles shall not vary on any grading size fraction by more than the tolerances found in Table 3 upon which the job-mix formula was based. Should the gradation of coarse aggregates in the stockpiles vary by more than the allowed tolerance, the Engineer may stop production. If production is stopped, new aggregates shall be furnished that meet the gradations of the aggregates submitted for the job-mix formula, or a new mix design shall be formulated in accordance with Article 3., "Paving Mixtures".

When the volume of production from a commercial plant makes sampling of all coarse aggregate delivered to the stockpiles impractical, cold feeds will be sampled to determine stockpile uniformity. Should this sampling prove the stockpiles non-uniform beyond the acceptable tolerance, separate stockpiles which meet these specifications may be required.

(2) Storage and Heating of Asphaltic Materials. The asphaltic material storage capacity shall be ample to meet the requirements of the plant. Asphalt shall not be heated to a temperature in excess of 177 C. All equipment used in the storage and handling of asphaltic material shall be kept in a clean condition at all times and shall be operated in such a manner that there will be no contamination with foreign matter.

(3) Feeding and Drying of Aggregate. The aggregate shall be fed to the dryer at a moisture content of 6% or less. The feeding of various sizes of aggregate to the dryer shall be done through the cold aggregate bins and the proportioning device in such a manner that a uniform and constant flow of materials in the required proportions will be maintained. The aggregate shall be dried and heated to the temperature necessary to produce a mixture having the specified temperature.

(4) Feeding of Cellulose Fiber. The feeding of the cellulose fiber shall be performed in a manner such that the fibers are not damaged during the feeding and mixing processes and in a manner such that a uniform and constant flow of materials in the required proportions will be maintained. The cellulose fiber storage capacity shall be ample to meet the requirements of the plant. All equipment used in the storage and handling of cellulose fibers shall be kept in a clean condition at all times

and shall be operated in such a manner that there will be no contamination with foreign matter.

(a) Weigh-Batch Plant. Cellulose fiber shall be introduced into the pug-mill during the dry mixing of the aggregates, prior to injection of the asphalt.

(b) Modified Weigh-Batch Plant. The mixing requirements shall be the same as is required for a standard Weigh-Batch Plant.

(c) Drum-Mix Plant. Cellulose fiber shall be added to the mixture during the dry mixing process, unless otherwise approved by the Engineer. The cellulose fiber should be uniformly dispersed in the mixture. If Type B cellulose fiber is required, the fiber shall be introduced into the drum dryer at the recycle port by use of a vane feeder unless otherwise approved by the Engineer.

(5) Mixing and Storage.

(a) Weigh-Batch Plant. In introducing the batch into the mixer, all aggregates and then all cellulose fiber shall be introduced first and shall be mixed thoroughly for a minimum period of 5 seconds to uniformly distribute the various sizes of the aggregate and cellulose fiber throughout the batch before the asphaltic material is added. The asphaltic material shall then be added and the mixing continued for a wet mixing period of not less than 15 seconds. The mixing period shall be increased if, in the opinion of the Engineer, the mixture is not uniform or the aggregates are not properly coated.

Temporary storing or holding of the asphaltic mixture by the surge-storage system will be permitted during the normal day's operation. Overnight storage will not be permitted.

(b) Modified Weigh-Batch Plant. The mixing and storage requirements shall be the same as is required for a standard weigh-batch plant.

(c) Drum-Mix Plant. The amount of aggregate, cellulose fiber and asphaltic material entering the mixer and the rate of travel through the mixing unit shall be so coordinated that a uniform mixture of the specified grading, cellulose fiber content and asphalt content will be produced.

Temporary storing or holding of the asphaltic mixture by the surge-storage system will be required during the normal day's operation. Overnight storage will not be permitted.

(d) Mixing and Discharge Temperature. The Engineer will select the target discharge temperature of the mixture between 163 C and 177 C. The mixture, when discharged from the mixer, shall not vary from this selected temperature more than 5 C, but in no case shall the temperature exceed 182 C (360 F).

(e) Moisture Content. The mixture produced from each type of mixer shall have a moisture content not greater than 0.5 percent by mass when discharged from the mixer, unless otherwise shown on the plans and/or approved by the Engineer. The moisture content shall be determined in accordance with Test Method Tex-212-F.

(f) Summary of Temperature Requirements for:

	PG 76-22 PG 76-28
Dry & Preheat Aggregate at	163-177 C (325-350 F)
Mixing and discharge temperature for HMAC	163-177 C (325-350 F)
Deliver Hot Mix to Paver (as measured in truck just prior to dumping into spreader)	157 C (315 F) min
Spread HMAC on road surface (as measured immediately behind screed)	146-155 C (295-311 F)
Compaction/rolling begins at	146 C (295 F) min
Compaction/rolling ceases at	132 C (270 F) min
Open to traffic at	60 C (140 F) max

6. Construction Methods.

(1) General. It shall be the responsibility of the Contractor to produce, transport, place and compact the specified paving mixture in accordance with the requirements herein.

The asphaltic mixture, when placed with a spreading and finishing machine, or the tack coat shall not be placed when the air temperature is below 15.0 C and is falling, but it may be placed when the air temperature is above 10.0 C and is rising.

The air temperature shall be taken in the shade away from artificial heat.

SMA mats shall not be placed when the temperature of the surface on which the mat is to be placed is below 10 C.

It is further provided that the tack coat or asphaltic mixture shall be placed only when the humidity, general weather conditions, temperature and moisture condition of the base, in the opinion of the Engineer, are suitable.

If, after being discharged from the mixer and prior to placing, the temperature of the asphaltic mixture is 5 C or more below the selected discharge temperature established by the Engineer, all or any part of the load may be rejected and payment will not be made for the rejected material.

Control of construction shall be accomplished by the following tests:

Sample hot mix from truck before the truck departs the plant. Sample of 10 to 20 kg shall be placed in an insulated container and taken directly to the lab where the following tests will be performed using a Marshall compactor, 50 blows per side:

Rice Gravity	-----
Bulk Density, %	95.5-96.5
Air Void, %	3.5- 4.5
VMA, %	17 min
Asphalt, %(mass)	Table 3
Gradation	Table 3
Moisture Content %(mass)	0.5 max
VFA, %	75-84

The Contractor shall sample hot mix from driving lanes after compaction and after complete cooling to ambient temperature, at locations corresponding to the approximate placement of the same truck load from which the lab sample was taken, or as directed by the Engineer. Perform the following tests using 4 in-place 150 mm Diameter cores:

Rice Gravity	-----
Bulk Density, %	94-96
Air Voids, %	4-6
VMA, %	17 min
Asphalt	Table 3
Gradation	Table 3

All tests listed above shall be performed at least once for each 600 Mg of produced hot mix, or fraction thereof. These tests will be performed by the District Laboratory; but the core holes shall be repaired/filled by the contractor, as approved by the Engineer.

(2) Tack Coat. The surface upon which the tack coat is to be placed shall be cleaned thoroughly to the satisfaction of the Engineer. The surface shall be given a uniform application of tack coat using asphaltic materials of this specification. This tack coat shall be applied, as directed by the Engineer, with an approved sprayer at a rate not to exceed 0.23 liters residual asphalt per

square meter of surface. Where the mixture will adhere to the surface on which it is to be placed without the use of a tack coat, the tack coat may be eliminated by the Engineer. All contact surfaces of curbs and structures and all joints shall be painted with a thin uniform application of tack coat. During the application of tack coat, care shall be taken to prevent splattering of adjacent pavement, curb and gutter and structures. The tack coat shall be rolled with a pneumatic tire roller when directed by the Engineer.

(3) Transporting Asphaltic Concrete. The asphaltic mixture shall be hauled to the work site in tight vehicles previously cleaned of all foreign material. The dispatching of the vehicles shall be arranged so that all material delivered is placed and all rolling completed during daylight hours unless otherwise shown on the plans. In cool weather or for long hauls, covering and insulating of the truck bodies may be required. If necessary, to prevent the mixture from adhering to the body, the inside of the truck may be given a light coating of release agent satisfactory to the Engineer. See Article 7., "Authorized Release Agents" in this specification. Excess release agent shall not be allowed to pool in truck beds.

(4) Placing.

(a) The asphaltic mixture shall be dumped and spread on the approved prepared surface with the spreading and finishing machine. After compaction, the finished pavement shall be smooth, of uniform texture and shall meet the requirements of the typical cross sections and the surface tests specified in Special Specification, "Ride Quality for Pavement Surfaces". In addition, the placing of the asphaltic mixture shall be done without tearing, shoving, gouging or segregating the mixture and without producing streaks in the mat.

Hand raking of the asphaltic pavement mat behind the spreading and finishing machine will not be allowed. If the surface of the mat placed with the spreading and finishing machine "pulls" or contains voids and/or surface irregularities, the Contractor shall repair these areas and by shoveling additional mix to fill the void areas in advance of the first pass of the roller.

Unloading into the finishing machine shall be controlled so that bouncing or jarring the spreading and finishing machine shall not occur and the required lines and grades shall be obtained without resorting to hand finishing.

When shown on the plans, dumping of the asphaltic mixture in a windrow and then placing the mixture in the finishing machine with windrow pick-up equipment will be permitted. The windrow pick-up equipment shall be operated in such a manner that substantially all the mixture deposited on the roadbed is picked up and loaded into the finishing machine without contamination by foreign material. The windrow pick-up equipment will be so operated that the finishing machine will obtain the required line, grade and surface without resorting to hand finishing. Any operation of the windrow pick-up equipment resulting in the accumulation and subsequent shedding of accumulated material into the asphaltic mixture will not be permitted.

(b) The mixture temperature at time of placement through the paver shall be between 146 C and 155 C, as measured immediately behind the screen.

(c) The spreading and finishing machine shall be operated at a uniform forward speed consistent with the plant production rate, hauling capability, and roller train capacity to result in a continuous operation. The speed shall be slow enough that stopping between trucks is not ordinarily necessary. If, in the opinion of the Engineer, sporadic delivery of material is adversely affecting the mat, the Engineer may require paving operations to cease until acceptable methods are provided to minimize starting and stopping of the paver.

The hopper flow gates of the spreading and finishing machine shall be adjusted to provide an adequate and consistent flow of material. These shall result in enough material being delivered to the augers so that they are operating approximately 85 percent of the time or more. The augers shall provide means to supply adequate flow of material to the center of the paver. Augers shall supply an adequate flow of material for the full width of the mat, as approved by the Engineer. Augers should be kept approximately one-half to three-quarters full of mixture at all times during the paving operation.

(d) Adjacent to flush curbs, gutters and structures, the surface course shall be finished uniformly high so that when compacted it will be slightly above the edge of the curb or structure.

(e) Construction joints of successive courses of asphaltic material shall be offset at least 150 millimeters. Construction joints on surface courses shall coincide with lane lines, or as directed by the Engineer.

(f) If a pattern of surface irregularities or segregation is detected, the Contractor shall make an investigation into the causes and immediately take the necessary corrective actions up to and including removal and replacment. With the approval of the Engineer, placement may continue for no more than one full production day from the time the

Contractor is first notified and while corrective actions are being taken. If the problem still exists after that time, paving shall cease until the Contractor further investigates the causes and the Engineer approves further corrective action to be taken.

(5) Compacting.

(a) The pavement shall be compacted thoroughly and uniformly with the necessary rollers to obtain the compaction and cross section of the finished paving mixture as directed by the Engineer. Due to the nature of the SMA mixture, rolling should begin immediately behind the spreader. Rolling shall be done in straight, or curved lines parallel to the center line of the roadway. No turning of rollers on the mat is permitted.

(b) When rolling with three-wheel or tandem rollers, rolling shall start by first rolling the joint with the adjacent pavement and then continue by rolling longitudinally at the sides and proceed toward the center of the pavement, overlapping on successive trips by at least 0.3 meter, unless otherwise directed by the Engineer. Alternate trips of the roller shall be slightly different in length. On super-elevated curves, rolling shall begin at the low side and progress toward the high side, unless otherwise directed by the Engineer.

The motion of the rollers shall be slow enough to avoid other than usual initial displacement of the mixture. If any displacement occurs, it shall be corrected to the satisfaction of the Engineer. The roller shall not be allowed to stand on pavement which has not been fully compacted. To prevent adhesion of the surface mixture to the steel-wheel rollers, the wheels shall be kept thoroughly moistened with water, but an excess of water will not be permitted. Necessary precautions shall be taken to prevent the dropping of diesel, gasoline, oil, grease or other foreign matter on the pavement, either when the rollers are in operation or when standing.

(c) The edges of the pavement along curbs, headers and similar structures, and all places not accessible to the roller, or in such positions as will not allow thorough compaction with the rollers, shall be thoroughly compacted with tamps which have been sprayed with asphalt release agent (See Article 7.).

(d) Rollers in a vibratory mode, with high frequency and low amplitude, shall not be used except on written approval by the Engineer. However, care must be exercised so that the asphalt mastic does not migrate to the surface or that aggregate break-down does not occur. Vibratory rollers shall not be used on mats less than 38 millimeters thick.

(e) Test Strips. Unless otherwise shown on the plans, the Contractor will be required to place one test strip for each proposed mixture design at a location shown on the plans, or approved by the Engineer prior to placment on the roadway. Minimum dimensions for each test strip shall be shown on the plans. Maximum test strip length is 322 meters, each.

(6) In-Place Compaction Control. In-place compaction control is required for all mixtures. Unless otherwise shown on the plans, air void control shall be required.

(a) Air Void Control. The Contractor shall be responsible for determining the number and type of rollers to be used to obtain compaction to within the air void range required herein. The rollers shall be operated in accordance with the requirements of this specification and as approved by the Engineer.

Asphaltic concrete shall be placed and compacted to contain from four (4) to six (6) percent air voids corresponding to 94 to 96 percent density. The percent air voids will be calculated using the theoretical maximum specific gravity of the mixture determined according to Test Method Tex-227-F. Roadway specimens, which shall be either cores or sections of asphaltic pavement, will be tested according to Test Method Tex-207-F. The nuclear-density gauge or other methods which correlate satisfactorily with results obtained from project roadway specimens may be used when approved by the Engineer. Unless otherwise shown on the plans, the Contractor shall be responsible for obtaining the required roadway specimens at his expense and in a manner and at locations selected by the Engineer.

If the percent air voids in the compacted placement is greater than 6.0 percent, production may proceed after changes in the construction operations and/or mixture. If the air void content is not reduced to between four (4) and six (6) percent within four hours' production from the time the Contractor is notified, production shall cease. At that point, a test section as described below shall be required.

If the percent air voids is more than 6.5 percent, production shall cease immediately and a test section shall be required as described below.

In either case, the Contractor shall only be allowed to place a test section of one lane width, not to exceed 322 meters in length, to demonstrate that compaction to between four (4) and six (6) percent air voids can be be obtained. This procedure will continue until a test section with four (4) to six (6) percent air voids can be produced. When a test section producing satisfactory air void content is placed, full production may then resume.

Test sections shall be placed at location(s) shown on the plans, or approved by the Engineer.

Increasing the asphalt content of the mixture in order to reduce pavement air voids will not be allowed.

If the percent air voids is determined to be less than 3.5 percent in lab-molded samples or 4.0 percent in road cores, immediate adjustments shall be made to the plant production by the Contractor, as approved by the Engineer, within the tolerances as outline in Subarticle 3.(4), so that an adequate air void level results.

The Contractor is encouraged to perform supplemental compaction testing for his own information.

Rolling patterns shall be established by the Contractor as outlined in Test Method Tex-207-F, Part IV, to achieve the desired compaction, unless otherwise directed by the Engineer. The selected rolling pattern shall be followed unless changes in the mixture or placement conditions occur which affect compaction. When changes in the mixture or placement conditions occur, a new rolling pattern shall be established.

(b) Compaction Temperatures. Breakdown compaction shall begin prior to the mixture cooling to below 146 C, unless otherwise directed by the Engineer.

All rolling for compaction shall be completed before the mixture temperature drops below 132 C.

(7) Ride Quality. Unless otherwise shown on the plans, ride quality will be required in accordance with Special Specification Item 5000, "Ride Quality for Pavement Surfaces". Use Surface Test Type A or B as shown on the plans.

(8) Opening to Traffic. The pavement shall be opened to traffic when directed by the Engineer. Traffic will not be allowed on the placed asphaltic pavement until the material cools (60 C max) sufficiently to avoid picking up and raveling of the asphaltic pavement mat. The Contractor's attention is directed to the fact that all construction traffic allowed on the pavement open to the public will be subject to the State laws governing traffic on highways.

If the surface ravels, flushes, ruts or deteriorates in any manner prior to final acceptance of the work, it will be the Contractor's responsibility to correct this condition at his expense, to the satisfaction of the Engineer and in conformance with the requirements of this specification.

7. Authorized Release Agents.

(1) The use of diesel and other solvents as an asphalt release agent on equipment used in contact with Hot Mix Asphalt is prohibited. Only authorized release agents shall be used for this purpose.

(2) An authorized asphalt release agent, is one which has passed the relevant parts of TxDOT Test Procedure TEX-239-F and conforms to Specification No. 190-90-19 (June 1996). The determination of which parts of TEX-239-F must be passed is related to the nature of the equipment on which it is to be used.

(3) Asphalt release agents which pass Parts I, II, and IV of TEX-239-F are authorized for use on Truck Beds only.

Asphalt release agents which pass Parts I, II, III, and IV of TEX-239-F are authorized for use on all equipment used in contact with Hot Mix Asphalt Concrete.

(4) A list of authorized release agents can be obtained from the Engineer.

8. Measurement. The quantity of asphaltic concrete will be measured by the composite mass method.

(1) Composite Mass Method. Asphaltic concrete will be measured by the megagram of the composite "Stone Matrix Asphaltic Concrete" of the type actually used in the completed and accepted work in accordance with the plans and specifications for the project. The composite asphaltic concrete mixture is hereby defined as the asphalt, aggregate, and additives as noted on the plans and/or approved by the Engineer.

If mixing is done by a drum-mix plant or modified weigh-batch plant, measurement will be made on scales as specified herein.

If mixing is done by a weigh-batch plant, measurement will be determined on the batch scales unless surge-storage is used. Records of the number of batches, batch design and the mass of the composite "Stone Matrix Asphaltic Concrete" shall be kept. Where surge-storage is used, measurement of the material taken from the surge-storage bin will be made on truck scales or suspended hopper scales.

(2) Ride Quality. Ride quality will be measured as described in Special Specification; "Ride Quality for Pavement Surfaces".

(3) Test Strips. Test strips are not measured since they are subsidiary to bid item "Stone Matrix Asphaltic Contract".

9. Payment.

(1) The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be

paid for at the unit price bid for the "Stone Matrix Asphaltic Concrete" of the type specified.

Measurement Method	Bid Item	Unit of Measure
Composite Mass	Stone Matrix Asphaltic Concrete	Megagram

The payment based on the unit bid price shall be full compensation for quarrying, furnishing all materials, additives, freight involved, for all heating, mixing, hauling, test strips, cleaning the existing base course or pavement, tack coat, placing, rolling and finishing stone matrix asphaltic concrete mixture, and for all manipulations, labor, tools, equipment and incidentals necessary to complete the work.

(2) When Surface Test Type-B, as specified in Special Specification, "Ride Quality for Pavement Surfaces", is used, a bonus or deduction for each 160 meter section of each travel lane will be calculated in dollars and cents. A running total of this will be determined for each day's production. The bonus or deduction for ride quality will be paid separately from the payment for the material placed.

(3) All templates, straightedges, core drilling equipment, scales and other weighing and measuring devices necessary for the proper construction, measuring and checking of the work shall be furnished, operated and maintained by the Contractor at his expense.

(4) Approved additives when required under Subarticle 2.(3) will not be paid for separately or directly but shall be considered subsidiary to the Item, "Stone Matrix Asphaltic Concrete Pavement". The lime treatment of the aggregate or other approved treatment for antistripping shall be considered as a part of the aggregate, asphalt or mix and the additive mass shall not be deducted from the individual ingredient masses nor the composite mixture mass for payment.

(5) All work performed in placing all test strips for each proposed mixture design including furnishing all materials, for all heating, mixing and hauling, cleaning the existing surface where the test strip is to be placed, tack coat, placing, rolling and finishing the asphaltic concrete mixture, will not be paid for directly but shall be considered subsidiary to the Item, "Stone Matrix Asphaltic Concrete Pavement".

SPECIAL SPECIFICATION

ITEM 3025

CELLULOSE FIBER FOR BITUMINOUS MIXTURES

1. Description. This item shall govern furnishing cellulose fibers for bituminous mixtures.

2. Materials. Cellulose fibers shall meet the requirements of one of the following types. Written certification from the fiber manufacturer or supplier shall be furnished to the Department by the contractor that the cellulose fibers meet the following requirements.

(1) Type A. Type A shall be loose fiber meeting the following physical requirements.

Cellulose Content	75% minimum
PH value	7.4 to 7.6
Maximum Fiber Length	5.1 mm
Average Fiber Length	1.0 to 1.5 mm
Average Fiber Thickness	0.05 mm
Bulk Density	24.0 to 36.8 Kg/M3

The fiber should be packaged in sacks which will melt at 143-163 C, and is otherwise suitable for addition directly into a pugmill mixer without adversely affecting the quality of the hot paving mixture. If the fiber is not to be added directly into a pugmill mixer, packaging shall be suitable for the method of addition to be utilized, in the opinion of the engineer.

(2) Type B. Type B shall be fiber meeting type a physical requirements furnished as granulates which are a blend of bitumen and fiber. The granulates shall meet the following physical requirements.

Size	approximately 4.1 mm diameter by 6.1 mm length
Bulk Density	approximately 450.0 Kg/M3

Bitumen used in the cellulose granulates shall be of such content and properties that the granulates will not adhere to one another during storage and use. The percent by weight bitumen and fiber in the granulates shall be provided to the Engineer by the fiber supplier. The viscosity grade of the bitumen will also be provided to the Engineer by the fiber supplier.

Type B fiber shall be packaged in a manner suitable for the method of addition to be utilized, in the opinion of the engineer.

3. Construction Methods. The cellulose fibers shall be metered or weighed into the mixer at the addition rate shown on the plans or specified by the engineer. Alternatively, for weigh-batch and modified weigh-batch plant types, fiber sacks of known weight may be manually added to the mixer. Sacks shall not be split between batches. Additional dry and wet mixing time may be required by the engineer. In any case, the method of addition, mixture temperature and other factors shall be suitable to obtain a complete dispersion of fiber in the paving mixture.

   The fibers shall be stored in a manner to protect them from exposure to moisture. Any material which is moisture or soil damaged, or otherwise harmed, will be rejected and replaced at the Contractor's expense.

4. Measurement and Payment. Work performed and materials furnished as prescribed by this Item will not be measured or paid for directly, but shall be considered subsidiary to the governing specifications for the items of construction in which these materials are used.

Special Specification

ITEM 8888

STONE MATRIX ASPHALTIC (SMA) CONCRETE PAVEMENT

Designer's Discussion and Plan Notes:

Reference Para.	**Discussion and General Plan Notes**
Spec Note	Insert the following Special Note in the P.S. & E.: "A pre-bid meeting is required for projects which include this ITEM. Only bids of those who attend this meeting will be considered." Add to the above note the date, time and place for the meeting. The District Materials Engineer will chair this meeting.
2.0	Show additional requirements on plans or notes as required. This specification should never be used with QC/QA type conditions where the contractor determines all parameters of the mix design. Do not allow RAP to be used in SMA hot mixes.
2.0(1) a	Lightweight aggregate is not permitted. Indicate required polish value (PV) in the plan notes. Example Note: The coarse aggregate Polish Value shall be a minimum of _______. Coarse and Fine aggregates shall be from the same source (pit) and both aggregates shall be products of crushing operations. See discussion for Para 3.0. So far we have been able to blend standard products from a single pit to obtain the required composite gradation for all Types listed in Table 2. For example, thus far, all the composite gradations have been achieved using a pit's standard "D" Rock, "C" Rock (or another of their standard gradations) and #10 Screenings, plus a different source for the mineral filler. Mineral Filler may be from a different source than the Coarse and Fine aggregate; but shall be a product of crushing operations, and meet gradation requirements.

3.0	Asphalt grade, aggregate type (rock name) for both coarse and fine aggregates, mineral filler, and gradation type (Table 2) will be chosen by the Dist. Materials Engineer, but must be included in the plan notes. Informational to the Designer, the choices are: Asphalt: AC-20 w/ 2% Latex, AC-30 w/ 1% Latex, or MG-20/40 multigrade Rock Types for coarse and fine aggregates from a single pit: Ryolite — Basalt (Trap rock) Dolomite — Granite & Diorite (if fine grained) Dolomitic Limestone — Silicious Limestone (softer limestones are not appropriate) Sandstones with silica (quartz) or calcite cement. Quartzite — Metaquartzite Mineral Filler: Product of crushing from any of the rock types allowed for coarse or fine aggregates, above. Gradation: Give Type, and reference Table 2. Example Note: Mix design will be based on the following materials: MG- 20/40 multigrade Crushed Ryolite for both coarse and fine aggregates from a single pit. Crushed Dolomite fines for mineral filler Type B gradation (See Table 2).
3.0(1)	If the contractor is to be charged for redesigns of SMA hot mix, a charge must be stated in the plan notes (otherwise, the redesign costs him nothing). Example Note: For each additional SMA redesign the contractor shall be charged a sum of $1,500.00.
5.0(f)	The designer must show location(s) for test strips on the plans. Test strips should not be allowed in the lanes to be paved on this SMA project. Ideally the test strips should be located off the project on a nearby intersecting roadway or an adjacent service road if it's not to receive an SMA pavement. Parking lots are another possibility, but the designer would need to make arrangements with the owner. Include consideration for these test strips in your traffic control plan.

6.0(1)	A minimum mat thickness of 38.0 mm should be used for all gradations of SMA.
6.0(7)	Ride Quality. The designer must include a general note requiring either Surface Test Type A (3.048 m straight edge), or Surface Type B (profilograph). Example: Ride Quality shall be determined by Surface Test Type ______, in accordance with Item 5000, "Ride Quality for Pavement Surfaces".

Special Specification

ITEM 8888

STONE MATRIX ASPHALTIC (SMA) CONCRETE PAVEMENT

REFERENCE ITEMS: (300)(301)(340)(520)(3086*)(5000)

*This Item number is for the English Unit version; the number will be different in the metric version. The Item number for the Metric Unit version will be provided when it is assigned by the specification review committee. Until the specification review committee assigns a number to use with the one-time SMA Spec, it will be designated as Item 9999 for the metric version.

Do not include the general note on percent stripping allowed on reference Item 301. This information has been incorporated into the specification.

SPECIAL PROVISIONS: (300---013)

LABORATORY DESIGN OF STONE MATRIX ASPHALT (SMA) MIXTURES WITH FIBERS USING THE MARSHALL MIX DESIGN METHOD

BACKGROUND

In Germany this mixture is called Stone Mastic Asphalt (SMA). In keeping with U.S. practice we will designate this as titled above. The techniques used in Germany for the design of Stone Matrix Asphalt (SMA) mixtures are not greatly different from those used in the United States for designing hot mix asphaltic concrete mixtures. In Germany the Marshall test method is used to prepare and compact the test speciments to be used in the evaluation of the mixture. This is the same test method used by many United States agencies.

However, for SMA mixtures, Marshall stabilities and flows are not used in the evaluation of the mix design because those values are less meaningful than with dense-graded mixtures. Properties such as aggregate gradation, asphalt grade and content, air void content, voids in the mineral aggregate, voids filled with asphalt, and asphalt draindown are analyzed and specified.

SMA mixtures consist basically of one or more coarse aggregates, fine aggregates and mineral fillers blended in a combined aggregate mix in which intermediate sizes are absent or greatly reduced, and containing a fairly high quantity of filler. A small a mount of cellulose fiber is added to the mixture in order to enable the mixture to hold a high asphalt content. This results in a mixture with a high percentage of voids in the mineral aggregate (VMA) and a high percentage of voids filled with asphalt (VFA).

The high content of coarse aggregate creates a stone skeleton to resist deformation and provide good wear resistance and surface texture. The rich mortar (aggregates passing the 4.75 mm sieve, plus mineral filler and asphalt) provides improved low temperature properties, long-term durability, and a thick asphalt film on the aggregate to resist moisture damage.

AGGREGATE AND GRADATION

The coarse and fine aggregates and mineral filler selected for an SMA project shall all be products of crushing with 100% crushed faces. Natural gravel and field sand are not to be used under any circumstances. A good quality mineral filler should be a product of a crushing operation and the parent stone should meet the same quality requirements as the coarse and fine aggregates except for polish value (PV). The mineral filler should have a minimum of 60% passing 0.075 mm sieve and not more than 20% passing 0.020 mm sieve when measured by washed sieve analysis. Except in unusual cases, both the coarse and fine aggregates should be from the same pit (source).

Quality Criteria:

LA Abrasion		30% max
Soundness	Magnesium Sulfate	30% max
	Sodium Sulfate	25% max
Absorption	Natural Aggregate	2% max
Polish Value		As Specified
Crushed Faces		100% min
Flat and Elongated particles (Flakiness Index)		5% max (17 max)

Other criteria may be specified.

The combined gradations for various nominal maximum aggregate sizes are shown in TABLE 1.

ASPHALT CEMENT

The following asphalt cements are suitable for SMA designs:

AC - 20 with 2% Latex
AC - 30 with 1% Latex
MG- 20/40 multigrade

(Equivalent Performance Grades (PG) may also be used.)

CELLULOSE FIBER

When needed to control drainage, cellulose fiber meeting the requirements of Special Specification Item 3XXY shall be used in the mixture. Only the loose fiber (Type A) is used in the Laboratory Design and the mixture should contain 0.3% based on the total weight of the mixture. The weight of the fibers, however, is not included in the mix design calculations--it's just added in.

SAMPLE PREPARATION AND COMPACTION

In general, the Marshall method is used to prepare and compact the specimens to be used in evaluation of the mix design; however, as stated before, stability and flow values are not used in the evaluation, as those values appear to be meaningless for SMA mixtures. See ASTM D1559.

The compactive effort to be used is 50 blows per side, using the standard Marshall hammer and 101.6 mm (4.0") diameter x 63.5 mm (2.5") height molds. Three specimens should be prepared at each asphalt content to be used in the evaluation. The asphalt contents to be evaluated should range from 5.5% to 7.5% inclusive, in 0.5% increments. (The ideal asphalt content is considered to be 6.5%.) Specimen weight will be about 1150 g to 1200 g each. The tolerance on the height of the molded sample is ±1.6 mm.

The mixing temperature should be:

AC - 20 and AC - 30	155 - 163 deg C
MG- 20/40 multigrade	172 - 177 deg C

TABLE 1: STANDARD SMA GRADATIONS*

SIEVE SIZE, mm	TYPE A	TYPE B	TYPE C	TYPE D	TYPE E
25.4					As Shown on
22.2	100				the Plans
19.0	80 - 100	100			
15.9	68 - 86	80 - 100	100		
12.7	53 - 70		80 - 100	100	
9.5	35 - 53	53 - 75	55 - 80	80 - 100	
6.4	15 - 28				
4.75	14 - 25	15 - 28	15 - 28	15 - 28	
2.00	11 - 20	11 - 20	11 - 20	11 - 20	
0.425	10 - 17	10 - 17	10 - 17	10 - 17	
0.180	9 - 16	9 - 16	9 - 16	9 - 16	
0.075	9 - 15	9 - 15	9 - 15	9 - 15	
VMA min. %	17	17	17	17	

*Test Method TEX-200-F, Part II (Washed Sieve Analysis) shall be used.

Compaction should begin at 146 C and be completed before reaching 121 C. The cellulose fiber, either loose or pelletized form, should be added and thoroughly blended with the hot aggregate prior to the addition of the hot asphalt cement. Care should be exercised so that the mixtures containing loose fiber are not overmixed during the initial dry mixing cycle, which could result in shredding the fibers.

Mixing --- Loose Fiber

The loose fiber should be added to the fine aggregate and stirred by hand. (The fine aggregate is defined as all aggregate and mineral filler passing the 4.75 mm sieve.) After the loose fiber has been distributed, then this mixture may be added to the coarse aggregate fraction and blended. After the aggregate/fiber mixture has been reheated to the mixing temperature, the hot asphalt cement is added and mechanical mixing is begun. This wet mixing time should require no more than 3 or 4 minutes if a mechanical mixer is used.

ANTISTRIPPING AGENTS

Normally, an antistripping agent is required in the hot mix in order to prevent the asphalt cement from being stripped from the aggregate. Antistripping agents include both liquid antistrip as manufactured by various companies, and hydrated lime. The hot mix design should be tested for stripping at 1.0% concentration of antistrip agent by weight of asphalt.. Since hydrated lime ($Ca(OH)_2$) antistrip also acts in the same manner as mineral filler in controlling drainage, the hydrated lime is the preferred agent.

PROPERTIES TO BE DETERMINED AND EVALUATED

In order to evaluate SMA mixtures, the following properties must be measured or calculated:

1. Combined gradation of aggregates
2. Asphalt content
3. Bulk specific gravity and water absorption of the aggregates
4. Maximum theoretical density of the mixture.
5. Bulk specific gravity of the compacted specimen
6. Air void content
7. Voids in the mineral aggregate
8. Voids filled with asphalt (VFA)
9. Stripping
10. Segregation (draindown or drainage)

TABLE 2 summarizes the requirements for production of a good SMA mix. Figures 1A, 1B and 1C illustrate typical graphical presentation of the test data.

TABLE 2: SMA SPECIFICATIONS

ITEM	SPECIFICATION
Marshall Compaction	50 blows/Side
Asphalt Cement	AC-20*; AC-30* or MG-20/40 Multigrade
Asphalt Content, %	6.0 to 7.5
Air Void Content, %	3.0 to 4.0
Aggr Absorption, %	2.0 Maximum
VMA, %	17 Minimum
VFA, %	75 to 84
Stripping, %	None Allowed
Draindown, %	0.3 Maximum
Cellulose Fiber, %	0.3

Note: All percentages based on total weight of mixture. *May also contain 1% to 2% Latex.

Asphalt Content (A_s). This is the percentage of asphalt in the mixture, based on the total weight of the mixture.

Bulk Specific Gravity (G_{sb}). This is the bulk specific gravity of the combined aggregates and is determined as follows:

$$G_{sb} = \frac{100}{\frac{P_1}{G} + \frac{P_2}{G} + \frac{P_3}{G} + etc.}$$

where, P_1, P_2, P_3 etc = percentage by weight of each aggregate used, and

G_1, G_2, G_3 etc = bulk specific gravity of each aggregate used.

Mixture Bulk Specific Gravity (G_{mb}). The bulk specific gravity of the compacted mixture is determined by the *immersion in water* method.

Maximum Theoretical Density (G_r). This is determined by using the Rice procedure (ASTM D2041).

Air Void Content (AV). The percent Air Void Content is calculated by:

$$AV = 100 - \frac{G_{mb}}{G_r} X 100$$

Voids in the Mineral Aggregate (VMA). The percent voids in the mineral aggregate is calculated by:

Test Procedure TEX-207-F.

Voids Filled with Asphalt (VFA). This property is calculated by:

$$VFA = \frac{VMA - AV}{VMA} x 100$$

Asphalt Draindown Test. This test is performed in the laboratory in order to determine whether an unacceptable amount of asphalt cement drains from the mixture. Test Procedure TEX-235-F, "Determination of Draindown Characteristics in Bituminous Materials" shall be used.

Asphalt Antistripping Agents and Tests. The proposed SMA at optimum asphalt content should be evaluated for moisture susceptibility by performing a stripping test in accordance with Item 301,"Asphalt Antistripping Agents", Test Method TEX-530-C. Zero percent stripping is required. The preferred antistripping agent is Lime, in accordance with Item 301, paragraph 301.4 (2), in concentrations up to 1% by weight of the asphalt.

APPENDIX B:
SMA MIX DESIGNS

WESTERN ROCK PRODUCTS, INC.
PEDERNAL PIT
ENCINIO, NM

MATERIALS INFORMATION

DESIGN #SMA1 01-02-97

****

	Material	Bulk Specific Gravity	Source	Source Number
Coarse 1	Ty C Coarse	2.814	Pedernal	
Coarse 2	Ty C Intermediate	2.816	Pedernal	
Coarse 3	NM 1/2" Chips	2.792	Pedernal	
Fine 1	Ty C Screenings	2.764	Pedernal	
Fine 2	Filler	2.892	Unimin	
	Asphalt, AC-0	1.040	40 AMI	
	Anti-Strip			
	Latex			

****

Material	Loss by Decant.	Del. Matl.	L.S.	Sand Equiv.	Laboratory Number
Ty C Coarse	0.0	0			
Ty C Intermediate	0.0	0			
NM 1/2" Chips					
Ty C Screenings			N/A		
Filler			N/A		
Total Mixture				N/A	

****

QUALITY TEST VALUES

Source	Magnesium Sulfate	Los Angeles Abrasion	Polish Value	Crushed Particles
Pedernal	3	14	37	
Lab Number	E0050309	E0050309	10-96RSVP	
Pedernal				
Lab Number				

This design is to be considered out of date and void Dec. 31, 1996

****

REMARKS: For surface courses without latex, we recommend an asphalt with a penetration value of less than 90.

GRADATION

Design #SMA1 Date : 01-02-97

SIEVE SIZES	Ty C Coarse Coarse 1	27 %	Ty C Interm Coarse 2	8 %	NM 1/2" Chi Coarse 3	47 %	Ty C Screen Fine 1	5 %	Filler Fine 2	13 %	Combine 100 %	Spec. Ty B
19.0	100.0	27.0	100.0	8.0	100.0	47.0	100.0	5.0	100.0	13.0	100.0	100
15.9	98.0	26.5	100.0	8.0	100.0	47.0	100.0	5.0	100.0	13.0	99.5	80 -100
9.5	11.0	3.0	98.6	7.9	70.9	33.3	100.0	5.0	100.0	13.0	62.2	53 - 80
4.75	1.3	0.4	31.6	2.5	6.4	3.0	99.9	5.0	100.0	13.0	23.9	15 - 28
2.00	0.8	0.2	7.1	0.6	1.0	0.5	74.4	3.7	100.0	13.0	18.0	11 - 20
0.425	0.7	0.2	2.7	0.2	0.9	0.4	23.0	1.2	100.0	13.0	15.0	10 - 17
0.180	0.6	0.2	2.2	0.2	0.8	0.4	13.5	0.7	97.4	12.7	14.2	9 - 16
0.075	0.5	0.1	1.8	0.1	0.7	0.3	9.1	0.5	69.8	9.1	10.1	9 - 15

SPECIFIC GRAVITIES

SIZE	COARSE 1	COARSE 2	COARSE 3	FINE 1	FINE 2
22.2-15.9	0.000	0.000	0.000	0.000	0.000
15.9-9.5	0.000	0.000	0.000	0.000	0.000
9.5-4.75	2.814 *	2.816 *	0.000	0.000	0.000
4.75-2.00	0.000	2.816	2.792 *	2.622	0.000
2.00-0.180	0.000	0.000	0.000	2.816 *	2.655
-0.180	0.000	0.000	0.000	0.000	2.899 *

SPECIFIC GRAVITY OF ASPHALT = 1.040

COMBINED BULK SPECIFIC GRAVITY (G) = 2.811

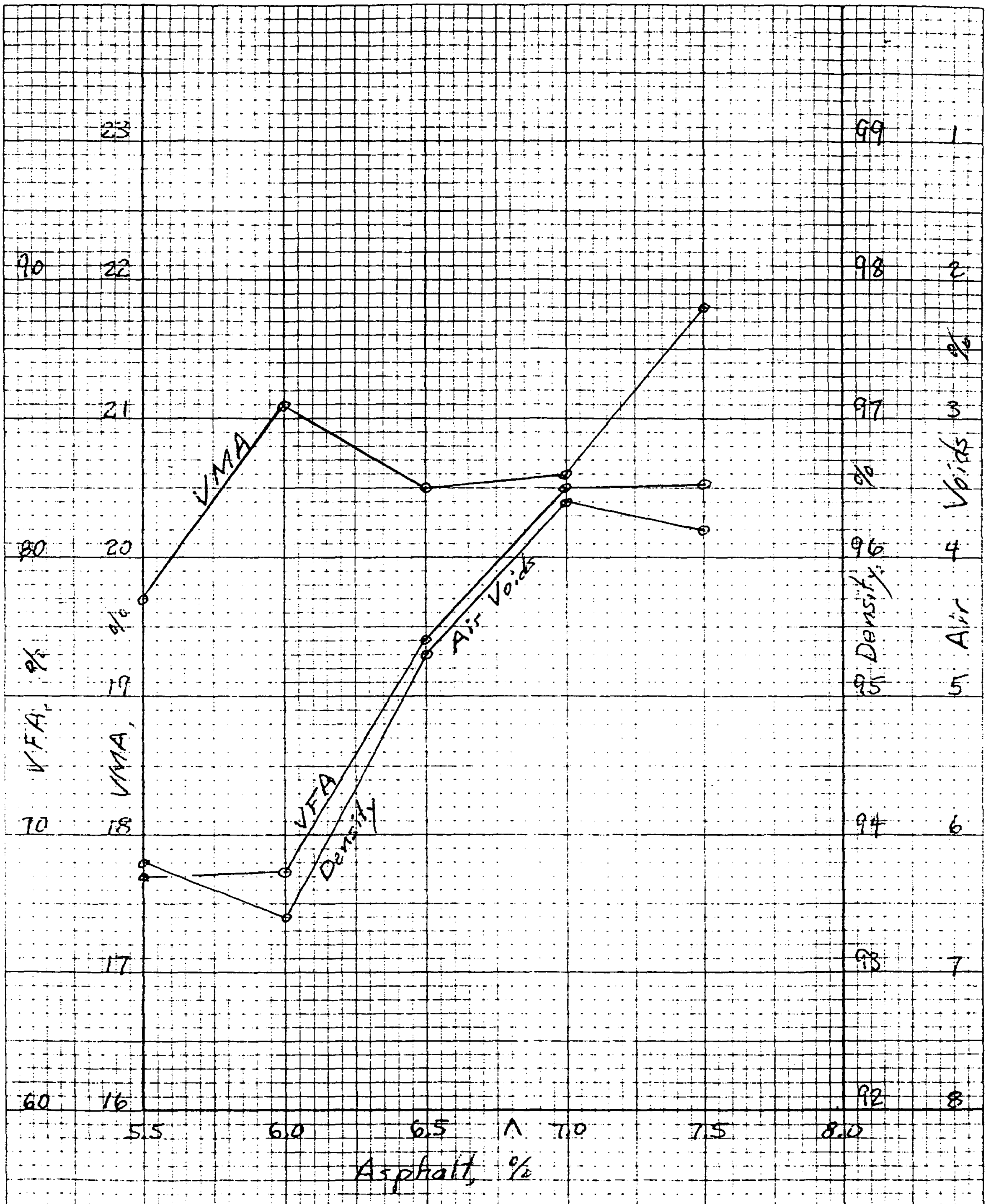
Results of SMA Mix Design

Pit : Pedernal

Gradation: TY B (15.9 mm)

Asphalt, %	5.5	6.0	6.5	6.8	7.0	7.5
Density, %	93.8	93.4	95.3	96.0	96.4	96.2
Air Voids, %	6.2	6.6	4.7	4.0	3.6	3.8
VMA, %	19.7	21.1	20.5	21	20.6	21.8
VFA, %	68.5	68.7	77.0	81.0	82.5	82.6
Cellulose Fibers, %	0.3	0.3	0.3	0.3	0.3	0.3
Antistrip-UC 8162 %				NS		
				Λ		

NS = Non-stripping
Λ : Optimum



SMA Design No : SMA1
Type : B
Aggr Source : Pedernal

CAPITAL AGGREGATES, INC. (DELTA OPERATION)
BROWNLEA PIT
BURNETT COUNTY, TX

MATERIALS INFORMATION

DESIGN #SMA1 12-19-96

****

	Material	Bulk Specific Gravity	Source	Source Number
Coarse 1	Ty C	2.620	Brownlee	
Coarse 2	Ty D	2.620	Brownlee	
Coarse 3				
Fine 1	Screenings	2.614	Brownlee	
Fine 2	Filler	2.899	Unimin	
	Asphalt, AC-0	1.040	40 AMI	
	Anti-Strip			
	Latex			

****

Material	Loss by Decant.	Del. Matl.	L.S.	Sand Equiv.	Laboratory Number
Ty C	N/A	0			
Ty D	N/A	0			
Screenings			0		
Filler			0		
Total Mixture				0	

****

QUALITY TEST VALUES

Source	Magnesium Sulfate	Los Angeles Abrasion	Polish Value	Crushed Particles
Brownlee	15	26	40	
Lab Number	E1402704	E1402704	10-96RSPV	
Brownlee				
Lab Number				

This design is to be considered out of date and void Dec. 31, 1996

****

REMARKS: For surface courses without latex, we recommend an asphalt with a penetration value of less than 90.

GRADATION

Design #SMA1 Date : 12-19-96

SIEVE SIZES	Ty C Coarse 1	5 %	Ty D Coarse 2	74 %	Coarse 3	0 %	Screenings Fine 1	11 %	Filler Fine 2	10 %	Combine 100 %	Spec. Ty B
19.0	100.0	5.0	100.0	74.0	0.0	0.0	100.0	11.0	100.0	10.0	100.0	100
15.9	98.4	4.9	100.0	74.0	0.0	0.0	100.0	11.0	100.0	10.0	99.9	80 -100
9.5	9.5	0.5	51.7	38.3	0.0	0.0	100.0	11.0	100.0	10.0	59.8	53 - 80
4.75	2.0	0.1	3.5	2.6	0.0	0.0	98.8	10.9	100.0	10.0	23.6	15 - 28
2.00	0.8	0.0	1.7	1.3	0.0	0.0	72.1	7.9	100.0	10.0	19.2	11 - 20
0.425	0.6	0.0	1.2	0.9	0.0	0.0	38.3	4.2	100.0	10.0	15.1	10 - 17
0.180	0.6	0.0	1.1	0.8	0.0	0.0	28.9	3.2	97.4	9.7	13.7	9 - 16
0.075	0.6	0.0	1.0	0.7	0.0	0.0	20.1	2.2	69.8	7.0	9.9	9 - 15

SPECIFIC GRAVITIES

SIZE	COARSE 1	COARSE 2	COARSE 3	FINE 1	FINE 2
22.2-15.9	0.000	0.000	0.000	0.000	0.000
15.9-9.5	0.000	0.000	0.000	0.000	0.000
9.5-4.75	2.620 *	2.621 *	0.000	0.000	0.000
4.75-2.00	0.000	2.601	0.000 *	2.596	0.000
2.00-0.180	0.000	0.000	0.000	2.590 *	0.000
-0.180	0.000	0.000	0.000	2.668	2.899 *

SPECIFIC GRAVITY OF ASPHALT = 1.040

COMBINED BULK SPECIFIC GRAVITY (G) = 2.645

Results of SMA Mix Design

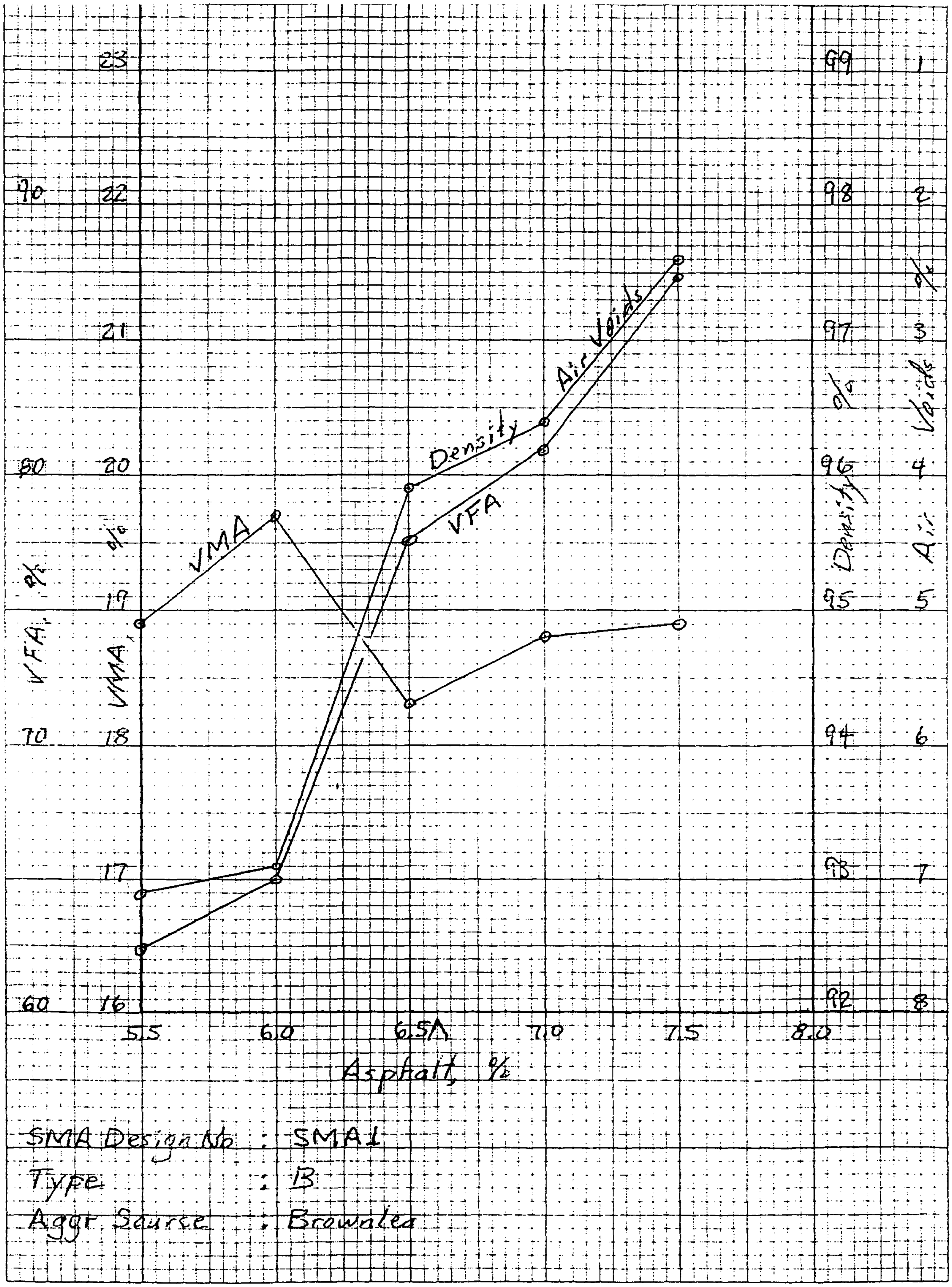
Pit: Brownlea

Gradation: TY B (15.9 mm)

Asphalt, %	5.5	6.0	6.5	6.6	7.0	7.5
Density, %	92.9	93.1	95.9	96.0	96.4	97.6
Air Voids, %	7.1	6.9	4.1	4.0	3.6	2.4
VMA, %	18.9	19.7	18.3	18	18.8	18.9
VFA, %	62.4	65.0	77.6	77.8	80.9	87.3
Cellulose Fibers, %	0.3	0.3	0.3	0.3	0.3	0.3
Antistrip-UC 8162 %				NS		
				Λ		

NS = Non-stripping

Λ Optimum



23
22
21
20
19
18
17
16
90
80
70
60
VFA, %
VMA, %
99
98
97
96
95
94
93
92
1
2
3
4
5
6
7
8
Density %
Air Voids %
VMA
VFA
Density
Air Voids
5.5
6.0
6.5
7.0
7.5
8.0
Asphalt, %
SMA Design No : SMA1
Type : B
Aggr Source : Brownlea

MERIDIAN, INC.
SAWYER PIT
APPLE, OK

Sawyer

MATERIALS INFORMATION

DESIGN #SMA1 12-19-96

****

	Material	Bulk Specific Gravity	Source	Source Number
Coarse 1	Ty C	2.448	Meridian	
Coarse 2	Ty D	2.528	Meridian	
Coarse 3				
Fine 1	Screenings	2.659	Meridian	
Fine 2	Filler	2.899	Unimin	
	Asphalt, AC-0	1.040	40 AMI	
	Anti-Strip			
	Latex			

****

Material	Loss by Decant.	Del. Matl.	L.S.	Sand Equiv.	Laboratory Number
Ty C	N\A	0			
Ty D	N\A	0			
Screenings			0		
Filler			0		
Total Mixture				0	

****

QUALITY TEST VALUES

Source	Magnesium Sulfate	Los Angeles Abrasion	Polish Value	Crushed Particles
Meridian	15	26	38	
Lab Number	E0050437	E0050437	10-96RSVP	
Meridian				
Lab Number				

This design is to be considered out of date and void Dec. 31, 1996

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REMARKS: For surface courses without latex, we recommend an asphalt with a penetration value of less than 90.

GRADATION

Design #SMA1 Date : 12-19-96

SIEVE SIZES	Ty C Coarse 1	45 %	Ty D Coarse 2	35 %	Coarse 3	0 %	Screenings Fine 1	7 %	Filler Fine 2	13 %	Combine 100 %	Spec. Ty B
19.0	100.0	45.0	100.0	35.0	0.0	0.0	100.0	7.0	100.0	13.0	100.0	100
15.9	98.7	44.4	100.0	35.0	0.0	0.0	100.0	7.0	100.0	13.0	99.4	80 -100
9.5	21.9	9.9	91.2	31.9	0.0	0.0	100.0	7.0	100.0	13.0	61.8	53 - 80
4.75	1.3	0.6	7.1	2.5	0.0	0.0	98.4	6.9	100.0	13.0	23.0	15 - 28
2.00	1.1	0.5	2.3	0.8	0.0	0.0	74.9	5.2	100.0	13.0	19.5	11 - 20
0.425	0.9	0.4	1.4	0.5	0.0	0.0	28.5	2.0	100.0	13.0	15.9	10 - 17
0.180	0.7	0.3	1.1	0.4	0.0	0.0	13.9	1.0	97.4	12.7	14.4	9 - 16
0.075	0.4	0.2	0.6	0.2	0.0	0.0	7.3	0.5	69.8	9.1	10.0	9 - 15

SPECIFIC GRAVITIES

SIZE	COARSE 1	COARSE 2	COARSE 3	FINE 1	FINE 2
22.2-15.9	0.000	0.000	0.000	0.000	0.000
15.9-9.5	2.448	0.000	0.000	0.000	0.000
9.5-4.75	2.448 *	2.528 *	0.000	0.000	0.000
4.75-2.00	0.000	0.000	0.000 *	2.652	0.000
2.00-0.180	0.000	0.000	0.000	2.651 *	0.000
-0.180	0.000	0.000	0.000	2.705	2.899 *

SPECIFIC GRAVITY OF ASPHALT = 1.040

COMBINED BULK SPECIFIC GRAVITY (G) = 2.542

Results of SMA Mix Design

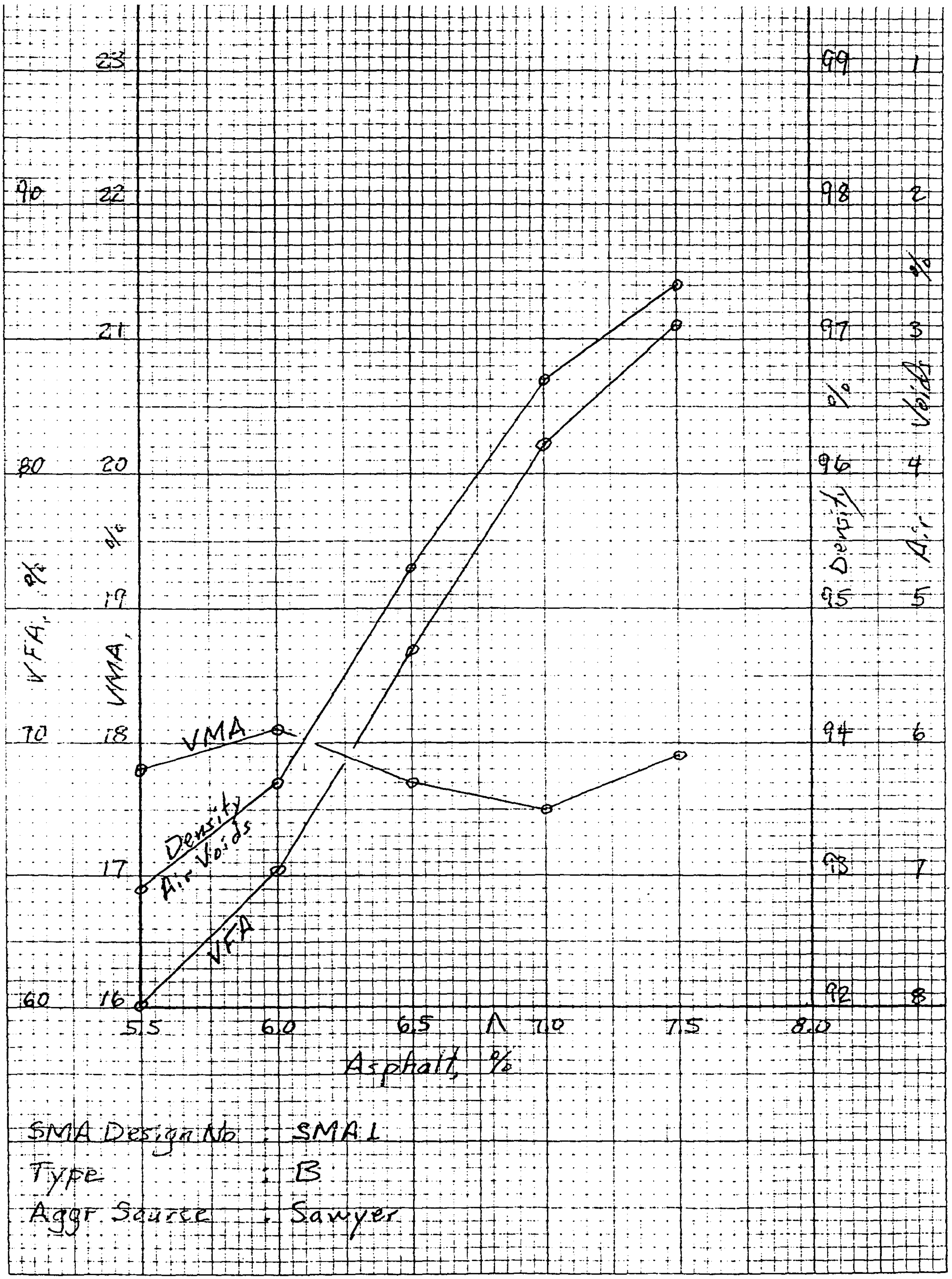
Pit : Sawyer

Gradation: TY B (15.9 mm)

Asphalt, %	5.5	6.0	6.5	6.8	7.0	7.5
Density, %	92.9	93.7	95.3	96.0	96.7	97.4
Air Voids, %	7.1	6.3	4.7	4.0	3.3	2.6
VMA, %	17.8	18.1	17.7	18	17.5	17.9
VFA, %	60.1	65.2	73.4	77.8	81.1	85.5
Cellulase Fibers, %	0.3	0.3	0.3	0.3	0.3	0.3
Antistrip - UC 8162 %				1.0		
				Λ		

NS = Non-stripping

Λ Optimum


23
22
21
20
19
18
17
16
90
80
70
60
VFA, %
VMA, %
99
98
97
96
95
94
93
92
1
2
3
4
5
6
7
8
% Density
% Air Voids
VMA
Density
Air Voids
VFA
5.5
6.0
6.5
7.0
7.5
8.0
Asphalt, %
SMA Design No : SMA 1
Type : B
Aggr Source : Sawyer

DOLESE BROS., INC.
CYRIL PIT
CYRIL, OK

MATERIALS INFORMATION

Cyril

DESIGN #SMA1 12-2-96

****

	Material	Bulk Specific Gravity	Source	Source Number
Coarse 1	#67	2.643	Dolese	
Coarse 2	#8	2.609	Dolese	
Coarse 3				
Fine 1	#10 Screenings	2.666	Dolese	
Fine 2	Filler	2.899	Unimin	
	Asphalt, AC-0	1.040	AMI	
	Anti-Strip			
	Latex		Goodyear 7676	

****

Material	Loss by Decant.	Del. Matl.	L.S.	Sand Equiv.	Laboratory Number
#67	N/A				
#8	N/A	0			
#10 Screenings					
Filler					
Total Mixture					

****

QUALITY TEST VALUES

Source	Magnesium Sulfate	Los Angeles Abrasion	Polish Value	Crushed Particles
Dolese	27	33	42	
Lab Number	E0050411	E0050411	10-96RSVP	
Dolese				
Lab Number				

This design is to be considered out of date and void Dec. 31, 1996

****

REMARKS: For surface courses without latex, we recommend an asphalt with a penetration value of less than 90.

GRADATION

Design #SMA1 Date : 12-2-96

SIEVE SIZES	#67 Coarse 1	84 %	#8 Coarse 2	0 %	Coarse 3	0 %	#10 Screeni Fine 1	5 %	Filler Fine 2	11 %	Combine 100 %	Spec. Ty B
19.0	100.0	84.0	100.0	0.0	0.0	0.0	100.0	5.0	100.0	11.0	100.0	100
15.9	100.0	84.0	100.0	0.0	0.0	0.0	100.0	5.0	100.0	11.0	100.0	80 -100
9.5	56.0	47.0	97.9	0.0	0.0	0.0	99.7	5.0	100.0	11.0	63.0	53 - 80
4.75	4.8	4.0	18.2	0.0	0.0	0.0	97.1	4.9	100.0	11.0	19.9	15 - 28
2.00	2.4	2.0	3.4	0.0	0.0	0.0	60.8	3.0	100.0	11.0	16.0	11 - 20
0.425	2.0	1.7	2.6	0.0	0.0	0.0	38.0	1.9	100.0	11.0	14.6	10 - 17
0.180	1.9	1.6	2.5	0.0	0.0	0.0	29.6	1.5	97.4	10.7	13.8	9 - 16
0.075	1.2	1.0	1.5	0.0	0.0	0.0	14.5	0.7	69.8	7.7	9.4	9 - 15

SPECIFIC GRAVITIES

SIZE	COARSE 1	COARSE 2	COARSE 3	FINE 1	FINE 2
22.2-15.9	0.000	0.000	0.000	0.000	0.000
15.9-9.5	2.649	0.000	0.000	0.000	0.000
9.5-4.75	2.639 *	2.617 *	0.000	0.000	0.000
4.75-2.00	0.000	2.573	0.000 *	0.000	0.000
2.00-0.180	0.000	0.000	0.000	2.650 *	0.000
-0.180	0.000	0.000	0.000	2.704	2.899 *

SPECIFIC GRAVITY OF ASPHALT = 1.040

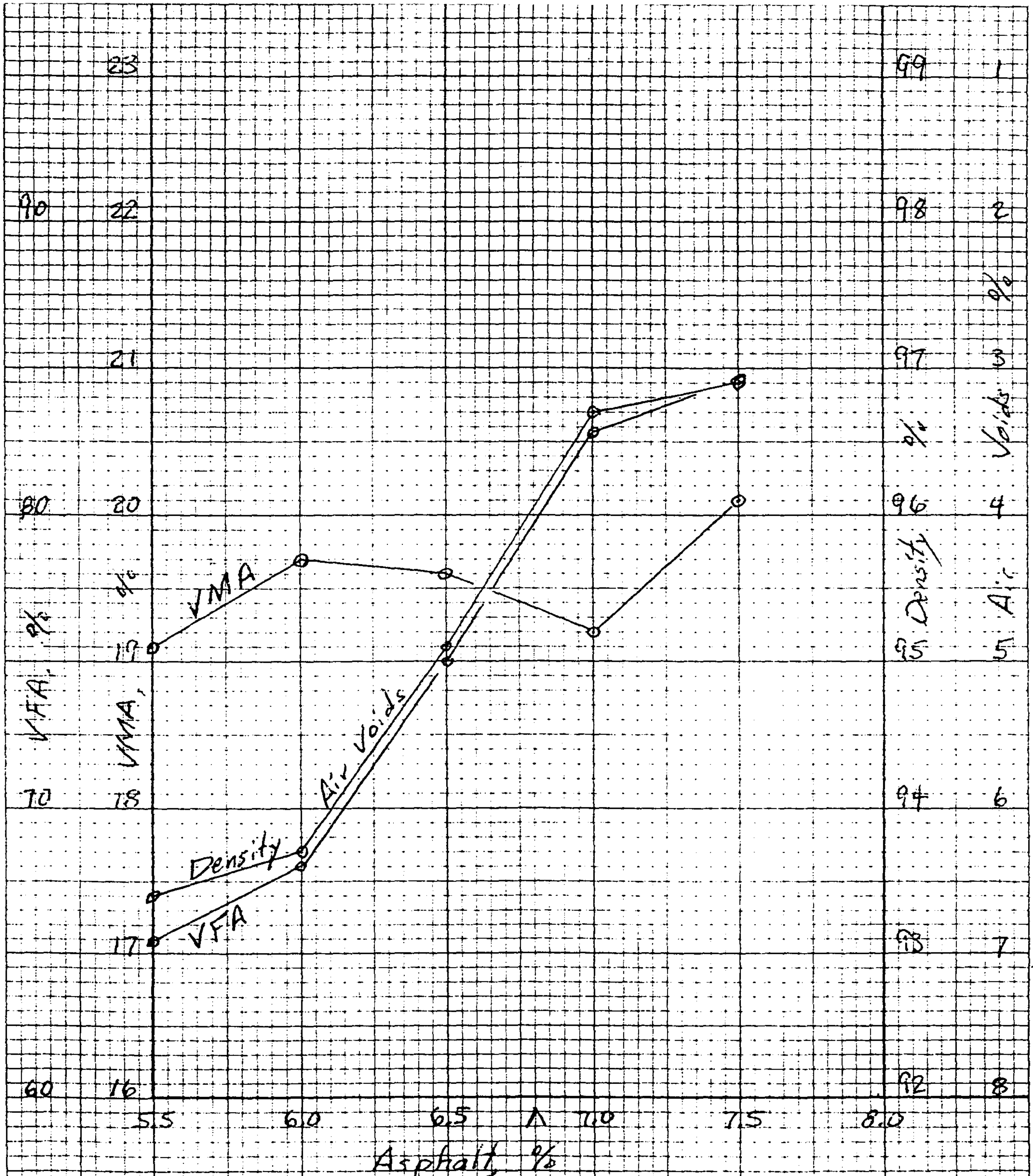
COMBINED BULK SPECIFIC GRAVITY (G) = 2.670

Results of SMA Mix Design

Pit: Cyril   Gradation: TY B (15.9 mm)

Asphalt, %	5.5	6.0	6.5	6.8	7.0	7.5
Density, %	93.4	93.7	95.1	96.0	96.7	96.9
Air Voids, %	6.6	6.3	4.9	4.0	3.3	3.1
VMA, %	19.1	19.7	19.6	19	19.2	20.1
VFA, %	65.4	68.0	75.0	78.9	82.8	84.6
Cellulose Fibers, %	0.3	0.3	0.3	0.3	0.3	0.3
Antistrip - UC 8162, %				NS		
				Λ		

NS : Non-stripping
Λ Optimum



SMA Design No : SMA1
Type : B
Aggr Source : Cyril

WESTERN ROCK PRODUCTS, INC.
DAVIS PIT
DAVIS, OK

MATERIALS INFORMATION

Davis

DESIGN #SMA1 10-11-96

****

	Material	Bulk Specific Gravity	Source	Source Number
Coarse 1	Type D	2.718	Davis	
Coarse 2	#67 Chips	2.723	Davis	
Coarse 3				
Fine 1	Screenings	2.714	Davis	
Fine 2	Filler	2.899	Unimin	
	Asphalt, AC-0	1.040	MultiGrade	
	Anti-Strip			
	Latex			

****

Material	Loss by Decant.	Del. Matl.	L.S.	Sand Equiv.	Laboratory Number
Type D	N\A	0			
#67 Chips	N\A	0			
Screenings			0		
Filler			0		
Total Mixture				0	

****

QUALITY TEST VALUES

Source	Magnesium Sulfate	Los Angeles Abrasion	Polish Value	Crushed Particles
Davis	5	16	39	
Lab Number	E0050439	E0050439	10-96RSVP	
Davis				
Lab Number				

This design is to be considered out of date and void Dec. 31, 1996

****

REMARKS: For surface courses without latex, we recommend an asphalt with a penetration value of less than 90.

GRADATION

Design #SMA1 Date : 10-11-96

SIEVE SIZES	Type D Coarse 1	52 %	#67 Chips Coarse 2	28 %	Coarse 3	0 %	Screenings Fine 1	7 %	Filler Fine 2	13 %	Combine 100 %	Spec. Ty B
19.0	100.0	52.0	100.0	28.0	0.0	0.0	100.0	7.0	100.0	13.0	100.0	100
15.9	100.0	52.0	83.0	23.2	0.0	0.0	100.0	7.0	100.0	13.0	95.2	80 -100
9.5	75.0	39.0	17.4	4.9	0.0	0.0	99.8	7.0	100.0	13.0	63.9	53 - 80
4.75	5.6	2.9	1.0	0.3	0.0	0.0	88.9	6.2	100.0	13.0	22.4	15 - 28
2.00	1.5	0.8	0.4	0.1	0.0	0.0	52.2	3.7	100.0	13.0	17.6	11 - 20
0.425	1.1	0.6	0.3	0.1	0.0	0.0	22.9	1.6	100.0	13.0	15.3	10 - 17
0.180	1.0	0.5	0.2	0.1	0.0	0.0	14.4	1.0	97.4	12.7	14.3	9 - 16
0.075	0.8	0.4	0.1	0.0	0.0	0.0	9.1	0.6	69.8	9.1	10.1	9 - 15

SPECIFIC GRAVITIES

SIZE	COARSE 1	COARSE 2	COARSE 3	FINE 1	FINE 2
22.2-15.9	0.000	0.000	0.000	0.000	0.000
15.9-9.5	0.000	2.719	0.000	0.000	0.000
9.5-4.75	2.718 *	2.745 *	0.000	0.000	0.000
4.75-2.00	0.000	2.673	0.000 *	2.695	0.000
2.00-0.180	0.000	0.000	0.000	2.704 *	0.000
-0.180	0.000	0.000	0.000	2.804	2.899 *

SPECIFIC GRAVITY OF ASPHALT = 1.040

COMBINED BULK SPECIFIC GRAVITY (G) = 2.741

Results of SMA Mix Design

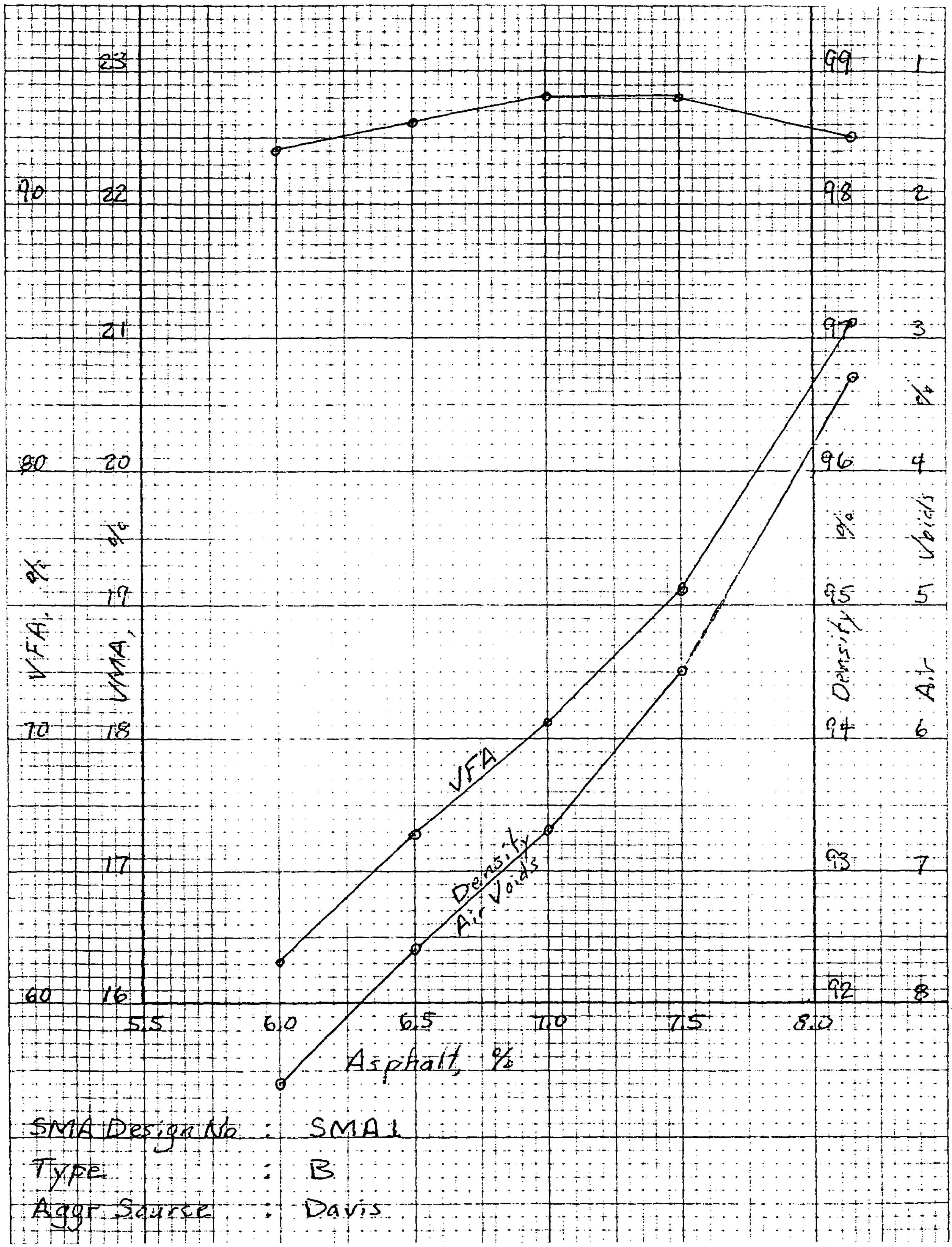
Pit: Davis

Gradation: TYB (15.9mm)

Asphalt, %	6.0	6.5	7.0	7.5	8.0	8.3
Density, %	91.4	92.4	93.3	94.5	96.0	96.7
Air Voids, %	8.6	7.6	6.7	5.5	4.0	3.3
VMA, %	22.4	22.6	22.8	22.8	23	22.5
VFA, %	61.6	66.4	70.6	75.6	82.6	85.3
Cellulose Fibers, %	0.3	0.3	0.3	0.3	0.3	0.3
Antistrip-UC 8163 %					NS	
					Λ	

NS = Non-stripping

Λ = Optimum



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92
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4
5
6
7
8
VFA, %
VMA, %
Density, %
Air Voids
VFA
Density
Air Voids
5.5
6.0
6.5
7.0
7.5
8.0
Asphalt, %
SMA Design No : SMA 1
Type : B
Aggr Source : Davis

SMITH CRUSHED STONE, INC.
BULLARD PIT
LIMESTONE COUNTY, TX

MATERIALS INFORMATION

Bullard

DESIGN #SMA1 12-30-96

****

	Material	Bulk Specific Gravity	Source	Source Number
Coarse 1	Ty C	2.618	Smith Cr Stone	
Coarse 2	Ty D	2.626	Smith Cr Stone	
Coarse 3				
Fine 1	Screenings	2.649	Smith Cr Stone	
Fine 2	Filler	2.899	Unimin	
	Asphalt, AC-0	1.040	40 AMI	
	Anti-Strip			
	Latex			

****

Material	Loss by Decant.	Del. Matl.	L.S.	Sand Equiv.	Laboratory Number
Ty C	N\A	0			
Ty D	0.6	0			
Screenings			0		
Filler			0		
Total Mixture				0	

****

QUALITY TEST VALUES

Source	Magnesium Sulfate	Los Angeles Abrasion	Polish Value	Crushed Particles
Smith Cr Stone	10	31	39	
Lab Number	E0914708	E0914708	10-96RSVP	
Smith Cr Stone				
Lab Number				

This design is to be considered out of date and void Dec. 31, 1996

****

REMARKS: For surface courses without latex, we recommend an asphalt with a penetration value of less than 90.

GRADATION

Design #SMA1 Date : 12-30-96

SIEVE SIZES	Ty C Coarse 1	34 %	Ty D Coarse 2	49 %	Coarse 3	0 %	Screenings Fine 1	5 %	Filler Fine 2	12 %	Combine 100 %	Spec. Ty B
19.0	100.0	34.0	100.0	49.0	0.0	0.0	100.0	5.0	100.0	12.0	100.0	100
15.9	96.5	32.8	100.0	49.0	0.0	0.0	100.0	5.0	100.0	12.0	98.8	80 -100
9.5	9.4	3.2	84.4	41.4	0.0	0.0	100.0	5.0	100.0	12.0	61.6	53 - 80
4.75	1.8	0.6	13.5	6.6	0.0	0.0	98.4	4.9	100.0	12.0	24.1	15 - 28
2.00	1.5	0.5	3.0	1.5	0.0	0.0	71.8	3.6	100.0	12.0	17.6	11 - 20
0.425	1.4	0.5	2.2	1.1	0.0	0.0	40.7	2.0	100.0	12.0	15.6	10 - 17
0.180	1.3	0.4	2.0	1.0	0.0	0.0	28.8	1.4	97.4	11.7	14.5	9 - 16
0.075	0.9	0.3	1.5	0.7	0.0	0.0	17.5	0.9	69.8	8.4	10.3	9 - 15

SPECIFIC GRAVITIES

SIZE	COARSE 1	COARSE 2	COARSE 3	FINE 1	FINE 2
22.2-15.9	0.000	0.000	0.000	0.000	0.000
15.9-9.5	2.618	0.000	0.000	0.000	0.000
9.5-4.75	2.618 *	2.626 *	0.000	0.000	0.000
4.75-2.00	0.000	0.000	0.000 *	2.642	0.000
2.00-0.180	0.000	0.000	0.000	2.623 *	0.000
-0.180	0.000	0.000	0.000	2.697	2.899 *

SPECIFIC GRAVITY OF ASPHALT = 1.040

COMBINED BULK SPECIFIC GRAVITY (G) = 2.654

Results of SMA Mix Design

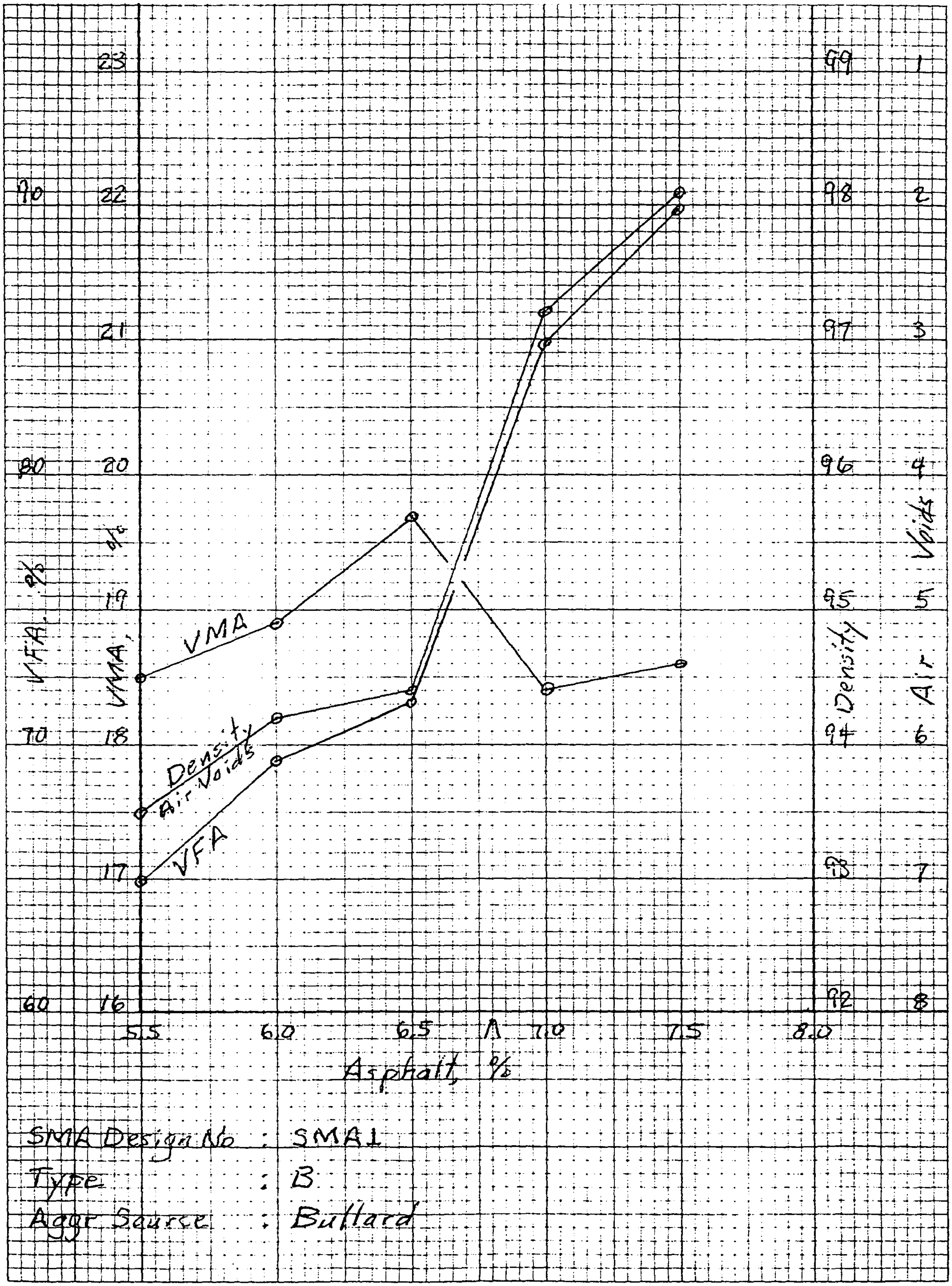
Pit : Bullard

Gradation: TYB (15.9 mm)

Asphalt, %	5.5	6.0	6.5	6.8	7.0	7.5
Density, %	93.5	94.2	94.4	96.0	97.2	98.1
Air Voids, %	6.5	5.7	5.6	4.0	2.8	1.9
VMA, %	18.5	18.9	19.7	19	18.4	18.6
VFA, %	64.9	69.3	71.6	78.9	84.8	89.8
Cellulose Fibers, %	0.3	0.3	0.3	0.3	0.3	0.3
Antistrip - UC 8162, %				NS		
				^		

NS = Non-stripping

^ Optimum



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4
5
6
7
8
VMA
Density
Air Voids
VFA
VFA, %
VMA, %
Density
Air Voids
5.5
6.0
6.5
7.0
7.5
8.0
Asphalt, %
SMA Design No : SMA1
Type : B
Aggr Source : Bullard

APPENDIX C:
RELATED INFORMATION

EFFECTS OF DIESEL CONTAMINATION IN HOT MIXED ASPHALT CONCRETE

August 25, 1997

BY

PAUL D.SHOVER

The effects of diesel contamination in Hot Mixed Asphalt Concrete have often been discussed but to our knowledge no actual quantitative tests have been recorded in the literature.

We devised a test using a Texas Department of Transportation standard 15.9 mm (type C) dense graded hot mix conforming to Spec Item 3022. Six samples were molded using the Texas Gyratory Press. All samples were 102 mm diameter x 51 mm in height. During the mixing and molding process two samples were left uncontaminated; two were contaminated with 0.2% diesel; and two were contaminated with 0.5% diesel by weight of total mix. These samples were then tested according to ASTM D4123, for resilient modulus by an independent testing laboratory.

Test results are shown in Table 1 and Figure 1.

Tests indicate that there is in fact a significant loss (30 to 60 percent) of strength from low levels of diesel contamination. It is interesting to note that the greatest losses of strength occur at 5 and 25 degrees Celsius. In the region of 5 degrees Celsius or less, one would also expect sensitivity to shrinkage (cold) cracking. Although specific tests were not devised for this particular failure mode, we would predict that diesel contamination would increase the sensitivity of a hot mix to cold cracking.

Table 1: Results of resilient modulus tests of diesel contaminated specimens.

Sample ID	Resilient Modulus @ Temperature, psi x 10^3		
	5 C	25 C	40 C
No Diesel	1013	180	27
0.2% Diesel	703	95	24
0.5% Diesel	537	67	25

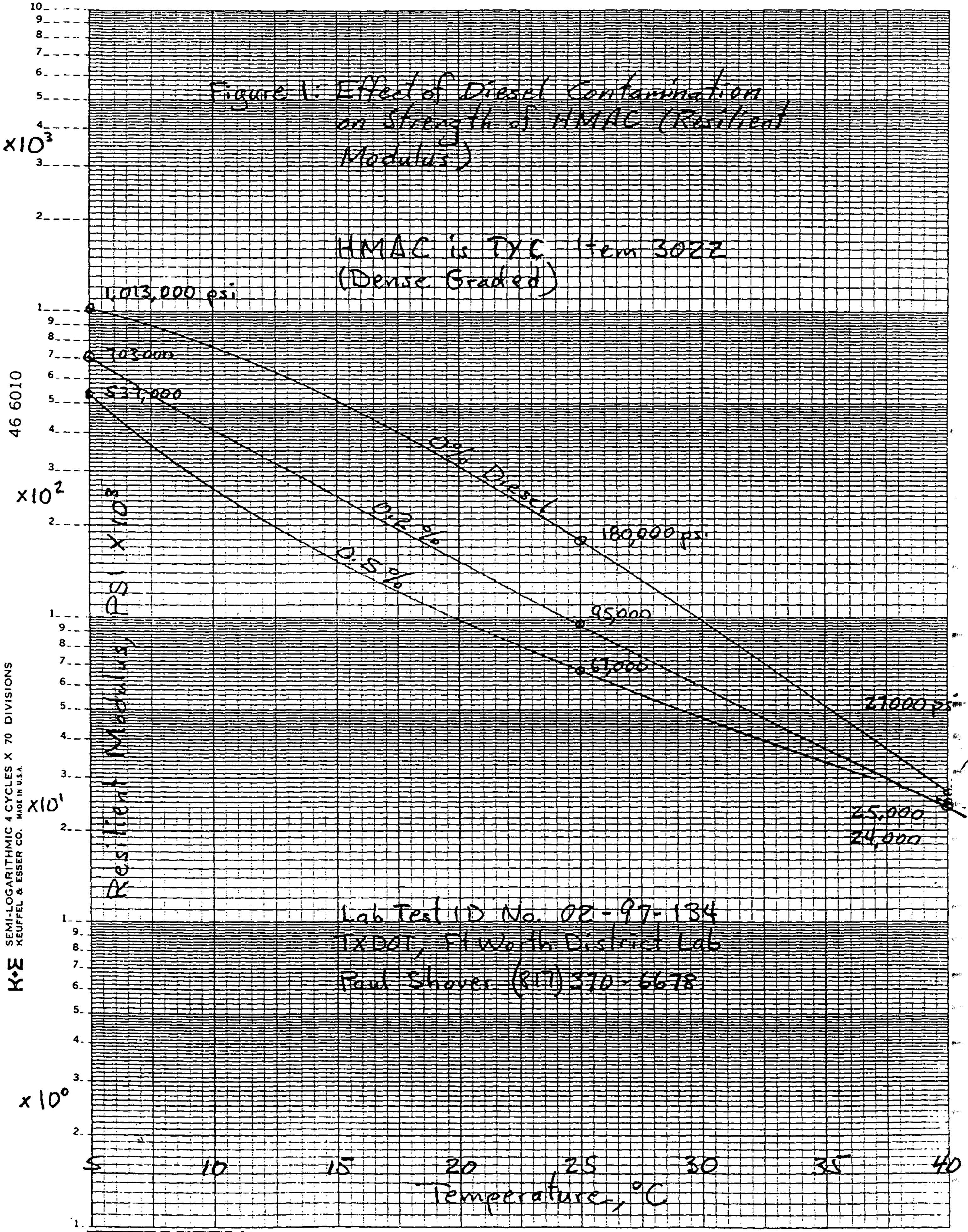
Figure 1: Effect of Diesel Contamination on Strength of HMAC (Resilient Modulus)
HMAC is TxC Item 3022 (Dense Graded)
1,013,000 psi
703,000
537,000
0% Diesel
0.2%
0.5%
180,000 psi
95,000
67,000
27,000 psi
25,000
24,000
Lab Test ID No. 02-97-134
TxDOT, Ft Worth District Lab
Paul Shover (817) 370-6678
Resilient Modulus, PSI x 10³
x10³
x10²
x10¹
x10⁰
Temperature, °C
5
10
15
20
25
30
35
40
46 6010
K•E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

\marshall.des.

(Metric) 1 October 1997

LABORATORY DESIGN OF STONE MATRIX ASPHALT (SMA) MIXTURES WITH FIBERS USING THE MARSHALL MIX DESIGN METHOD

BACKGROUND

In Germany this mixture is called Stone Mastic Asphalt (SMA), but in keeping with U.S. practice we will designate this as titled above. The techniques used in Germany for the design of Stone Matrix Asphalt (SMA) mixtures are not greatly different from those used in the United States for designing hot mix asphaltic concrete mixtures. In Germany the Marshall test method is used to prepare and compact the test specimens to be used in the evaluation of the mixture. This is the same test method used by many United States agencies.

However, for SMA mixtures, Marshall stabilities and flows are not used in the evaluation of the mix design because those values are less meaningful than with dense-graded mixtures. Properties such as aggregate gradation, asphalt grade and content, air void content, voids in the mineral aggregate, voids filled with asphalt, and asphalt draindown are analyzed and specified.

SMA mixtures consist basically of one or more coarse aggregates, fine aggregates and mineral fillers blended in a combined aggregate mix in which intermediate sizes are absent or greatly reduced, and containing a fairly high quantity of filler. A small amount of cellulose fiber is added to the mixture in order to enable the mixture to hold a high asphalt content. This results in a mixture with a high percentage of voids in the mineral aggregate (VMA) and a high percentage of voids filled with asphalt (VFA).

The high content of coarse aggregate creates a stone skeleton to resist deformation and provide good wear resistance and surface texture. The rich mortar (aggregates passing the 4.75 mm sieve, plus mineral filler and asphalt) provides improved low temperature properties, long-term durability, and a thick asphalt film on the aggregate to resist moisture damage.

AGGREGATE AND GRADATION

The coarse and fine aggregates and mineral filler selected for an SMA project shall all be products of crushing with 100% crushed faces. Natural gravel and field sand are not to be used under any circumstances. A good quality mineral filler should be a product of a crushing operation and the parent stone should meet the same quality requirements as the coarse and fine aggregates except for polish value (PV). The mineral filler should have a minimum of 60% passing 0.075 mm sieve and not more than 20% passing 0.020 mm sieve when measured by washed sieve analysis. Except in unusual cases, both the coarse and fine aggregates should be from the same pit (source).

Quality Criteria:

LA Abrasion		25% max
Soundness	Magnesium Sulfate	20% max
Absorption	Natural Aggregate	2% max
Polish Value		As Specified
Crushed Faces		100% min
Flat and Elongated particles (Flakiness Index)		5% max (17 max)
Other criteria may be specified by plan note.		

The combined gradations for various nominal maximum aggregate sizes are shown in TABLE 1.

ASPHALT CEMENT

The following polymer-modified, performance-graded asphalt cements are suitable for SMA designs:

PG 76-22
PG 76-28

CELLULOSE FIBER

When needed to control drainage, cellulose fiber meeting the requirements of Special Specification Item 3025 shall be used in the mixture. Only the loose fiber (Type A) is used in the Laboratory Design and the mixture should contain 0.3% based on the total weight of the mixture. The weight of the fibers, however, is not included in the mix design calculations--it's just added in.

SAMPLE PREPARATION AND COMPACTION

In general, the Marshall method is used to prepare and compact the specimens to be used in evaluation of the mix design; however, as stated before, stability and flow values are not used in the evaluation, as those values appear to be meaningless for SMA mixtures. See ASTM D1559.

The compactive effort to be used is 50 blows per side, using the standard Marshall hammer and 101.6 mm (4.0") diameter x 63.5 mm (2.5") height molds. Three specimens should be prepared at each asphalt content to be used in the evaluation. The asphalt contents to be evaluated should range from 5.5% to 7.5% inclusive, in 0.5% increments. (The ideal asphalt content is considered to be 6.5%.) Specimen weight will be about 1100 g to 1200 g each. The tolerance on the height of the molded sample is ±1.6 mm.

The mixing temperatures should be:	PG 76-22	163 - 177 deg C
	PG 76-28	163 - 177 deg C
	Aggregate	163 deg C min.

The hot mixture is aged 2 hours at 163 deg C before molding.

TABLE 1: STANDARD SMA GRADATIONS*

SIEVE SIZE, mm	TYPE A	TYPE B	TYPE C	TYPE D	TYPE E
25.4	100				As Shown on
22.2		100			the Plans
19.0	80 - 100		100		
15.9		80 - 100		100	
12.7	45 - 70		80 - 100		
9.5	20 - 28	53 - 70	55 - 75	80 - 100	
6.4				45 - 70	
4.75	15 - 23	20 - 28	20 - 28	20 - 28	
2.36	13 - 21	13 - 21	13 - 21	13 - 21	
0.600	10 - 17	10 - 17	10 - 17	10 - 17	
0.300					
0.075	9 - 15	9 - 15	9 - 15	9 - 15	
VMA min. %	17	17	17	17	

*Test Method TEX-200-F, Part II (Washed Sieve Analysis) shall be used.

Terminology regarding aggregate follows the practice of ASTM C125 and D8, which state that the Maximum Aggregate Size is the smallest sieve which 100% must pass; and the Nominal Maximum Aggregate Size is the smallest sieve which 100% may pass (ie, the first sieve which may retain any aggregate). By this terminology a TYPE B aggregate from Table 1 would have a 19 mm Maximum Aggregate and a 16 mm Nominal Maximum Aggregate. TYPE B would be called a 16 mm (5/8") aggregate.

The cellulose fiber, either loose or pelletized form, should be added and thoroughly blended with the hot aggregate prior to the addition of the hot asphalt cement. Care should be exercised so that the mixtures containing loose fiber are not over mixed during the initial dry mixing cycle, which could result in shredding the fibers.

The mixture is batch weighed and placed in the mold in one lift, after which the mixture is spaded (rodded) with a spatula (1-inch blade) across the middle of the mold as well as around the edges, ending up with a slightly rounded top surface which has been lightly compacted with a flat spoon. The purpose of this is to insure a mixture which will consolidate to a uniform texture. This must all be done very quickly and smoothly in order to minimize temperature loss.

Laboratory compaction should begin at 146 C (min) and be completed before reaching 132 C. The compaction with the Marshall hammer is accomplished with an actual 51 blows per side (even though this is refered to as a "50-blow per side compactive effort"). The first blow on each side is a "Seating Blow" and since this first blow is not resisted by a solid backing, it does not contribute to the compaction energy, and therefore is not counted.

Mixing --- Loose Fiber

The loose fiber should be added to the fine aggregate and stirred by hand. (The fine aggregate is defined as all aggregate and mineral filler passing the 4.75 mm sieve.) After the loose fiber has been distributed, then this mixture may be added to the coarse aggregate fraction and blended. After the aggregate/fiber mixture has been reheated to the mixing temperature, the hot asphalt cement is added and mechanical mixing is begun. This wet mixing time should require no more than 3 or 4 minutes if a mechanical mixer is used.

ANTISTRIPPING AGENTS

Normally, an antistripping agent is required in the hot mix in order to prevent the asphalt cement from being stripped from the aggregate. Antistripping agents include both liquid antistrip as manufactured by various companies, and hydrated lime. The hot mix design should be tested for stripping at 1.0% concentration of antistrip agent by weight of asphalt.. Since hydrated lime ($Ca(OH)_2$) antistrip also acts in the same manner as mineral filler in controlling drainage, the hydrated lime is the preferred agent.

PROPERTIES TO BE DETERMINED AND EVALUATED

In order to evaluate SMA mixtures, the following properties must be measured or calculated:

1. Combined gradation of aggregates
2. Asphalt content
3. Bulk specific gravity and water absorption of the aggregates
4. Maximum theoretical density of the mixture.
5. Bulk specific gravity of the compacted specimen
6. Air void content
7. Voids in the mineral aggregate

8. Voids filled with asphalt (VFA)
9. Stripping
10. Segregation (draindown or drainage)

As an aid to evaluation of the mix design and selection of the optimum asphalt content, plots of Density and Air Voids vs Asphalt Content; VMA vs Asphalt Content; and VFA vs Asphalt Content should be made and compared to the criteria in Table 2, SMA Specifications.

TABLE 2 summarizes the requirements for production of a good SMA mix.

TABLE 2: SMA SPECIFICATIONS

ITEM	SPECIFICATION
Marshall Compaction	50 blows/Side
Asphalt Cement	PG 76-22 or PG 76-28
Asphalt Content, %	6.0 to 7.5
Air Void Content, %	3.5 to 4.5
Aggr Absorption, %	2.0 Maximum
VMA, %	17 Minimum
VFA, %	75 to 84
Stripping, %	None Allowed
Draindown, %	0.3 Maximum
Cellulose Fiber, %	0.3

Note: All percentages based on total weight of mixture. *May also contain 1% to 2% Latex.

Asphalt Content (A_s). This is the percentage of asphalt in the mixture, based on the total weight of the mixture.

Bulk Specific Gravity (G_{sb}). This is the bulk specific gravity of the combined aggregates and is determined as follows:

$$G_{sb} = \frac{100}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + etc.}$$

where, P_1, P_2, P_3 etc = percentage by weight of each aggregate used, and

G_1, G_2, G_3 etc = bulk specific gravity of each aggregate used.

Mixture Bulk Specific Gravity (G_{mb}). The bulk specific gravity of the compacted mixture is determined by the *immersion in water* method. The Saturated Surface Dry (SSD) condition is determined as follows:

> Parafine is not used to coat the molded specimens. After obtaining weight of the specimen submerged in water, the excess water is removed by grasping the specimen in the hand and moving the sample with a rapid "slinging motion" of the hand and arm to develop a centrifugal force (don't let go of the specimen). Do this 5 times and then rotate the specimen 180 degrees and repeat. Then use a damp paper towel to blot excess moisture from the surface of the specimen. Then obtain SSD weight.

Maximum Theoretical Density (G_r). This is determined by using the Rice procedure (ASTM D2041). Cure these specimens for the same 2 hours at 146 deg C, as the molded specimens.

Air Void Content (AV). The percent Air Void Content is calculated by:

$$AV = 100 - \frac{G_{mb}}{G_r} x\ 100$$

Voids in the Mineral Aggregate (VMA). The percent voids in the mineral aggregate is calculated by:

> Test Procedure TEX-207-F.

Voids Filled with Asphalt (VFA). This property is calculated by:

$$VFA = \frac{VMA - AV}{VMA} x\ 100$$

Asphalt Draindown Test. This test is performed in the laboratory in order to determine whether an unacceptable amount of asphalt cement drains from the mixture. Test Procedure TEX-235-F, "Determination of Draindown Characteristics in Bituminous Materials" shall be used.

Asphalt Antistripping Agents and Tests. The proposed SMA at optimum asphalt content should be evaluated for moisture susceptibility by performing a stripping test in accordance with Item 301,"Asphalt Antistripping Agents", Test Method TEX-530-C. Zero percent stripping is required. The preferred antistripping agent is Lime, in accordance with Item 301, paragraph 301.4 (2), in concentrations up to 1% by weight of the asphalt. [END]

Special Specification

ITEM 3026

STONE MATRIX ASPHALTIC (SMA) CONCRETE PAVEMENT

Designer's Discussion and Plan Notes:

Reference Para.	**Discussion and General Plan Notes**
Spec Note	Insert the following Special Note in the P.S. & E.: NONE
2.0	Show additional requirements on plans or notes as required. This specification should never be used with QC/QA type conditions where the contractor determines all parameters of the mix design. Do not allow RAP to be used in SMA hot mixes.
2.0(1) a	Lightweight aggregate is not permitted. Indicate required polish value (PV) in the plan notes. Example Note: The coarse aggregate Polish Value shall be a minimum of _______. Coarse and Fine aggregates shall be from the same source (pit) and both aggregates shall be products of crushing operations. See discussion for Para 3.0. So far we have been able to blend standard products from a single pit to obtain the required composite gradation for all Types listed in Table 2. For example, thus far, all the composite gradations have been achieved using a pit's standard "D" Rock, "C" Rock (or another of their standard gradations) and #10 Screenings, plus a different source for the mineral filler. Mineral Filler may be from a different source than the Coarse and Fine aggregate; but shall be a product of crushing operations, and meet gradation requirements.
3.0	Asphalt grade, aggregate type (rock name) for both coarse and fine aggregates, mineral filler, and gradation type (Table 2) will be chosen by the Dist. Materials Engineer, but must be included in the plan notes. Informational to the Designer, the choices are:

3.0 Contd	
	Asphalt: PG 76-22 is the normal choice (North Central Texas) PG 76-28 is used if you anticipate cold (tension) cracking (Panhandle). Suitable rock types for coarse and fine aggregates from a single pit: Ryolite — Basalt (Trap rock) Dolomite — Granite & Diorite (if fine grained) Dolomitic Limestone (MgO = 21.0 % minimum) Siliceous Limestone (softer limestones are not appropriate) Trachyte Sandstones with silica (quartz) or calcite cement. Quartzite — Metaquartzite [Note that the quality characteristics of the coarse and fine aggregates have been changed somewhat: Now the following values apply (see Table 1 below): LA Abrasion — 25 max $MgSO_4$ Soundness — 20 max Polish Value (PV) — 32 min] Mineral Filler — Product of crushing from any of the rock types allowed for coarse or fine aggregates, above. IT IS IMPORTANT to match the density (specific gravity) of the mineral filler with densities of the coarse and fine aggregate. The densities of the coarse and fine aggregates should be almost identical since they are supposed to be from the same pit; but the mineral filler may come from a different source. If the coarse and fine aggregate have a high density, then the mineral filler should be chosen to have a high density also---this avoids the necessity of a volumetric mix design (always a messy proposition). Likewise a light or medium density aggregate should be matched with a light or medium density mineral filler, respectively. Generally, an aggregate specific gravity of 2.7 or higher would require a mineral filler with a density of 2.7 to 2.9----this would be indicative of a ryolite, basalt (traprock) or even some dolomitic aggregates, matched with an equally dense mineral filler of (probably) the same mineral type. One commercially available dolomitic mineral filler is known which has a specific gravity of 2.9. Gradation — Give Type, and reference Table 2. Example Note: Mix design will be based on the following materials: Asphalt: PG 76-22 Crushed Ryolite for both coarse and fine aggregates from a single pit. Crushed Dolomite fines for mineral filler Type B gradation (See Table 2).

	[The contractor may submit something besides ryolite, which we would have to accept if it meets all specification requirements.]
3.0(1)	If the contractor is to be charged for redesigns of SMA hot mix, a charge must be stated in the plan notes (otherwise, the redesign costs him nothing). Example Note: For each additional SMA redesign the contractor shall be charged a sum of $2,000.00.
5.0(f)	The designer must show location(s) for test strips on the plans. Test strips should not be allowed in the lanes to be paved on this SMA project. Ideally the test strips should be located off the project on a nearby intersecting roadway or an adjacent service road if it's not to receive an SMA pavement. Parking lots are another possibility, but the designer would need to make arrangements with the owner. Include consideration for these test strips in your traffic control plan.
6.0(1) 6.0(7)	The minimum mat thickness of SMA should be 4 times (4X) the nominal maximum aggregate size, or 3 times (3X) the maximum aggregate size. [However, FHWA suggests a minimum of a little more than twice the maximum aggregate size in the model specification for SMA----experts now feel this is not thick enough, hence the 3X or 4X mentioned above. Personally, I feel that a 2" or 2 1/4" thick mat for a 5/8" nominal maximum size aggregate SMA would be adequate.] Ride Quality. The designer must include a general note requiring either Surface Test Type A (3.048 m straight edge), or Surface Test Type B (profilograph). Example: Ride Quality shall be determined by Surface Test Type ______, in accordance with Item 5000, "Ride Quality for Pavement Surfaces".

Table 1 is a selection chart for SMA aggregates based on the Materials and Test Division's "Aggregate Quality Monitoring Program (AQMP) and a Rated Source Catalog (RSQC)", and rated specifically for Polish Value (PV), LA Abrasion and Mg SO_4 Soundness. These data will be revised periodically to conform to the current RSQC. Reference Special Specification Item 3026, for required aggregate quality characteristics.

TABLE 1: Sources for Coarse and Fine Aggregate Selected for Lower values of LA Abrasion (25) and MgSQSoundness (20)

Valid thru 30 November 1997

Producer	Pit	Location	Type of Stone	PV	LA Abrasion	$MgSO_4$ Soundness
Western R	Pedernal 0050309	N.M.	Ryolite	37	14	3
Western R	Davis 0050439	Davis, OK	Ryolite	39	17	5
Capitol Ag (Delta)	Brownlea 1402704	Burnett County	Sandstone w/ Calcite Cement	40	24	15
Jobe Conc	Vado 0050310	N.M.	Granite	35	21	4
Jobe Conc	McKellig 2407201	El Paso County	Dolomite	29	25	8
Amis Matl	Springtow 0050407	OK	Limestone	33	22	15
Pioneer	Clinton 1402701	Burnett County	Dolomite	25	21	1
Vulcan	Brownwoo 2302501	Brown County	Limestone	(29)	24	10
Vulcan	Knippa 1523206	Uvalde County	Basalt (Traprock)	33	15	17
Meridian	Snyder 0050435	OK	Granite	29	25	7
Meridian	Mill Creek 0050438	OK	Basalt (Traprock)	34	24	7

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STONE MATRIX ASPHALTIC (SMA) CONCRETE PAVEMENT

REFERENCE ITEMS: (300)(301)(340)(520)(3025)*(5000)

Do not include the general note on percent stripping allowed on reference Item 301. This information has been incorporated into the specification.

SPECIAL PROVISIONS: (300---025) Used to invoke Performance Graded* asphalt.

*We will not use the new Special Specification Item 3030 to invoke use of Performance Graded asphalt, at this time for two reasons:

1) This spec (Item 3030) is still in development and is subject to change. We will not use it until this spec is implemented state-wide.
2) The number of the specification may change when implemented state-wide.

Texas Department of Transportation

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