Quality Improvement Series 122

NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION

Designing and Constructing SMA Mixtures— State-of-the-Practice

U.S. Department of Transportation
Federal Highway Administration

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This publication is provided by the Members of the National Asphalt Pavement Association (NAPA), who are the nation's leading Hot Mix Asphalt (HMA) producers/contractor firms and those furnishing equipment and services for the construction of quality HMA pavements.

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Abstract

Stone Matrix Asphalt (SMA) is a tough, stable, rut-resistant mixture. The SMA design concept relies on stone-on-stone contact to provide strength and a rich mortar binder to provide durability. These objectives are usually achieved with a gap-graded aggregate coupled with fiber and/or polymer-modified, high asphalt content matrix.

Although SMA is a relatively new mix type in the U.S., over 4 million tons have been placed since 1991. The estimated 20–25 percent increase in cost is more than offset by the increase in life expectancy of the mix, primarily though decreased rutting and increased durability. SMA is considered to be a premium mix by several state Departments of Transportation for use in areas where high-volume traffic conditions exist and frequent maintenance is costly.

As with any HMA production process, close communication and cooperation between agency and contractor are necessary to minimize SMA production problems. Attention to detail in every phase of the manufacturing process is required.

The recommendations for mix design, plant production, paving, compaction, and quality assurance discussed in this report should provide the guidance necessary to maximize the potential for SMA and minimize production problems.

Acknowledgements:

This publication was first developed in 1998 and reviewed by NAPA's Quality Improvement Committee. The principal author was Charles S. Hughes. This edition was revised by Prithvi S. Kandhal, Associate Director Emeritus of the National Center for Asphalt Technology (NCAT).

Key Words:
SMA, stone matrix asphalt, Hot Mix Asphalt, stone-on-stone contact, mixture design, plant production, construction practices, permanent deformation.

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Executive Summary

Stone Matrix Asphalt (SMA) is a tough, stable, rut-resistant mixture that relies on stone-to-stone contact to provide strength and a rich mortar binder to provide durability. Although it is a relatively new mix type in the U.S., more than 4 million tons have been placed since 1991. The estimated 20-25 percent increase in cost is more than offset by the increase in life expectancy of the mix, primarily through the decreased rutting and increased durability. SMA is considered to be a premium mix by several state Departments of Transportation for use in areas where high-volume traffic conditions exist and frequent maintenance is costly.

There are several mixture design factors that must be met. Among these are:

- Provide stone-on-stone contact through the selection of the proper gradation,
- Use hard, cubical, durable aggregate,
- Design at an asphalt content of at least 6 percent and air void content of 4 percent, for most mixtures,
- Design for voids in the mineral aggregate such that at least 17 percent is obtained during production, and
- Check for and meet moisture susceptibility and draindown requirements.

There are also several good production and construction practices that should be followed:

- Maintain close control of plant stockpiles and cold feed,
- Maintain close control of plant temperature,
- Maintain a consistent paving speed and compaction effort,
- Use the necessary number of rollers to achieve a minimum density of 94 percent of maximum density,
- Avoid hand work whenever possible,
- Minimize the number and extent (size) of fat spots that appear behind the paver,
- Use good quality assurance practices including frequent monitoring of all aspects of production, paving, and compaction.

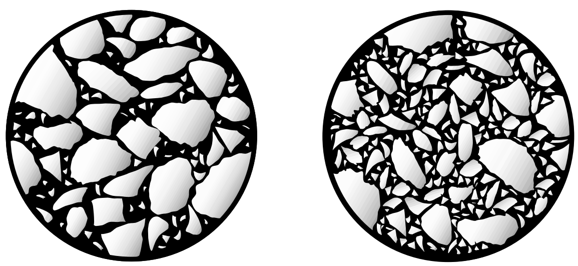
An example mix design is appended.

C H A P T E R   O N E

Introduction

Stone Matrix Asphalt (SMA) is a tough, stable, rut-resistant mixture that relies on stone-to-stone contact to provide strength and a rich mortar binder to provide durability. *Figure (1)* provides a graphic representation of the difference between SMA and dense-graded conventional mixtures.

Figure 1



Stone Matrix Asphalt SMA | **Conventional Hot Mix Asphalt HMA**

Brief History of SMA

SMA is a relatively new paving mixture in the United States. The use of this mixture in the United States came about as a result of the European Asphalt Study Tour that took place in the Fall of 1990. One of the more promising technologies that evolved from this tour was the introduction of the SMA as a surface mixture. On the Study Tour, SMA was found to have been used successfully in Europe for more than 20 years.

In early 1991, the Federal Highway Administration (FHWA) established a Technical Working Group (TWG) to develop model guidelines for materials and construction of SMA mixtures. Considerable work was done by this group and its role in establishing guidelines for material and construction was instrumental in getting early sections of SMA built in the U.S.

Any success in transferring SMA technology to the U.S. can be directly attributed to the early efforts of this TWG. Several of the members — (contractors, state chief engineers, and agency staff) — participated in the European Asphalt Study Tour. Early SMA projects were undertaken in true partnership fashion with sharing of the risk and free exchange of information. It can stand as the model for true technology transfer with full buy-in by industry, government, and the research community. Its success is evident. The publication[1] that emanated from the TWG was entitled *Guidelines for Materials, Production, and Placement of Stone Matrix Asphalt (SMA)* and it became the early primer for SMA mixtures (the document is reproduced in Appendix A). However, even before the guidelines were published, trial SMA mixture sections were designed and placed in North America. The first SMA was placed in the U.S. in Wisconsin in 1991 followed by Michigan, Georgia, and Missouri during the same year.

By the Summer of 1997, at least 28 states had constructed well over 100 projects totaling more than 3 million tons of SMA. The National Center for Asphalt Technology (NCAT), through funding by the FHWA, conducted a summary of performance of SMA in 1997[2]. The majority of the projects included in the survey were constructed between 1992 and 1996, and most were placed in heavy traffic conditions. One of the findings of this survey was that ". . .SMA mixtures continue to provide good performance in high-traffic volume areas. The extra cost for construction should be more than offset by the increased performance."

The first SMA projects in the U.S. were designed essentially following "recipe" type German specifications[3]. The National Center for Asphalt Technology (NCAT) has now developed a detailed, rational mix design method for SMA in the National Cooperative Highway Research Program Project 9-8. The mix design and construction of SMA in this report are largely based on NCHRP Report 425, "Designing Stone Matrix Asphalt Mixtures for Rut-Resistant Pavements" prepared by NCAT[4].

The following AASHTO standards emanated from NCHRP Report 425.

- MP8 Specification for Designing Stone Matrix Asphalt (SMA)
- PP41 Practice for Designing Stone Matrix Asphalt (SMA)

Advantages of SMA

The primary advantage of SMA is the extended life with improved pavement performance compared to conventional dense-graded hot-mix asphalt (HMA). The other advantages are noise reduction, improved frictional resistance, and improved visibility. The discussion of these advantages follows.

Improved Pavement Performance

As mentioned earlier, NCAT evaluated the performance of 85 SMA projects within the U.S.[2] The following observations were made:

- Over 90 percent of SMA projects had rutting measurements of less than 4 mm and 25 percent had no measurable rutting.
- SMA mixtures appeared to be more resistant to cracking than dense-graded HMA, probably due to relatively high asphalt contents.
- There was no evidence of raveling on the SMA projects.

Experience in Georgia[5] has indicated the following:

- SMA has 30–40 percent less rutting than dense-graded HMA.
- SMA has 3 to 5 times greater resistance to fatigue cracking compared to dense-graded HMA.

Experience in Germany[6] has indicated a 20–30 year service life of SMA is not exceptional. Stripping, surface cracking (both temperature and traffic induced), and raveling are failure mechanisms not generally experienced in SMA.

Noise reduction

Several research studies have indicated a significant reduction in noise level when SMA surface course is substituted for dense-graded HMA surface course. Brief conclusions from some of these studies are as follows:

- One study in Germany[7] indicated the noise reduction may be as much as 2.5 dB(A) when dense-graded HMA is replaced with SMA.
- The Transport Research Laboratory (TRL) of U.K. evaluated[8] the relationship between aggregate size and noise levels for some mixtures. Three SMA mixes with nominal maximum aggregate sizes of 14 mm, 10 mm, and 6 mm were included in the study. The 14 mm SMA was 2.7 dB(A) quieter than conventional hot-rolled asphalt (typically used in U.K.). In turn, 10 mm SMA was 0.8 dB(A) quieter than 14 mm, with 6 mm SMA another 1.8 dB(A) quieter still.
- The acoustical characteristics of SMA were compared[9] with dense-graded HMA at three sites in Frederick County, Maryland. The demonstrated acoustical benefits of SMA were found to be similar to open-graded friction courses.
- Another study in Germany[10] showed a 2.0 dB(A) reduction in noise when SMA was used in lieu of dense-graded HMA.
- As much as 7.0 dB(A) reduction in noise level has been reported[6] at 110 km/h in Italy when a 15 mm nominal size SMA was compared to a 15 mm dense-graded HMA.
- Up to 5.2 dB(A) reduction in noise level has been reported[6] at 70–90 km/h in another study in U.K. when 6 mm nominal size SMA was compared to hot-rolled asphalt.
- Two acoustical studies have been conducted in Michigan. The first study[11] conducted on Interstate 275, west of Detroit, indicated on average Superpave was 4–5 dB(A) quieter than PCC pavement. The second study[12] conducted on Interstate 94 west of Ann Arbor indicated a 12.5 mm SMA was approximately 4 dB(A) quieter than 12.5 mm Superpave.

Improved frictional resistance

Although water does not drain through SMA, its surface texture is similar to that of open-graded friction course (OGFC). Therefore, SMA surface has high frictional resistance, which provides improved safety to motoring public when traveling on wet pavements. Frictional resistance measurements of SMA pavements using SCRIM (Sideways Coefficient Routine Investigation Machine) or MU meter made in France at 60 km/h on highways and 100 km/h on motorways have been reported to be very good[13].

Similar to OGFC, the SMA surface causes significantly less splash and spray compared to dense-graded HMA.

Visibility

The rough surface texture of SMA as compared to dense-graded HMA means that more water can be held within the SMA rather than on the surface. This results in reduced glare at night from reflection of lights of oncoming vehicles, increased visibility of pavement markings, and reduced splash and spray.

Economic Considerations

The cost of SMA mixture has been reported to be 20–25 percent higher than the cost of conventional dense-graded mixtures. The cost of fibers, modified binders, and possible higher asphalt contents are potential reasons for increased costs. However, some of the increased cost may be offset by using less SMA per project than is possible with conventional mixture. The added benefit of reduced noise that can be achieved with SMAs may also lead to reduced costs in that fewer noise barriers may have to be constructed.

However, even considering the potential for increased costs, both the Georgia and Maryland DOTs have found the use of SMA to be quite cost effective based on improved performance and the potential for increased service life. It is clear from the increased use of SMA by other DOTs, that SMA is considered to be a cost effective mixture.

A life-cycle cost analysis was conducted by the Georgia DOT[14], which compared SMA with dense-graded HMA as an overlay on an existing PCC pavement. The analysis used rehabilitation intervals of 7.5 and 10 years for dense-graded HMA and SMA, respectively. This comparison corresponds to the 30–40 percent expected increase in SMA pavement life as generally experienced in Europe. A 30-year life cycle period was used to provide a common base period for comparing the two mixes. The results of the annualized cost comparison are shown in *Table 1*.

Table 1
Annualized Cost Comparison: SMA vs Dense-Graded HMA

Pavement Type	Rehab. Intervals (years)	Annualized Cost
Dense-graded HMA	7.5	$79,532
SMA	10.0	$50,095

It is obvious from *Table 1* that SMA is significantly cost effective as shown in this analysis. It should be noted that the rehabilitation intervals of 7.5 and 10 years are considerably shorter than can be expected with either conventional HMA or SMA.

Potential Uses of SMA

Normally, SMA mixtures are primarily used on pavements carrying heavy traffic volumes or on pavements carrying heavy loads and/or high tire pressures. As mentioned earlier, the increase in service life and improved performance can offset the additional cost when using SMA in lieu of dense-graded HMA.

There are other potential uses of SMA as follows.

High stressed pavement areas

SMA is quite suited for high stress pavement areas, such as at intersections and truck terminals. A 40-mm thick 11-mm nominal size SMA mix was used successfully on a container terminal road in the Netherlands, which required a 3-year warranty[15].

Thin overlays

Five to 8 mm nominal size SMA mix in Europe is well suited for providing thin overlays (20–30 mm) to renew frictional resistance or maintenance of existing pavements[16,13].

Resistance to wear from studded tires

SMA was developed in the 1960s in Germany primarily to provide a pavement surface to resist wear from studded tires, which are no longer in use there now. However, SMA is used in countries where studded tires are legal. SMA mixes with high nominal aggregate size and aggregate with excellent resistance to wear are preferred for this purpose. Studies in Sweden[17] have indicated increasing nominal aggregate size from 12 to 16 mm in SMA decreased wear from studded tires by 40 percent.

Scope of Document

The objective of this publication is to provide a State-of-the-Practice of SMA mixture design methods and criteria and construction procedures. Because of the evolutionary nature of mixture and construction guidelines, an up-to-date compilation of these is deemed desirable. For a more thorough discussion of a literature review, mixture design method, construction guidelines, and quality control procedures the reader is directed to

NCHRP Report No. 425[4], which is a product of an NCAT research project on SMA.

Scope

This publication addresses the necessary steps in mixture design and construction processes, recommended engineering practices, and recommendations to avoid some of the more common construction problems associated with SMA. AASHTO standards on SMA which emanated from NCHRP Report No. 425 and the experiences of leading SMA states are also included in the appendix.

Mix Design Considerations

Mixture Design Overview

Stone Matrix Asphalt is Hot Mix Asphalt consisting of two parts: a coarse aggregate skeleton and a binder-rich mortar. SMA's stone-on-stone concept is illustrated in *Figure 2*. The rationale used in the SMA mix design is to first develop an aggregate skeleton with coarse aggregate-on-coarse-aggregate contact that is generally referred to as stone-on-stone contact. The definition of coarse aggregate is determined by its relationship to the nominal maximum aggregate size used and ranges, as discussed below, from the aggregate fraction retained on the 4.75 mm (No. 4) sieve to that retained on the 1.18 mm (No. 16) sieve. The second part of the mix design rationale is to provide sufficient mortar of the desired consistency. Satisfactory mortar consistency and, thus, good SMA performance requires a relatively high asphalt cement content. For this reason, the voids in the mineral aggregate (VMA), or the design asphalt cement content, must exceed some minimum requirement.

Five steps are required to obtain a satisfactory SMA mixture, as shown in *Figure 3*. They are:

- select proper aggregate materials,
- determine an aggregate gradation yielding stone-on-stone contact,
- ensure the chosen gradation meets or exceeds minimum VMA requirements or allows the minimum binder content to be used,
- choose an asphalt content that provides the desired air void level, and
- evaluate the moisture susceptibility and asphalt cement draindown sensitivity.

Figure 2

SMA Aggregate Skeleton

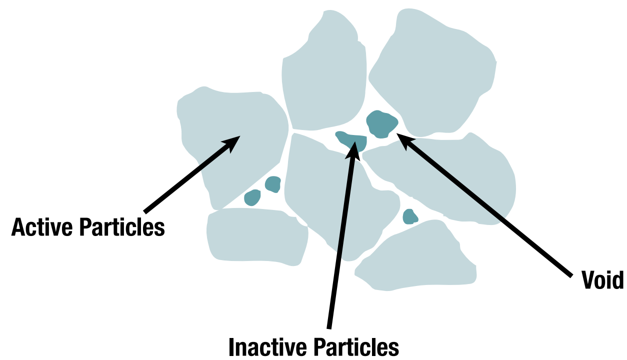
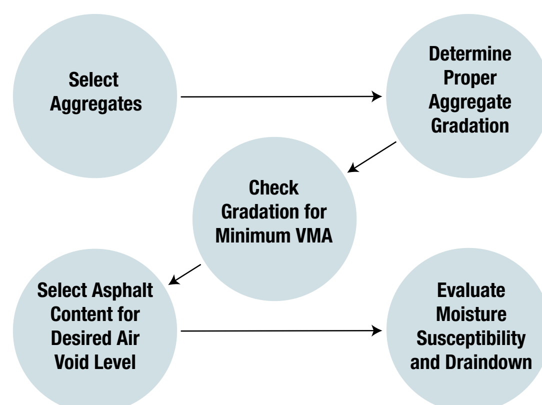


Figure 3

Flow Chart for SMA Mix Design



Composition of SMA

The first step in the mixture-design process is to select aggregates that meet specification requirements. The coarse aggregate quality requirements are shown in *Table 2* and the fine aggregate quality requirements are shown in *Table 3*. These aggregate properties are extremely important. Because the stone-on-stone contact is the vital backbone of SMA mixtures, aggregate hardness and shape are even more important than in conventional dense-graded mixtures. For example, about 90 percent of the projects evaluated by NCAT had Los Angeles (L.A.) Abrasion values below 30. Also, most of the SMA mixtures designed to date have used all crushed aggregate. As shown in *Table 2*, a maximum L.A. Abrasion Loss of 30 percent is recommended to provide adequate hardness. Studies[18,19] have indicated a fairly good correlation between L.A. Abrasion values and aggregate degradation during compaction in the Superpave gyratory compactor. For the aggregate particle shape, a maximum of 20 percent must meet 3:1 Flat and Elongated (F&E) requirement and 5 percent must meet 5:1 F&E requirement.

Table 2

Coarse Aggregate Quality Requirements

Test	Method	Specif cation
LA Abrasion, % Loss	AASHTO T 96	30* max
Flat and Elongated, %	ASTM D 4791	
3:1		20 max
5:1		5 max
Absorption, %	AASHTO T 85	2 max
Soundness (5 Cycles), %	AASHTO T 104	
Sodium Sulfate		15 max
Magnesium Sulfate		20 max
Crushed Content, %	ASTM D 5821	
One face		100 min
Two faces		90 min

*Although aggregates with higher Los Angeles Abrasion loss above 30 have been used successfully, excessive aggregate breakdown may occur in the laboratory compaction process or during in-place compaction with these aggregates.

Next, the asphalt binder and fiber are selected. Most earlier SMA projects in the U.S. used the same grade of asphalt cement as used in conventional dense-graded HMA, such as AC-10, AC-20, or AC-30 viscosity grades or equivalent. The trend now is to use a binder or modified asphalt cement to meet PG grading one or two grades higher than recommended for geographical area by Superpave.

Table 3

Fine Aggregate Quality Requirements

Test	Method	Specif cation
Soundness, % Loss	AASHTO T 104	
Sodium Sulfate		15 max
Magnesium Sulfate		20 max
Angularity, %	AASHTO TP 33 (Method A)	45 min
Liquid Limit, %	AASHTO T 89	25 max
Plasticity Index	AASHTO T 90	Non-plastic

Either cellulose or mineral fiber can be used. Studies[20,21] have shown the use of polymer-modified asphalt binder in conjunction with fiber increases resistance to both rutting and fatigue cracking. Plastomers are preferred for rut resistance and elastomers are preferred for fatigue. However, both plastomers and elastomers improve the resistance to both rutting and fatigue cracking[21]. Once satisfactory aggregate materials have been identified, the optimum aggregate gradation and asphalt cement content are selected. This is accomplished by first selecting an appropriate aggregate blend. The blended gradation should comply with the gradation specified to provide an aggregate skeleton with stone-on-stone contact, and furnish a mixture that meets or exceeds the minimum VMA requirement. Because aggregate blends often combine aggregates (including mineral filler) with different bulk specific gravities, the recommended procedure is to determine the gradations based on percent volume and then convert the gradations to those based on mass for the mixture design process.

Table 4 gives five gradation specification bands for nominal maximum aggregate sizes (NMAS) of 25 mm, 19 mm, 12.5 mm, 9.5 mm, and 4.75 mm. These gradation bands were developed by NCAT in NCHRP Project 9-8[4] after extensive testing of these five NMAS mixes to ensure stone-on-stone contact. However, 2.5 and 4.75 mm do not reflect typical applications at this time.

The NCHRP Project 9-8[4] also concluded the SMA mix permeability increased as the NMAS was increased from

Table 4

Stone Matrix Asphalt Gradation Specif cation Bands (Percent Passing by Volume)

Sieve size, mm	*25 mm NMAS[1]		19 mm NMAS		12.5 mm NMAS		9.5 mm NMAS		*4.75 mm NMAS	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
37.5	100	100								
25.0	90	100	100	100						
19.0	30	86	90	100	100	100				
12.5	26	63	50	74	90	100	100	100		
9.5	24	52	25	60	26	78	90	100	100	100
4.75	20	28	20	28	20	28	26	60	90	100
2.36	16	24	16	24	16	24	20	28	28	65
1.18	13	21	13	21	13	21	13	21	22	36
0.6	12	18	12	18	12	18	12	18	18	28
0.3	12	15	12	15	12	15	12	15	15	22
0.075	8	10	8	10	8	10	8	10	12	15

[1]NMAS - Nominal Maximum Aggregate Size - one size larger than the first sieve that retains more than 10 percent.

*25 mm and 4.75 mm gradations do not reflect typical practice for SMA applications.

Table 5

Maryland and Georgia Gradation Specif cation Bands for 19.0 mm, 12.5 mm, and 9.5 mm NMAS SMA

Sieve size, mm	Maryland			Georgia		
	19.00 mm	12.5 mm	9.5 mm	19.0 mm	12.5 mm	9.5 mm
25	100	—	—	100	—	—
19	100	100	—	90–100	100	—
12.5	82–88	90–99	100	44–70	85–100	100
9.5	60 max	70–85	70–90	25–40	50–75	80–100
4.75	20–28	30–42	30–50	20–28	20–28	28–50
2.36	14–20	20–23	20–30	15–22	16–24	15–30
0.075	9–11	8–11	8–13	8–12	8–12	8–13

4.75 mm to 25 mm. A recent study in Virginia[22] also confirmed this trend and recommended that all SMA mixes should be compacted to less than 6 percent air voids in the field to make them relatively impermeable. This is especially important for large NMAS mixes such as 19 and 25 mm. It is recommended not to use these two NMAS mixes for the wearing course. The 19-mm NMAS SMA mix has been used by some states in the binder course overlaid with a 12.5 mm NMAS SMA mix in the wearing course. In such applications it should be ensured that the 19 mm or 25 mm mix used in the binder course is compacted to less than 6 percent air voids, otherwise there is a potential of moisture induced damage (stripping) in this or underlying courses.

The voids in the coarse aggregate (VCA) are determined for the coarse aggregate fraction of the mixture. The blended gradation, along with two variations, are next combined with asphalt cement and compacted. These mixtures are analyzed and the gradation and/or asphalt cement content is altered if necessary to optimize the volumetric properties of the mixture. A coarse aggregate skeleton with stone-on-stone contact occurs when the VCA of the SMA mixture is equal to or less than the VCA of the coarse aggregate fraction as determined by the dry rodded unit weight test. (AASHTO T19).

Aggregate Skeleton

The integrity of the aggregate skeleton is assured by establishing that the VCA of the SMA mixture is equal to or less than the VCA of the coarse aggregate fraction as determined by the dry rodded unit weight test. When designing SMA mixtures, it is suggested that at least three trial gradations be initially evaluated. It is also suggested that the three trial gradations fall along the coarse and fine limits of the specification gradation band (*Table 4*) along with one gradation falling in the middle. These trial gradations are obtained by adjusting the percentages of fine and coarse aggregate in each blend. The percent passing the 0.075 mm (No. 200) sieve should be approximately 10 percent for each trial gradation with the exception of the 4.75 mm (No. 4) nominal maximum aggregate size SMA mixtures; this mixture should have approximately 14 percent passing the 0.075 mm sieve. These amounts of material passing the 0.075 mm sieve are higher than required in conventional dense-graded mixtures, but these quantities of fines are important in providing a good SMA mortar.

With some aggregates, particularly soft ones, it may be difficult to meet the VMA requirements no matter how the aggregates are blended. The inability to meet the VMA requirements may be the result of excessive aggregate breakdown which is an indication the aggregates may be unsuitable for use in SMA mixtures. Thus, every effort should be made to meet the VMA requirement.

Determination of VCA in the Coarse Aggregate Fraction

The assurance of an adequate aggregate skeleton through stone-on-stone contact is vital. This is done by establishing the VCA of the coarse aggregate fraction and testing the VCA of the compacted SMA mixture (designated VCA_{MIX}) to assure that this latter value is equal to or less than the VCA of the coarse aggregate fraction. The coarse aggregate fraction is defined as that portion of the total aggregate blend retained on the "break" sieve as shown below.

Definition of Coarse Aggregate Fraction

Nominal Max Aggregate Size		Portion of Aggregate Retained on Break Sieve	
MM	IN	MM	IN
25	1	4.75	#4
19	¾	4.75	#4
12.5	½	4.75	#4
9.5	⅜	2.36	#8
4.75	#4	1.18	#16

Example: For 25 mm mix, the coarse aggregate is defined as the portion retained on the 4.75 mm sieve.

The SMA is very sensitive to changes in the material passing the respective "break" sieve (for example, 4.75 mm and 2.38 mm are break sieves for SMA mixtures of NMAS 12.5 mm and 9.5 mm, respectively). Excessive material passing the break sieve (reduction in the coarse aggregate fraction) will cause the mix to lose stone-on-stone contact. Therefore, it is of paramount importance to maintain a tight tolerance on the material passing the break sieve during production.

Several methods of establishing stone-on-stone contact were investigated by NCAT. The methods that produced VCA values that were approximately equal and appeared not to be too severe were the dry-rodded method and a vibrating table. Since the dry-rodded method is the easiest to perform and a standard procedure exists, it is recommended as the preferred method.

Thus, the VCA of the coarse aggregate fraction (VCA_{DRC}) is determined by compacting the aggregate with the dry-rodded technique according to AASHTO T 19, *Unit Weight and Voids in Aggregate*. When the dry-rodded density of the coarse aggregate fraction has been determined, the VCA_{DRC} for the fraction can be calculated using the following equation:

$$VCA_{DRC} = \left(\frac{G_{ca}\gamma_w - \gamma_s}{G_{ca}\gamma_w}\right)100$$

where,

VCA_{DRC} = voids in the coarse aggregate in the dry-rodded condition

γ_s = unit weight of the coarse aggregate fraction in the dry-rodded condition (kg/m³),

γ_w = unit weight of water (998 kg/m³), and

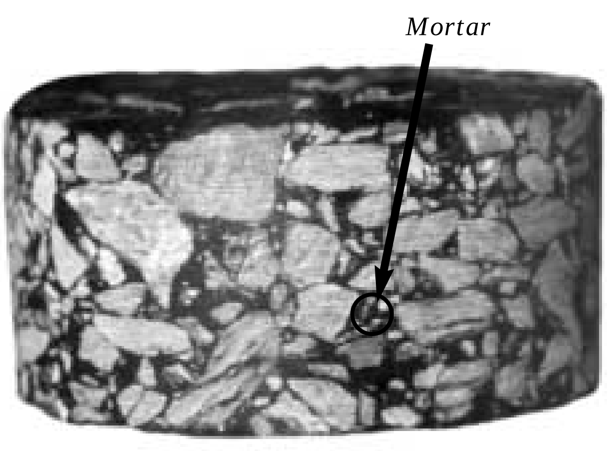
G_{ca} = bulk specific gravity of the coarse aggregate.

Mortar

The mortar is a combination of the asphalt cement, the aggregate filler (typically that portion of the aggregate passing the 0.075 mm (No. 200) sieve), and the stabilizing agent when one is used. *Figure 4* illustrates the mortar portion of the mix. All the SMA projects evaluated by NCAT used a stabilizer (or modified asphalt binder) to prevent draindown of the binder. In almost all cases, a cellulose or mineral fiber or a polymer was used as the stabilizing agent. One DOT requires both fiber and polymer in SMA work, with the fiber preventing draindown and the polymer improving the low and high temperature properties of the asphalt cement.

Figure 4

Mortar in SMA



Trial Asphalt Content and Sample Preparation

The minimum desired asphalt content for SMA mixtures is 6 percent by total mixture weight. It is recommended that the mixture initially be designed at an asphalt content in excess of 6 percent to allow for adjustments during plant production without falling below the minimum.

For aggregates with a bulk specific gravity less than about 2.75, the trial asphalt cement content can be increased approximately 0.1 percent for each increment of 0.05 below 2.75. If the bulk specific gravity of the coarse aggregate exceeds 2.75, the trial asphalt cement content can be reduced by about 0.1 percent for each increment of 0.05 above 2.75.

The asphalt cement and stabilizing additive (fiber and/or polymer) should be combined with the aggregate in a uniform manner. Slightly higher laboratory mixing times may be required to achieve good aggregate coating because of the increased surface area created by the filler and fiber. To assure complete mixing of SMA ingredients, the mixing temperature is very important and should be determined in accordance with AASHTO T 245, Section 3.3.1, or in the case of polymer modified binders, that recommended by the manufacturer.

A total of twelve samples are initially required, four samples at each of three trial gradations. Each sample is mixed with the trial asphalt content and three of the four samples for each trial gradation are compacted. The remaining sample from each trial gradation is used to determine the theoretical maximum specific gravity according to AASHTO T 209.

Laboratory Compaction

The compaction temperature is determined in accordance with AASHTO T 245, section 3.3.2, or that recommended by the producer when polymer-modified binders are used. Laboratory samples of SMA should be compacted using either the Superpave gyratory compactor (SGC) with 150 mm (6") diameter specimens or the fat-faced, static base, mechanical Marshall hammer with 100 mm (4") diameter specimens. When using the Superpave gyratory compactor, 100 gyrations is typically used for aggregates with L.A. Abrasion less than 30. And

The Difference Between VCA_{DRC}, VCA_{MIX}, and VMA

Here's an explanation to help you understand the difference between VCA_{DRC}, VCA_{MIX}, and VMA. VCA_{DRC} is obtained from the Dry Rodded Unit Weight of just the coarse aggregate as shown in *Figure A*. VCA_{MIX} is calculated to include everything in the mix except the coarse aggregate as shown in *Figure B*. VMA as shown in *Figure C* includes everything in the mix except the aggregate (both coarse and fine). For the VCA_{MIX} and VMA calculations, asphalt absorbed into the aggregate is considered part of the aggregate.

Figure A

Voids in Coarse Aggregate (DRC)

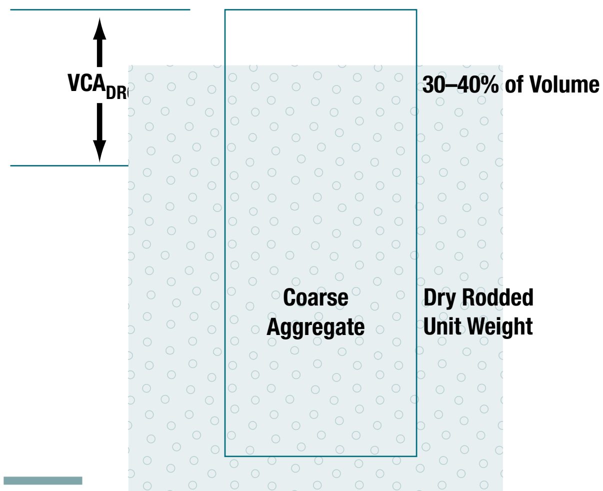


Figure B

Voids in Coarse Aggregate (Mix)

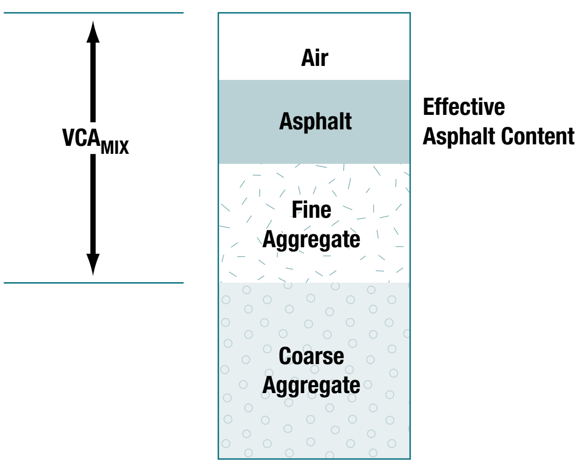
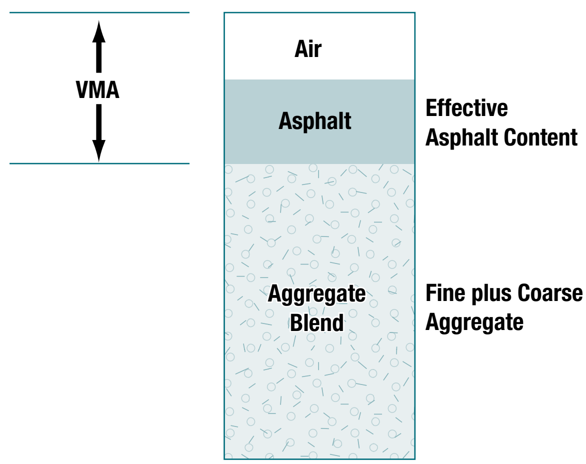


Figure C

Voids in Mineral Aggregate



75 gyrations may be used for L.A. Abrasion between 30 and 45. However, higher L.A. Abrasion aggregate should not be used in wearing surface. When designing mixes using the Marshall hammer, 50 blows/side is recommended. Comparative study[4] of compaction of SMA mixtures by SGC and Marshall hammer in NCHRP Project 9-8 indicated that 50-blow Marshall compaction was on average equivalent to 78 gyrations in SGC. This can be rounded off to 75 gyrations to correspond to N_{design} gyrations used in AASHTO PP28-01.

Selection of Desired Gradation

After the samples have been compacted and allowed to cool they are removed from the molds and tested to determine their bulk specific gravity, G_{mb}, (AASHTO T 166). The uncompacted samples are used to determine theoretical maximum specific gravity, G_{mm}, (AASHTO T 209). The percent air voids (V_a), VMA, and VCA_{MIX} can be calculated as shown below:

$$V_a = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right)$$

$$VCA_{MIX} = 100 - \left(\frac{G_{mb}}{G_{ca}} P_{CA}\right)$$

$$VMA = 100 - \left(\frac{G_{mb}}{G_{sb}} P_s\right)$$

where:

P_s = percent of aggregate in the mixture,
P_{CA} = percent of coarse aggregate in mix by weight of total mix,
G_{mm} = theoretical maximum specific gravity of mix,
G_{mb} = bulk specific gravity of mix,
G_{sb} = bulk specific gravity of the total aggregate,
G_{ca} = bulk specific gravity of the coarse aggregate.

Of the three trial gradations evaluated, the one with the lowest percent of coarse aggregate that meets or exceeds the minimum VMA requirement and has a VCA_{MIX} less than the VCA_{DRC} is selected as the desired gradation. *The selected gradation should have a VMA higher than 17 percent (typically at least 17.5 to 18.0 percent) to allow for a reduction in VMA during plant production.* The trial gradation selected based on the above conditions is referred to as the optimum gradation.

Selection of Optimum Asphalt Content

Once the gradation of the mixture has been chosen, it will likely be necessary to adjust the asphalt content to obtain the proper percent air voids in the mixture. In this case, additional samples should be prepared using the selected gradation and varying the asphalt cement content. The optimum asphalt cement content is chosen to produce 4 percent air voids in the mixture. The NCAT performance evaluation of SMA pavements suggests that choosing the asphalt content to produce an air void content near 4 percent will provide protection against fat spots after laydown and provide better rut resistance,

Table 6

SMA Mixture Specification for Marshall Compacted Designs

Property	Requirement
Asphalt Cement, %	6 minimum*
Air Voids, %	4
VMA, %	17 minimum**
VCA, %	Less Than VCA_{DRC}
Stability, N	6200 (1400 lb.) min***
TSR, %	70 min.
Draindown @ Production Temp., %	0.30 maximum

* Minimum AC % can be reduced slightly if bulk specific gravity of aggregate exceeds 2.75.

** Minimum VMA during production.

*** This is a suggested stability value based on experience.

Table 7

SMA Mixture Specif cation for Superpave Gyratory Compacted Designs

Property	Requirement
Asphalt Cement, %	6 minimum*
Air Voids, %	4
VMA, %	17 minimum**
VCA, %	Less Than VCA_{DRC}
TSR, %	70 min.
Draindown @ Production Temp., %	0.30 maximum

* Minimum AC % can be reduced slightly if bulk specific gravity of aggregate exceeds 2.75.

** Minimum VMA during production.

particularly in warm climates. Cold climates may use an air void content near 3.5 percent.

The number of samples needed for this part of the mixture design procedure is, again, twelve. This provides for three compacted and one uncompacted sample at each of three asphalt contents. The mixture properties are again determined, and the optimum asphalt content selected. The SMA mixture selected should have properties meeting the criteria shown in *Table 6* or *7*, depending on the compaction method used. If these criteria are not met, the mixture must be modified so that they are met.

Moisture Susceptibility

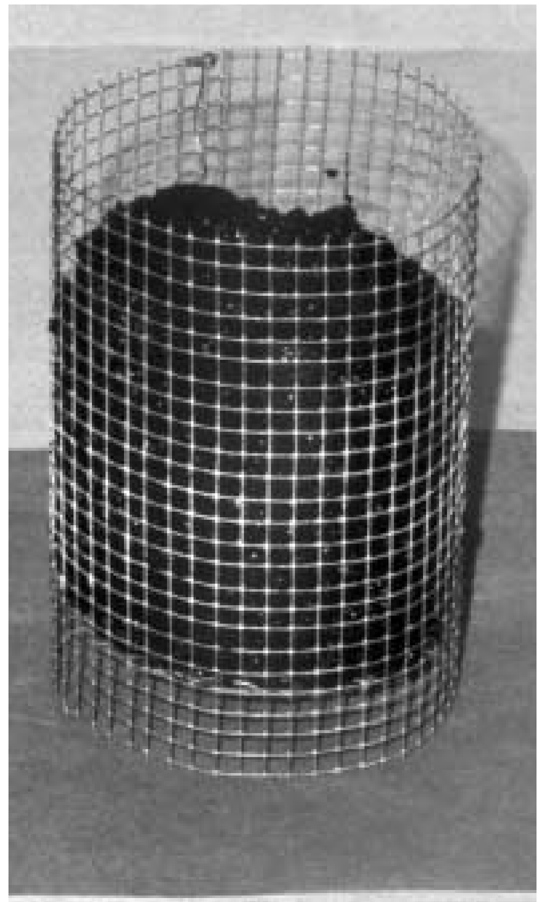
As in any HMA mixture, the evaluation of moisture susceptibility is important. The moisture susceptibility of the selected SMA mixture is determined by using AASHTO T 283. The specimens for the T 283 test are compacted to an air void level of 6 ± 1 percent.

Draindown Sensitivity

Draindown sensitivity is more important for SMA mixtures than for conventional dense-graded mixes. The test developed for this purpose by NCAT is intended to simulate conditions that the mixture is likely to encounter as it is produced, stored, transported, and placed. Draindown is that portion of the mixture (fines and asphalt cement) that separates and flows downward through the mixture.

Figure 5

Draindown Test Apparatus



AASHTO T305, "Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures," or ASTM D6390, which have been adapted from the NCAT procedure, should be used. *Figure 5* shows the test apparatus. The essential aspects of the test are to place a sample of the mixture in a wire basket, position the basket on a plate that is placed in a forced draft oven for one hour, and measure the mass of material that passes through the basket and collects on the plate. This mass is then expressed as a percentage of the initial sample. The test should be run at two temperatures. One of the temperatures should be the anticipated asphalt plant production temperature and the second temperature should be 15°C (27°F) above the first temperature. Duplicate samples should be run, thus, requiring a minimum of four samples.

The draindown sensitivity is determined by measuring the draindown at the anticipated asphalt plant temperature, and should meet the criterion in *Tables 4* or *5*. The draindown evaluation at the higher temperature (+15°C) provides information as to how sensitive the SMA mixture is to plant temperature fluctuations.

Mortar Properties

Currently, no specific performance testing of the SMA mortar is performed. The NCHRP[4] project done by NCAT on SMA suggests that the Superpave binder test procedures may be appropriate to evaluate mortar properties. The concept of using minimum mortar stiffness to promote a stiff mortar for resistance to permanent deformation and a maximum stiffness at low temperature to resist thermal cracking is appealing. However, there is not adequate experience or knowledge using the equipment to recommend its use at this time. The reader may refer to the NCHRP No. 425[4] Report for further information.

Mix Design Example

A complete SMA mix design example is given in Appendix B.

Recent Trends in SMA Design

Most asphalt paving technologists believe Marshall stability and flow test is not an appropriate strength test for SMA mix. Studies[6] in Europe have indicated triaxial test and wheel tracking test have potential to evaluate the rut resistance of SMA mixes. However, further research is needed to develop the necessary test criteria.

Trouble Shooting

Materials

It is extremely important to verify the materials that will be used in producing the mix and to use those in the evaluation. Any mixture design is only as good as the materials evaluated and used. SMA, being a relatively new design concept in the U.S., makes this seemingly logical statement all the more important.

Air Voids

The amount of air voids in the mixture can be controlled by the asphalt cement content. However, a problem will occur when a low air void content exists at an asphalt cement content of 6 percent or lower. The VMA of the produced mixture must be at least 17 percent to ensure an adequate asphalt content.

Voids in the Mineral Aggregate

The VMA may be increased by decreasing the percentage of aggregate passing the 4.75 mm (No. 4) sieve or by decreasing the percentage passing the 0.075 mm (No. 200) sieve. Changing aggregate sources is another potential way of increasing the VMA.

Voids in the Coarse Aggregate

If the VCA_{MIX} is higher than that in the dry-rodded condition (VCA_{DRC}), the mixture grading must be modified. This can most easily be done by decreasing the percentage passing the 4.75-mm sieve for most mixtures.

Moisture Susceptibility

If the mixture fails to meet the moisture susceptibility requirements, lime or a high quality liquid anti-strip additive may be used. If these materials prove ineffective, the aggregate source and/or asphalt cement source may need to be changed to obtain better compatibility between the aggregate and asphalt cement.

Draindown Sensitivity

Problems with draindown sensitivity can be solved by increasing the amount or type of stabilizer. Fibers have proven effective in reducing draindown.

Recommendations for Materials Selection and SMA Mixture Design

Table 8 lists recommendations for Materials Selection to provide a good SMA mixture. These recommendations were provided by Georgia and Maryland state DOTs, both of whom have extensive experience with SMA.

Table 6

Recommendations for SMA Materials Selection

- ✓ Use a binder or modified asphalt cement to meet PG grading one or two grades higher than recommended for geographical area by Superpave.
- ✓ Use coarse aggregates with no more than 20 percent F & E particles with a 3:1 ratio.
- ✓ Use crushed aggregates, not alluvial gravel or rounded sand.
- ✓ Use mineral or cellulose fibers to stabilize binder.
- ✓ Use a high-quality mineral filler to meet desired mastic properties.

Table 9 lists recommendations for Mixture Design to provide a good SMA mixture.

Table 9

Recommendations for SMA Mixture Design

- ✓ Perform dry rodding of coarse aggregate to maximize stone-on-stone aggregate structure.
- ✓ Determine optimum binder at 4 percent air voids for warm climates and 3.5 to 4.0 percent for cold climates.
- ✓ Use one of the following laboratory compactive efforts:
  -100 gyrations in SGC
  -50 blow Marshall
- ✓ 75 gyrations in SGC may be used if the aggregate is a soft mix to be used below wearing surface.
- ✓ Design the mixture with >17 percent VMA.
- ✓ The minimum asphalt binder content should be 6 percent.
- ✓ Perform draindown test to assure adequate quantity of stabilizing additive.
- ✓ Consider performing rut-susceptibility testing.

C H A P T E R T H R E E

Construction Procedures

Construction Overview

This chapter will provide an overview of areas of mixture production, placement, compaction, and quality assurance. However, since many aspects of production and placement of SMA are similar to those of conventional HMA, only those areas of differences or of potential problems unique to SMA are covered in detail. Plant production encompasses those procedures done at the plant to produce the mixture, such as aggregate handling, mixing times, and plant calibration. Placement and compaction procedures involve all operations from transporting the mixture to the construction site, placing it on the roadway, to compacting the mixture. Quality assurance includes all testing and inspection to assure a quality product is obtained.

Plant Production

Aggregates

To obtain the stone-on-stone contact necessary for SMA, the mixture must contain a high percentage of coarse aggregate. As in any HMA, it is typical to blend two or three aggregate stockpiles (coarse, intermediate, and fine) to obtain the proper gradation. The coarse aggregate is usually 72–80 percent of the blend. Thus, the gradation of the coarse aggregate tends to have a tremendous effect on the mixture produced. Therefore, it is imperative that the aggregates be carefully handled, stockpiled, and blended. Each coarse aggregate may need to be fed through more than one cold feeder since such a high percentage of material is being fed. Because of the importance of maintaining a gradation that provides the stone-on-stone contact necessary for the SMA to perform well, the necessity of closely controlling the gradation cannot be over emphasized. One of the ways that this can be done is frequent measurement and close control of the material passing the 4.75 mm (No. 4) and 0.075 mm (No. 200) sieves.

Mineral Filler

Mineral filler, other than that naturally occurring in the aggregate, is not routinely used in most conventional dense-graded mixtures produced in the United States. By contrast, SMA gradations usually require approximately 10 percent passing the 0.075-mm sieve. Even with the use of baghouse fines returned to the mixture, this high fines requirement typically means that at least 5 percent commercial mineral filler must be added to the mixture. In most SMA construction projects in the U.S., the ability to add commercial mineral filler to the mixture governs the plant production rate. For example, an HMA facility producing at the rate of 275 metric tonnes (Mton) (300 tons) per hour will need the mineral filler delivered at the approximate rate of 14 Mton (15 tons) per hour. Additionally, SMA mixtures are very sensitive to mineral filler content. Handling, storing, and introducing the mineral filler into the SMA mixture are vital to proper mix production.

The best method of handling and storing mineral filler is in bulk quantities. Purchasing, shipping, and storing mineral filler in bulk tends to reduce cost. However, to handle mineral filler in bulk requires a mineral filler silo at the plant site, as shown in *Figure 6*. These silos are

Figure 6

Mineral Filler Silo

closed systems in that the filler is stored until needed. To deliver the filler to the proper part of the plant, a vane feeder containing an airlock or auger system is used. These systems are capable of metering the proper amount of filler. A blower mounted beneath the feeder system blows the filler into the pugmill or weigh hopper of a batch plant or the drum of a drum mix plant. These systems must handle heavy filler loads but have produced excellent results so long as the feed system is kept in proper calibration. Conveyor belts should not be used because the rate of feed cannot be closely controlled from the cold feed or from a RAP feeder. An additional serious deficiency in open conveyor systems is that they can create a dust problem on windy days.

It is important to ensure that the filler is captured by asphalt cement or coarser aggregate as soon as it is added to the mixture. In a batch plant, this is normally done by adding fine aggregate to the pugmill immediately after introducing the filler. In a drum plant, the mineral filler line into the drum should be next to the asphalt cement line so that the filler is coated with asphalt cement before it is exposed to the high velocity gas flow through the drum. These methods of introducing filler keep the filler in the mixture rather than losing it to the fines recovery system.

Liquid Asphalt

The handling and storage of liquid asphalt cement for SMA production is similar to that for any HMA mixture. When modified binders are used, the storage temperatures may increase slightly from those of neat asphalt cements. The manufacturers' recommendations for circulation and storage of modified binders should be obtained and followed. Metering and introducing the asphalt cement into the mixture may be done by any standard method using a temperature compensating system. The importance of accurately metering the binder cannot be overly emphasized.

Stabilizing Additives

Due to the high asphalt cement contents in the SMA mortar, a stabilizing additive of some type must be used to hold the mortar on the coarse aggregate during hauling and placement. If a stabilizing additive is not used, the asphalt binder will drain from the mix during hauling and placement resulting in flushed spots in the finished pavement. Two types of stabilizing methods have been used in the U.S. The most common is the use of cellulose or mineral fibers. The second stabilizing method is to modify the asphalt cement in some manner. This may be done by modifying the asphalt cement at the terminal or refinery or by adding an asphalt cement modifier to the SMA mixture during production. Some projects have used both a fiber and a modified asphalt cement. Specifications for both cellulose and mineral fibers can be found in the specification given in *Appendix A*.

Fibers

As mentioned, both cellulose and mineral fibers have been used in SMA in the United States. Typical dosage rates by total mixture mass are 0.3 percent for cellulose and 0.3–0.4 percent for mineral fiber. Fibers can generally be purchased in two forms: loose fibers and pellets. Fibers in a dry, loose state come packaged in plastic bags or in bulk. Fibers can also be pelletized. Both cellulose and mineral fibers have been blown into batch and drum mix plants successfully.

For batch plant production, loose fibers are sometimes delivered to the plant site in pre-weighed bags. The bags are usually made from a material that melts easily at mixing temperatures. The bags can, therefore, be added to the pugmill during each dry mix cycle. When the bags melt only the fiber remains. The bags of fibers are added by workers on the pugmill platform. At the appropriate time in every dry mix cycle, the workers add the correct number of bags to the pugmill. The fiber bags can be elevated to the pugmill platform by a conveyor belt. While this method of manual introduction works satisfactorily, it is labor intensive and is best suited for relatively low tonnage projects.

Another method for feeding of fibers into a batch plant is to blow them in using a machine typically designed and supplied by the fiber manufacturer. *Figure 7* illustrates a bulk fiber handling system. To use this method, the dry, loose fiber is placed in the machine hopper where it is fluffed by large paddles. The fluffed fiber then enters the auger system and is conditioned to a known density. The fiber is then metered by the machine and blown into the pugmill or weigh hopper at the appropriate time. These machines can determine the proper amount of fiber by mass or by metered volume.

Figure 7

Bulk Fiber Handling System

This fiber-blown method can also be used in a drum mix plant. The same machine is used and the fibers are blown into the drum. When using this method in a drum mix plant, it is imperative that the fiber line be placed in the drum beside the asphalt cement line and merged into a mixing head. This allows the fibers to be captured by the asphalt cement before being exposed to the high velocity gases in the drum. If the fiber is not properly introduced into the gas stream, it will enter the dust control system of the plant. There are also potential combustion hazards if fibers become airborne[23].

The pelletized form of fibers also can be used in both drum mix and batch plants. However, the pellets are usually most economical in smaller (9,000 Mton [10,000 ton] or less) drum plant projects. The pellets are shipped to the plant in bulk form and placed in a hopper. From the hopper they can be metered and conveyed to the drum or pugmill via a calibrated conveyor belt. The pellets are added at the RAP collar of the drum mix plant or directly into the pugmill of a batch plant. Here the pellets are mixed with the aggregate. The heat from the aggregates causes the pellet binder to become fluid allowing the fiber to mix with the aggregate. Some pelletized fibers contain a small amount of asphalt cement that must be accounted for in the overall asphalt content of the mixture. The fiber manufacturer must supply the pellet asphalt cement content so that the proper asphalt content can be determined.

Appropriate feed calibration is again an imperative step. The fiber addition, whether it is bulk or pelletized, must be calibrated to ensure that the mixture continually receives the correct amount of fiber. If the fiber content is not accurately controlled at the proper level, fat spots will almost certainly result on the surface of the finished pavement. For assistance with the fiber storage, handling, and introduction into the mixture, the fiber manufacturer should be consulted.

Asphalt Cement Modifiers

Asphalt cement modifiers provide another form of stabilization to SMA. The asphalt cement in SMA can be modified at the terminal refinery, or, in some cases, the modifier is added at the hot mix plant. For binders modified at the terminal or refinery, the hot mix producer takes delivery of the modified asphalt cement and meters it into the SMA mixture in a traditional manner. Special storage techniques and/or temperatures may be required. When the binder is modified at the hot mix plant, the hot mix producer must ensure that the proper amount of modifier is uniformly added and thoroughly mixed with the asphalt cement.

Two different methods can be used to add asphalt cement modifier at the hot mix plant. The modifier is either blended into the asphalt cement before it is injected into the mixture, or it is added directly to the dry aggregates during production. The modifier can be added to the asphalt cement by either in-line blending or by blending the two in an auxiliary storage tank. If the modifier is added to the aggregates rather than the asphalt cement, it can be added directly into the pugmill or, in a drum mix plant, it can be delivered to the drum via the RAP delivery system. Use of the RAP belt weigh bridge is not recommended because of poor accuracy and a special metering device may be necessary if the RAP feeder cannot be calibrated.

Regardless of the form of stabilization, advice and assistance should be sought from the stabilizer supplier. It is imperative that the system used to add the modifier be calibrated to ensure the mixture receives the proper dosage. Background information on the use of modifiers can be obtained from NAPA publication, QIP-114A, *Using Additives and Modifiers in HMA.*

Mixture Production

Production of SMA is similar to standard HMA from the standpoint that care should be taken to ensure a quality mixture is produced. Areas of production where SMA quality may be significantly affected are discussed in this section.

Plant Calibration

Calibration of the various feed systems is critically important. All of the feed systems for the HMA facility must be carefully calibrated prior to production of SMA. The aggregate cold feeds can make a significant difference in the finished mixture even in a batch plant where hot bins exist. Calibration of the aggregate cold feed bins should, therefore, be performed with care. Another practice used to more closely control the gradation is the use of more cold feed bins than might be used for a conventional dense-graded mix, as shown in *Figure 8*.

Figure 8

Additional Cold Feed Bins for SMA

The stabilizing additive delivery system should be calibrated and continually monitored during production. Whether fibers, an asphalt cement modifier, or both are being used, variations in the amount of additive can have a detrimental impact on the finished pavement. Manufacturers of stabilizing additives will usually assist the hot mix producer in setting up, calibrating, and monitoring the additive delivery system.

Two very important, interrelated systems in SMA production are the mineral filler feed system and the dust collection/return system. These two systems must be working properly in order to ensure quality in the mixture. If the mineral filler is not being delivered to the mixture in proper quantities or in a proper manner, it can be captured in the fines recovery system. This can plug the system or, at the very least, cause an improper amount of fines to be added to the SMA mixture. If the fines recovery system completely removes fines from the plant, by the use of a wet collector for example, then the mineral filler feed system should be calibrated for any loss of mineral filler that may occur. The ability to add mineral filler to the mixture has governed mix production rates for most U.S. SMA projects.

Production Temperatures

Production temperatures of SMA mixtures will vary according to aggregate moisture contents, weather conditions, grade of asphalt cement, and type of stabilizing additive used. However, experience in the U.S. seems to indicate that normal HMA production temperatures or slightly higher are generally adequate. Typically, a temperature of 145–155°C (290–310°F) can be used. Temperatures higher than this may be needed on some occasions, such as when a polymer modifier is employed, but should be used with caution as rapid oxidation begins to occur at higher temperatures. As the mixture temperature is increased, the chance of the mortar draining from the coarse aggregate also increases. Production temperatures significantly below 145°C (290°F) should rarely be employed. The temperature should be chosen to ensure that the temperature is uniform throughout the mixture and to allow sufficient time for transporting, placing, and proper compacting of the mixture.

Mixing Time

When adding fibers to the SMA mixture, experience has shown that the mixing time should be increased slightly over that of conventional HMA. This additional time allows for the fiber to be sufficiently distributed in the mixture. In a batch plant, this requires that both the dry and wet mix cycles be increased from 5 to 15 seconds each. In a parallel flow drum mix plant, the asphalt cement injection line may be relocated when pelletized fibers are used to allow for complete mixing of the pellets before the asphalt cement is added. In both cases, the proper mixing times can be evaluated by visual inspection of the mixture. If clumps of fibers or pellets are observed in the mixture at the discharge chute, or if aggregate particles are not sufficiently coated, mixing times should be increased or other changes made. For other plants, such as double barrels and plants with coater boxes, the effective mixing time can be adjusted in a number of ways including reduction in production rate, slope reduction of the drum, etc.

Mixture Storage

The SMA mixture should not be stored for extended periods of time at elevated temperatures. This could cause unnecessary and detrimental draindown. In general, experience has shown that SMA can be stored for 2–3 hours without detriment. In no instance should the SMA mixture be stored in the silo overnight.

Recommendations for Plant Production of SMA

Table 10 lists recommendations for plant production to provide a good SMA mixture.

Table 10

Recommendations for Plant Production of SMA

- ✓ Maintain a temperature of approximately 170°C (340°F) when using a modified asphalt, taking care that the asphalt is not overheated.
- ✓ Stabilize and maintain consistent plant production temperature.
- ✓ Preheat plant, conveyors, and other moving parts with hot aggregate prior to adding polymer-modified asphalt.
- ✓ Maintain stockpiles properly and monitor gradation of incoming aggregates.
- ✓ Calibrate mineral filler, fiber, and anti-strip agent feed systems to plant production rate and maintain interlock system.
- ✓ Establish and maintain adequate mixing time taking into consideration that longer mixing times may be required for the use of mineral filler and fiber.
- ✓ Use three-drop loading system to minimize potential for segregation.*
- ✓ Minimize the time the SMA mixture is allowed to be kept in the storage silo.

* A detailed discussion of ways to prevent segregation is presented in the joint AASHTO/NAPA document, *Segregation: Causes and Cures for Hot Mix Asphalt (QIP-110).*

Placement and Compaction Procedures

Weather Limitations

In order to achieve proper placement and compaction, SMA mixtures should not be placed in cold or inclement weather. A minimum pavement temperature of 10°C (50°F) is recommended for placement of SMA mixtures. However, the decision to place SMA will also depend on wind conditions, humidity, the lift thickness being placed, and the temperature of the existing pavement.

Mixture Transportation

Haul times for SMA should be as short as possible. It is important that the temperature of the SMA mixture not be raised arbitrarily in order to facilitate a longer haul time. The increased temperature in conjunction with vibrations typical in haul vehicles can serve to separate the mortar from the coarse aggregate. The mixture should arrive at the paving site so that it is placed at temperatures of approximately 140–150°C (280–300°F). If polymer modifiers are used, slightly higher temperatures may be needed. These increased temperatures help ensure that proper compaction is achieved.

Due to its thick mortar, SMA mixtures may adhere to truck beds to a greater extent than conventional HMA mixtures. This is particularly true when asphalt cement modifiers are employed. It is, therefore, prudent to use a release agent and clean the truck beds frequently. Most agencies have approved lists of release agents. However, if not carefully used, these agents may cause problems with SMA mixtures. If the agent is allowed to pool in the bottom of the truck bed, it may cause the mortar to flush from the SMA pavement surface. The bed of the truck should be thoroughly coated with release agent. Any excess agent should be removed before loading the SMA mixture by raising the truck bed after the agent has been sprayed into the truck. Any excess agent will then be discharged.

The use of fuel oils as a release agent, in any form, should be strictly prohibited.

Segregation of aggregate is not a significant problem with most SMA mixtures. SMA and dense-graded HMA have inverse segregation problems[2]. In dense-graded HMA, the coarse aggregate usually separates from the fine aggregate, usually at the end of a truck load. In case of SMA, reverse segregation occurs. SMA already has a very high coarse aggregate content, so the problem becomes small local sections with insufficient coarse aggregate and excessive mortar, resulting in fat spots and rutting. Care should be taken to observe "good engineering practices" that minimize the potential for segregation.

Pavement Surface Preparation

When placing SMA, preparation of the surface to be covered will depend on the type of surface. This preparation is generally the same as for conventional HMA. SMA is normally applied in any of several situations: over an old HMA pavement, over an old portland cementc oncrete pavement, over rubblized portland cement concrete, or over a new HMA concrete binder or base course. Some states have also placed SMA surface courses over SMA binder courses.

If an old pavement surface is to be covered by SMA, then proper repair should first be performed. Areas containing large permanent deformations should be milled or filled using a leveling course. Any distressed areas should be properly repaired. While SMA has shown superior performance, it cannot be expected to perform as desired when it is used to cover-up existing pavement problems.

For all surfaces to be overlaid, a tack coat should be used. Types of materials and their application rates can be the same as conventional HMA construction.

Paver Operation

Charging the Paver

The SMA mixture is normally delivered to the paver in the traditional manner of backing in trucks. Some agencies, such as the Georgia DOT, recommend that a material transfer vehicle (MTV) be used for improved continuity of delivery. The decision as to whether or not auxiliary equipment is needed depends on whether the SMA is being delivered to the paver in a consistent manner without segregation or producing fat spots.

Paver Calibration

Prior to placement of the SMA, the paver should be correctly calibrated. This is no different than when placing conventional HMA and involves properly setting the flow gates, the slat conveyors, and the augers. The flow gates should be set to allow the slat conveyors to deliver the proper amount of mixture to the augers. A discussion of good paver practices can be found in NAPA publication, IS-125, *Paver Operations for Quality*.

Paving Speed

When placing SMA, the paving speed is, for the most part, dictated by the ability of the rolling operation to compact the mixture. It is critical that the plant production, mixture delivery, and ability to compact be coordinated so that the paver does not have to stop. Paver stops and starts should be held to an absolute minimum because they can have a significant negative impact on the final smoothness of the pavement.

In addition to continuous paver movement, the SMA mixture delivery and paver speed should be calibrated so that the augers can be kept turning 85–90 percent of the time. This helps ensure the slowest possible speed for the augers. Running the augers very fast for short periods of time should be avoided. The high auger speed may have a tendency to shear the mortar from the coarse aggregate thus causing fat spots in the pavement. The paver wings should not be folded except when the material is to be discarded. A procedure for determining production rates can be found in NAPA publication, IS-120, *Balancing Production Rates*.

Lift Thickness

The majority of SMA pavements placed in the U. S. have been placed 40 mm (1½ inches) thick. It is imperative that the yield not be balanced by adjusting the thickness of the SMA lift. This can cause unsatisfactory performance. A tolerance of ± 6 mm (¼ inch) in the lift thickness is allowable.

Many highway agencies in Europe specify a minimum and a maximum lift thickness for SMA mixtures of different nominal sizes. The Georgia DOT specifies 28–40 mm for 9.5 mm SMA; 32–75 mm for 12.5 mm SMA; and 44–75 mm for 19 mm SMA. For more information, reference NAPA's HMA Pavement Mix Type Selection Guide, Publication No. IS-128.

Placement and Finishing

Immediately behind the paver, SMA mixtures are known to be harsh and very sticky. For this reason, a minimum of raking and hand working should be performed. When absolutely necessary, a minimum of hand placement of the material can be accomplished, but should be performed with care.

It takes extra effort to obtain a good longitudinal joint between lanes of SMA. The key is to keep the overlap between the new and previously placed mat as minimal as possible, preferably no more than 12 mm (½ inch). Too much overlap will cause the aggregate in the new mat to crush under the roller and thus induce raveling.

Rolling

Minimum SMA density of 94 percent of maximum theoretical density is recommended. To achieve this goal, densification of the SMA mixture should be accomplished as quickly as possible after placement. By its very nature, SMA becomes difficult to compact once it begins to cool. For this reason it is imperative that the rollers operate immediately behind the paver as shown in *Figure 10*. Polymer-modified SMA has a more narrow temperature window than does fiber-stabilized SMA. Polymer mixtures should generally be completely compacted before they cool below 138°C (280°F).

Figure 10

Keep Rollers Close to Paver!

Rolldown of SMA mixtures is approximately one-half that of conventional HMA mixtures. While conventional HMA mixtures rolldown approximately 20–25 percent of the lift thickness, SMA will normally rolldown only 10–15 percent of the lift thickness.

Breakdown rolling should begin immediately behind the paver and the roller should stay close behind the paver at all times. If the rolling operation lags behind, placement of SMA should slow down until the rollers catch up with the paver.

Two or three rollers are typically used in conventional HMA construction. This number normally serves well for SMA. If density cannot be achieved quickly enough, then an additional roller should be added to the compaction train. A roller pattern should be established and followed that provides a density that meets the specification requirements.

Steel-wheeled rollers weighing at least 9 Mtons (10 tons) should be used when compacting the SMA mixture. Roller speed should not exceed 5 km/h (3 mph) and the drive roll should be kept toward the paver. Six to eight passes of the breakdown rollers should be sufficent to achieve the desired density. SMA mixes should be stable under compaction-rollers can overhang unconfined edges of the mat without displacing the mix[24]. If it becomes necessary for the rollers to sit idle, they should be taken off the mat, if possible. As in paving with conventional mixtures, idle rollers sitting on the mat can cause unnecessary roughness in the finished surface.

It is normal practice to mix a minimum amount of release agent with the water in the roller drum to prevent the asphalt cement from sticking to the drum.

Most experience with vibratory rollers to date indicates that they can be used successfully on SMA with the vibrator engaged. However, if vibrating is allowed, it must be used with caution. The vibration of the roller may break aggregate and/or force the mortar to the surface of the mat. Vibratory rollers, if used, should be used in a high frequency, low amplitude mode. Although vibratory rollers have been used on SMA projects with success, their performance must be closely monitored during compaction to assure they are causing no detrimental conditions.

Pneumatic-tired rollers are not recommended for use on SMA. The rubber tires tend to pick up the mortar, causing surface defects.

In addition to these recommendations, NAPA publication IS-121, *Roller Operations for Quality*, provides useful information regarding proper roller operation.

Recommendations for Placement and Compaction of SMA

Table 11 provides recommendations for Placement and Compaction of a good SMA mixture.

Avoiding Fat Spots

Fat spots (as shown in *Figure 10*) are one of the most objectionable occurrences in SMA mixtures. They can be either cosmetic or functional. Cosmetic fat spots usually occur on only the surface of the mat and wear off under traffic. Functional fat spots usually extend throughout the thickness of the mat and may lead to early deformation and deterioration of the pavement. Fat spots may result from one or more of the following conditions:

- Lack, or inconsistent distribution, of fibers.
- Excess release agents in bed of haul vehicle.
- Excess temperature, particularly with modified asphalts.
- Excess tack coat.
- Inconsistent mineral filler feed.
- Excess moisture in mineral filler.
- Excess haul time, or haul vehicle waiting on project.
- Excessive water on roller.

Figure 10

Fat Spot in SMA

Table 11

Recommendations for Placement and Compaction of SMA

- ✓ Assure that a minimum air temperature of 10°C (50°F) is maintained when placing SMA.
- ✓ Start with a clean haul vehicle.
- ✓ Use only approved release agents, such as water-based liquid soap or dry soap powder.
- ✓ Drain all excess release agents from truck beds.
- ✓ Use tarps on truck beds and make sure they fit truck bed securely so as to prevent excessive cooling during haul.
- ✓ Provide area for truck clean-out after unloading.
- ✓ A material transfer device or other auxiliary equipment may be used to provide consistent mix temperature, avoid segregation, and improve continuity of operation.
- ✓ Maintain continuous paving operation.
- ✓ Minimize starts and stops of paver.
- ✓ Keep roller close to paver.
- ✓ Keep augers going.
- ✓ Complete rolling before mixture reaches a temperature of approximately 140°C (280°F) when using a modified asphalt and 130°C (260°F) with a neat asphalt.
- ✓ Don't stop the roller on the hot mat.
- ✓ Pneumatic-tired rollers should not be used.
- ✓ Exercise care in folding wings of the hopper to ensure that cold mixture from the edge of the paver hopper is not dumped onto the conveyors.
- ✓ Perform placement and compaction to minimize temperature loss in the mixture.
- ✓ Consider the use of a vibratory roller for breakdown rolling, but use it with caution.
- ✓ Use two or three rollers as necessary to achieve a minimum density of 94 percent Maximum Density.
- ✓ Roll mat quickly while mixture is hot.
- ✓ Minimize hand work.
- ✓ Use special care in inspection and construction of longitudinal joints to ensure proper alignment and compaction.

Quality Assurance

Good quality assurance programs are important in guaranteeing that the mixture produced and placed meets the project specifications. Methods of quality assurance as they pertain to SMA are discussed below.

Aggregates

As with conventional HMA, the producer should periodically monitor the aggregate stockpiles being used for the production of the SMA mixture. Stockpile gradations can change as additional material is added to the stockpile during mixture production. Even if the stockpiles do not receive additional aggregates during mixture production, their gradations may change due to stockpiling and/or load out procedures. Therefore, the monitoring program must be frequent enough to warn the producer that a change has taken place before a significant amount of the aggregate has been used in SMA mixtures.

In both batch and drum mix plants, the cold feed gradations should also be monitored. Variations or deviations of aggregate gradation from the specified job-mix formula (JMF) are more critical to the performance of SMA mixtures than they are for conventional HMA. Therefore, tighter gradation tolerances should be considered for SMA mixtures. In addition to cold feed gradation analyses in batch plant operations, hot bin analyses should also be performed. This testing serves as a further check of aggregate gradations.

Asphalt Cement

The asphalt cement used in the SMA should be tested as it is for any conventional HMA project. Some modified asphalt cements may require special testing techniques.

Trial Sections

Prior to full-scale production and placement of SMA mixtures, a trial or demonstration section of the mixture should be produced and placed by the contractor. This trial section should be at the actual construction site. The trial section should consist of between 200 and 500 Mtons (220 and 550 tons) of mixture. The length of the trial section depends upon the capacity of the plant and other variables in the mixture production and placement operations. However, the trial section needs to be of sufficient size to allow the plant components to operate to the point of producing consistent mixture. The trial section is a good opportunity to determine any proportioning problems with the final JMF. In order to determine if draindown is a potential problem, the haul distance or time in the haul vehicle should be approximately that of the project.

The trial section should also determine the proper rolling pattern to be used. However, if the trial section is placed at a location other than the actual site to be paved during full-scale production, care should be taken in drawing conclusions about achieved densities due to the possibility of dissimilar base characteristics.

The trial section should be constructed prior to the production paving to allow time for testing and adjustment in the JMF, and to allow for a second trial section if major adjustments need to be made. Agency requirements for the trial section to be placed before the production vary from one day to one week.

Mixture Sampling

Most agencies have established their own requirements for where and how mixture sampling must be done. SMA should be sampled according to these recognized procedures. Experience has shown that quartering of SMA can be difficult due to its tendency to stick to the tools, thus, potentially causing a low asphalt content to be measured.

Frequency of sampling and testing is usually established by the owner. As a minimum, at least two test series per day should be performed. More frequent testing (e.g., four tests per day) is advisable in order to maintain good quality control. Many agencies divide the mixture into lots and sublots and require three or four test series per lot. In addition, the time at which samples are taken should be obtained randomly so as not to bias the results.

Mixture Tests

Certain test data on the mixture must be collected to allow the producer of SMA to control the mixture as well as to allow the owner the ability to accept or reject the mixture. These tests are similar to those performed on conventional HMA.

Laboratory Compacted Specimens

Laboratory compacted specimens of plant-produced mix should be examined for compliance with volumetric properties required in the specifications and established during the mixture design. The compaction procedure must be the same as that used in mixture design. The bulk specific gravity of the specimens can be determined by AASHTO T 66 while the maximum theoretical specific gravity is determined by AASHTO T 209. Air voids may then be determined according to the method described for dense-graded bituminous mixtures in AASHTO T 269. The resulting air voids should be within the specified range, typically 3–4 percent, and VMA should meet or exceed the specified minimum requirements of at least 17 percent.

SMA mixtures become permeable to water at a lower air void level than that for dense-graded mixtures. When the air voids in SMA are approximately 6–7 percent or higher, the mixture is permeable. A method for measuring the density of porous mixtures should be used at these air void levels. If this is not done, a lower air void content will be measured than actually exists in the mixture.

Asphalt Content and Gradation Determination

The stabilizing additives used in SMA can sometimes hinder the solvent extraction process (AASHTO T164), and some experimentation may be necessary to determine the optimum method of extracting the mixture. However, most agencies are now determining the asphalt content by the ignition method (AASHTO T308 or ASTM D6307), which has worked well for SMA mixtures. After extraction or ignition, the aggregate should be graded according to AASHTO T11 and T27.

The resulting gradation and asphalt content should meet the JMF established for the mixture within the tolerance limits specified. Typical tolerance limits as suggested by the *Guidelines for Materials, Production, and Placement of Stone Matrix Asphalt (SMA)* are shown in *Table 12*[1]. As mentioned in Chapter 2, maintaining the tolerance on "break" sieve is very important so that stone-on-stone contact is ensured in the SMA mixture.

In-Place Density

In-place density of the mixture should be checked continually throughout pavement construction to ensure that proper density is being obtained. Current density specifications normally call for a minimum density of 94 percent of maximum theoretical density. The pavement density can be monitored using a nuclear density gauge. It is likely that the nuclear gauge is not as accurate for SMA pavements as it is for conventional HMA pavements because of the desirably rough surface texture of SMA mixtures as shown in *Figure 11*. Gauges should, therefore, be properly calibrated and periodically checked by comparison to cores taken from the pavement. The use of sand as an aid in properly seating the gauge may also be considered for improving the accuracy of the gauge. The nuclear gauge density locations, as well as the coring locations, should be randomly chosen. Care should be exercised when measuring core densities due to the higher permeability of SMA at lower air voids content, as discussed previously. A new method of determining density of SMA or OGFC-like mixtures by vacuum sealing the compacted specimen with thin plastic sheet is very promising; a round-robin testing study is being conducted by NCAT under FHWA sponsorship.

Table 12

Gradation Tolerances for Extracted SMA Samples

Sieve Size		Tolerance for Percent Passing
MM	Inches	
19.0	¾	±4.0
12.5	½	±4.0
9.5	⅜	±4.0
4.75	#4	±3.0
2.36	#8	±3.0
0.60	#30	±3.0
0.30	#50	±3.0
0.075	#200	±2.0
Asphalt Content (%)		±0.3

Figure 11

Texture of SMA

Draindown Test

As described under Mixture Design, a draindown test should also be performed as a quality-assurance measure. The use of this test method described is very important and should be performed daily at the plant mixing temperature. The acceptable value during design is 0.3 percent, but the actual values are often 0.1 percent or less. If the production value increases appreciably over that obtained during design, this should be an indication of a potential problem and an investigation of the cause should be undertaken.

Recommendations for Quality Assurance of SMA Mixtures

Table 13 lists recommendations for Quality Assurance for a good SMA mixture.

Table 13

Recommendations for Quality Assurance of SMA Mixtures

✓ Frequently monitor aggregate stockpiles and/or hot bin for gradation.

✓ Frequently monitor binder, especially modified binder.

✓ Construct a trial or demonstration section to allow contractor the opportunity to demonstrate ability to produce the JMF, required density, etc.

✓ Frequently monitor plant produced mixture properties, particularly volumetric properties.

✓ Frequently monitor in-place density results.

✓ Correlate nuclear density to cores to improve accuracy of the gauge.

✓ Consider sand as an aid to seating the nuclear gauge to improve the accuracy of the readings.

✓ Monitor product quality continuously during production.

CHAPTER FOUR

Conclusions and Recommendations

Stone Matrix Asphalt has proven to be a tough, stable, rut-resistant mixture. The SMA design concept relies on stone-on-stone contact to provide strength and a rich mortar binder to provide durability. These objectives are usually achieved with a gap-graded aggregate coupled with a fiber or polymer-modified, high asphalt content matrix. The following conclusions highlight key design and construction issues.

Conclusions

1. The selection of a hard (maximum L.A. Abrasion Loss 30 percent), cubical (maximum F & E ratios; 3:1, 20 percent; 5:1, 5 per cent), all-crushed aggregate is required for a well-performing SMA mixture.

2. Good control of the aggregate gradation is necessary for a consistently good SMA.

Figure 12

SMA Pavements Provide Strength and Durability for Demanding Conditions

3. It is necessary in the selection of the aggregate gradation to assure that 20–28 percent passes the 4.75 mm (No. 4) sieve and 8–10 percent passes the 0.075 mm (No. 200) sieve.

4. A mixture must be designed to meet all the requirements stated in this publication, particularly testing for stone-on-stone contact, requirements for minimum VMA, and asphalt content.

5. Because SMA often requires additional mineral filler, a stabilizing agent and a modified asphalt, maintaining the plant in proper calibration during production is an absolute necessity.

6. It is necessary to stabilize and maintain a consistent plant production temperature to allow the mixture to be workable and to prevent draindown.

7. Maintain a consistent paving speed and compaction effort.

8. Use two or three rollers as necessary for compaction to achieve a minimum density of 94 percent of maximum theoretical density.

9. Avoid hand work whenever possible.

10. Fat spots appear to be the major performance problem. Watch carefully for occurrence of this blemish and, if found, take immediate action to find the cause and solve the problem.

11. For good quality assurance, frequent monitoring of all aspects of production, paving, and compaction is required to ensure a high quality finished SMA pavement.

12. Although the cost of SMA may typically be 20–30 percent higher than that of conventional dense-graded mixtures, benefits — including an extended life expectancy, a reduction in rutting, reduced noise, and a possible thickness reduction — offset the increased cost.

13. Based on findings reported here, SMA mixtures should continue to provide good performance in high volume traffic areas.

In Summary

SMA has proven to be a tough, stable, rut-resistant mixture for use in high traffic conditions. With its stone-on-stone contact and asphalt-rich mortar, SMA mixtures provide both strength and durability for demanding pavement conditions.

As with any HMA production process, close communication and cooperation between agency and contractor are necessary to minimize SMA production problems. Attention to detail in each phase of the manufacturing process is required. The recommendations for mix design, plant production, paving, compaction, and quality assurance which are discussed in this report should provide the guidance necessary to maximize the potential for SMA and minimize the production problems.

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Appendix A

Guidelines for Materials, Production, and Placement of Stone Matrix Asphalt (SMA) was originally published by the National Asphalt Pavement Association in 1994 as a result of a cooperative effort by the Federal Highway Administration, NAPA, the Asphalt Institute, selected state Departments of Transportation, and state Asphalt Pavement Associations. It is included for historical reference, and it does not reflect the advances made since 1994.

Appendix A—
Guidelines for Materials, Production, and Placement of Stone Matrix Asphalt (SMA)

Introduction

The European Asphalt Study Tour which took place in the fall of 1990, found some technologies which had the potential to be transferred to the United States. One of the more promising was a surface mix, Stone Matrix Asphalt (SMA). At the Transportation Research Board (TRB) meeting in January of 1991, several of the Tour participants met to decide on strategies to implement some of the findings of the Tour, with particular emphasis on SMA.

Shortly thereafter, the Federal Highway Administration (FHWA) established a Technical Working Group (TWG) composed of representatives from Industry, the states, National Center for Asphalt Technology (NCAT), and FHWA. Among the tasks that the TWG assigned itself was to develop a set of model guidelines for materials and construction. The TWG has also undertaken to develop a research agenda, monitor performance on completed SMA projects, and assist states and contractors in mix design and construction of SMA.

Through 1993, 21 states have constructed approximately 54 projects with over 20 more planned. Despite this experience, there is no standard mix design procedure for SMA. Detailed work on mix design is being undertaken by NCAT under an NCHRP contract. More detailed construction guidelines are being developed by the TWG and will be published later when completed.

These guidelines specifically cover the SMA technology using fibers as a stabilizer. There has been some use of polymers in SMA as a stabilizing agent, but this is not covered in this publication. If polymer stabilization is to be used, the manufacturer should be consulted for design and construction recommendations.

SMA shows promise as a tough, stable, rut-resistant surface mix in certain applications. This publication is not intended as a detailed set of instructions for the use of SMA, but as general guidelines only. Speciifiers who are contemplating the use of SMA are advised to contact members of the TWG or others knowledgeable in the use of the mix for assistance.

Description

This work shall consist of constructing a surface course of fiber-stabilized Stone Matrix Asphalt pavement over an existing, properly prepared pavement in accordance with these specifications and in reasonably close conformity with the lines, grades, thicknesses, and typical cross sections shown on the established plans. (*See Notes to Engineer* for applicability to non-fiber stabilization)

Materials—Composition of the SMA Mixture (Job-Mix Formula)

The asphalt mixture shall be composed of aggregate(s), mineral filler and asphalt cement, plus required additives and shall be combined as necessary to meet the project requirements.

It is the Contractor's responsibility to ensure that, in addition to the aggregate gradation requirements, the produced material will provide an asphalt mixture that conforms to the applicable design parameters listed in *Table A-l*.

Table A-I

SMA Mix Requirements

Design Parameters– Marshall[1]	
(1) VTM, percent[2]	3–4
(2) Asphalt Content, percent[3]	6.0 min.
(3) VMA[4]	17 min.
(4) Stability, N (lbs)[5]	6200 (1400) suggested min.
(5) Flow, 0.25 mm (0.01 inch)	8–16
(6) Compaction, number of blows at each side of test specimen	50
(7) Draindown, percent[6]	0.3 max. (1 hour reading)

[1]Marshall procedures are in accordance with AASHTO T 245.

[2]VTM (Voids in Total Mix) is based on AASHTO T 166, T 209, and T 269. Maximum density will be based on AASHTO T 209.

[3]Based on weight of total mix.

[4]VMA to be determined in accordance with TAI Manual Series No. 2(MS-2).

[5]See *Notes to the Engineer*.

[6]NCAT SMA Asphalt Draindown Test — See *Notes to the Engineer* & *Appendix*.

The Contractor shall submit in writing to the Engineer the proposed job-mix formula (JMF) for approval including the following:

(a) The percentage (in units of 1 percent) of aggregate passing each specified sieve, (except the 75 µm (No. 200) sieve), based on the total dry weight of aggregate as determined by AASHTO T 11 and T 27.

(b) The percentage (in units of one-tenth of one percent) of aggregate passing the 75 µm (No. 200) sieve, based on the dry weight of aggregate as determined by AASHTO T 11.

(c) The percentage (in units of one-tenth of one percent) of aggregate finer than 0.020 mm in size, based on the dry weight of aggregate as determined by AASHTO T 88.

(d) The percentage (in units of one-tenth of one percent) of asphalt material to be added, based upon the total weight of mixture.

(e) The proposed percentage of each stockpile to be used, the average gradation of each stockpile, and the proposed target value for each sieve size. The target values and the combined average gradation of all the stockpiles when combined in accordance with the Contractor's recommended stockpile combinations shall be within the gradation ranges for the designated grading in *Table A-2*.

(f) The type and amount by weight of mix of stabilizer additive to be used.

Table A-2

Gradation Target Value Ranges for SMA

(Percentage by Weight Passing Sieves, AASHTO T 27 & T 11) *(See Notes To Engineer)*

Sieve Designation	Percent Passing
19.0 mm (¾ in)	100%
12.5 mm (½ in)	85–95
9.5 mm (⅜ in)	75 (maximum)
4.75 mm (No. 4)	20–28
2.36 mm (No. 8)	16–24
600 µm (No. 30)	12–16
300 µm (No. 50)	12–15
75 µm (No. 200)	8–10
20 µm	less than 3*

* To be controlled from a combination of aggregate and mineral filler taken from representative stockpile samples.

(g) Additional information required as part of the JMF shall include the following:
(1) The material sources for all ingredients.
(2) The material properties, as listed, for all ingredients:
- The specific gravities of the individual aggregates and asphalt.
- The L.A. Abrasion of the aggregates.
- The Sand Equivalent value of the combined aggregate.
- The Flat and Elongated Percent of the coarse aggregate (3:1 and 5:1 ratios), retained above the 4.75 mm (No. 4) sieve.
- The Plasticity Index of the aggregate.
- The absorption of the aggregates.
- The asphalt temperature/viscosity curves.

(3) The mixing temperature.
(4) The mix design test property values and curves used to develop the job mix in accordance with the Asphalt Institute's Manual Series No. 2 (MS-2).
(5) The plot of the gradation on the FHWA 0.45 power gradation chart.

Aggregate

Coarse Aggregate. Coarse aggregate shall be crushed, non-absorptive stone and unless otherwise stipulated, shall conform to the following quality requirements of AASHTO M 283 for Class A aggregates:

(1) Los Angeles abrasion, AASHTO T 96 30% max.

(2) Flat and Elongated Particles,
ASTM D 4791, *comparing length to thickness* (measured on material retained above the 4.75 mm (No. 4) sieve)
3:1 20% max.
5:1 5% max.

(3) Sodium sulfate soundness loss
(5 cycles), AASHTO T 104 15% max.
(20% max. if magnesium sulfate is used)

(4) Particles retained on the 4.75 mm (No. 4) sieve shall have at least:
one fractured face 100% min.
two fractured faces 90% min.

(5) Absorption, AASHTO T 85 2% max.

(6) Coarse and fine durability index,
AASHTO T 210 40 min.

Mixes with relatively pure carbonate aggregates or any aggregates known to polish shall not be used.

Fine Aggregate. Fine aggregate shall consist of a blend of 100% crushed, manufactured sand. It shall conform to the following quality requirements of AASHTO M 29. The sodium sulfate soundness loss in 5 cycles shall not exceed 15 percent. In addition, the liquid limit shall not exceed 25 as determined by AASHTO T 89.

The several aggregate fractions for the mixture shall be sized, graded, and combined in such proportions that the resulting composite blend conforms to *Table A-2* for the grading shown in the bid schedule.

Asphalt Cement

Asphalt cement shall conform to AASHTO M 226, *Table 2*. *(See Notes To Engineer)*

Asphalt cement shall be mixed at a temperature as required to achieve a viscosity of 170 ± 20 centistokes. Typical plant mixing temperature for SMA is 155°–163°C (310°–325°F). However, at no time shall the mixing temperature exceed 177°C (350°F).

Mineral Filler

Mineral filler should consist of finely divided mineral matter such as rock or limestone dust or other suitable material. At the time of use it should be sufficiently dry to flow freely and essentially free from agglomerations. Filler should be free from organic impurities and have a plasticity index not greater than 4. Filler material for the mix shall meet the requirements of AASHTO M 17.

Commercial mineral filler added to the SMA mixture, shall be limited to less than 20% of its weight smaller in size than 20 µm.

Stabilizer Additive

A fiber stabilizer, either cellulose or mineral fiber is to be utilized. Dosage rates for cellulose is 0.3% by weight of the total mix, and for mineral fiber is 0.4% by weight of total mix. Allowable tolerances of fiber dosage shall be ±10% of the required fiber weight.

The selected fiber should meet the properties described in *Table A-3* or *A-4* utilizing the listed test procedures.

Table A-3

Cellulose Fiber Properties

Cellulose Fibers	
Sieve Analysis	
Method A	
Air Jet Sieve[1] Analysis:	
Fiber Length:	6 mm (0.25") (maximum)
Passing 150 µm (No. 100) sieve	70% (±10%)
Method B	
Mesh Screen[2] Analysis:	
Fiber Length:	6 mm (0.25") (maximum)
Passing 850 µm (No. 20) sieve	85% (±10%)
425 µm (No. 40) sieve	65% (±10%)
106 µm (No. 140) sieve	30% (±10%)
Ash Content[3]:	18% (±5%) non-volatiles
pH[4]:	7.5 (±1.0)
Oil Absorption[5]:	5.0 (±1.0) (times fiber weight)
Moisture Content[6]	< 5% (by weight)

[1] **Method A - Air Jet Sieve Analysis.** This test is performed using an Air Jet Sieve. A representative 5 gram sample of fiber is sieved following the recommendations of the sieve manufacturer. The portion remaining on the screen is weighed.

[2] **Method B - Mesh Screen Analysis.** This test is performed using standard 850, 425, 250, 180, 150, 106 µm (No. 20, 40, 60, 80, 100, 140) sieves, nylon brushes and a shaker. A representative 10 gram sample of fiber is sieved, using a shaker and two nylon brushes on each screen. The amount retained on each sieve is weighed and the percentage passing calculated. Repeatability of this method is suspect and needs to be verified.

[3] **Ash Content.** A representative 2–3 gram sample of fiber is placed in a tared crucible and heated between 595° and 650°C (1100° and 1200°F). for not less than two hours. The crucible and ash are cooled in a desiccator and reweighed.

[4] **pH Test.** Five grams of fiber is added to 100 ml of distilled water, stirred, and left to sit for 30 minutes. The pH is determined with a probe calibrated with pH 7.0 buffer.

[5] **Oil Absorption Test.** Five grams of fiber is accurately weighed and suspended in an excess of mineral spirits for not less than 5 minutes to ensure total saturation. It is then placed in a screen mesh strainer (approximately 0.5 square millimeter hole size) and shaken on a wrist action shaker for 10 minutes (approximately 1¼ inch motion at 240 shakes per minute). The shaken mass is then transferred without touching to a tared container and weighed. Results are reported as the amount (number of times its own weight) the fibers are able to absorb.

[6] **Moisture Content.** Ten grams of fiber is weighed and placed in a 121°C (250°F) forced air oven for two hours. The sample is then reweighed immediately upon removal from the oven.

Table A-4

Mineral Fiber Properties

Mineral Fibers[1]		
Size Analysis:		
Fiber Length[2]:	6 mm (0.25") maximum mean test value	
Thickness[3]:	5 mm (0.0002") maximum mean test value	
Shot content[4]:	250 µm (No. 60) sieve	95% passing (minimum)
	63 µm (No. 230)	65% passing (minimum)

[1] The European experience and development of the above criteria are based on the use of **basalt** mineral fibers.

[2] The fiber length is determined according to the Bauer McNett fractionation.

[3] The fiber diameter is determined by measuring at least 200 fibers in a phase contrast microscope.

[4] Shot content is a measure of non-fibrous material. The shot content is determined on vibrating sieves. Two sieves, No. 60 and No. 230, are typically utilized; for additional information see ASTM C612.

Additional work is underway to develop a performance-based specification for fibers.

Some of the provisions of this guideline will need to be modified if utilized with polymer-stabilized SMA. (*See Notes to the Engineer*.)

SMA Mixing Plant

Plants used for the preparation of the SMA mixture shall conform to AASHTO M 156 and the following:

Handling Mineral Filler. Adequate dry storage shall be provided for the mineral filler, and provisions shall be made for proportioning the filler into the mixture uniformly and in the desired quantities. Mineral filler in a batch plant will be added directly into the weigh hopper. In a drum plant, mineral filler will be added directly into the drum mixer. Special attention is directed to providing appropriate equipment for accurately proportioning the relative large amounts of mineral filler required for an SMA mixture.

Fiber Addition. Adequate dry storage shall be provided for the fiber additive, and provisions shall be made for proportioning fiber into the mixture uniformly and in the desired quantities.

Batch Plant. Fiber shall be added through a separate inlet directly into the weigh hopper above the pugmill. The addition of fiber should be timed to occur during the hot aggregate charging of the hopper. Adequate dry mixing time is required to ensure proper blending of the aggregate and fiber stabilizer. Dry mixing time shall be increased 5 to 15 seconds. Wet mixing time shall be increased at least 5 seconds for cellulose fibers, and up to 5 seconds for mineral fibers, to ensure adequate blending with the asphalt cement.

Drum Mix Plant. In a drum mix plant, fiber shall be added into the drum mixer to ensure complete blending of the fiber into the mix. For this purpose, when adding loose fiber, a separate fiber-feeding system shall be utilized that can accurately and uniformly introduce fiber into the drum at such a rate as not to limit the normal production of mix through the drum. At no time shall there be any evidence of fiber in the baghouse or returned/wasted baghouse fines. (*See Notes To Engineer*.)

Hot-Mixture Storage. When the hot mixture is not to be hauled immediately to the project and placed, suitable bins shall be provided. Such bins shall be either surge bins to balance production capacity with hauling and placing capacity or storage bins which are heated and insulated and which have a controlled atmosphere around the mixture. The holding time shall be within limitations imposed by the Engineer, based on laboratory tests of the stored mixture. In no case will SMA mixture be kept in storage overnight or for the next day's paving.

Hauling Equipment

Hauling equipment should be of a type normally used for the transport of dense-grade asphalt hot mix. Truck beds shall be covered and insulated if necessary, so that the mixture may be delivered on the road at the specified temperature.

Pavers

Pavers shall be of a type normally used for the placement of dense-graded Hot Mix Asphalt. They shall be self-contained, power-propelled units provided with an adjustable activated screed, heated and capable of spreading and finishing courses of asphalt plant mix material in lane widths applicable to the specified typical section and thickness shown on the plans.

The paver shall be capable of being operated at forward speeds consistent with satisfactory placement and compaction of the mixture. The paver shall be capable of striking a smooth finish of uniform texture.

Weather Limitations

The SMA mixture shall be placed on a dry, unfrozen surface when the atmospheric temperature in the shade and of the roadbed is above 10°C (50°F) and rising and the mix conforms to the applicable requirements shown under "Placing and Finishing."

Conditioning of Existing Surface

Immediately before placing the SMA mixture, the existing surface shall be cleaned of loose or deleterious material by brooming or other approved means.

A thin tack coat of asphalt emulsion (SS-1, SS-1h, CSS-1, CSS-1h or similar material) conforming to AASHTO M 140 or M 208 shall be applied to ensure uniform and complete adherence of the overlay. The asphalt emulsion used for this purpose will be diluted with an equal part of water and the diluted emulsion be applied at between 0.05 and 0.1 gallons per square yard.

Where the existing surface is distorted, a leveling course of Hot Mix Asphalt shall be required to restore proper cross-section prior to construction of the overlay.

Control of Asphalt Mixture

The SMA mixture furnished by the Contractor shall conform to the job-mix formula, within the allowable deviations from the target values. The allowable deviations from the target values for the JMF of the aggregate shall be ±4% for the 19.0 mm (3/4"), 12.5 mm (1/2"), and 9.5 mm (3/8"), sieve, ±3% for the 4.75 mm (No. 4), 2.36 mm (No. 8), 600 µm (No. 30) and 300 µm (No. 50) sieve, and ±2% for the 75 µm (No. 200) sieve. The allowable deviation from the target value for the asphalt content shall be ±0.3%.

Placing and Finishing

The mixture, when delivered to the paver, shall have a temperature of not less than 143°C (290°F). The mixture temperature shall be measured in the truck just prior to dumping into the spreader.

The mixture shall be spread and struck off to the established grade and elevation with asphalt pavers.

Placing speed will be adjusted so that sufficient time is allowed for compaction operations and to provide continuity.

Compaction

Immediately after the mixture has been spread and struck off, it shall be thoroughly and uniformly compacted by rolling.

Due to the nature of SMA mixture the surface shall be rolled immediately. Rolling shall be accomplished with steel wheel rollers of a minimum weight of 9 tonnes (10 tons). Pneumatic tire rollers shall not be used on SMA. Rolling procedures should be adjusted to provide the specified pavement density. Rollers shall move at a uniform speed not to exceed 5 km/h (3 mph) with the drive roller nearest the paver. Rolling shall be continued until all roller marks are eliminated and the minimum density has been obtained but not after the mat has cooled to 116°C (240°F) or lower. The Contractor shall monitor density during the compaction process by use of nuclear density gauges to assure that the minimum required compaction is being obtained. (*See Notes To Engineer*.)

To prevent adhesion of the mixture to the rollers, it shall be necessary to keep the wheels properly moistened with water mixed with very small quantities of detergent or other approved material.

The pavement should be compacted to at least 94% of maximum theoretical density.

Once sufficient in-place density has been achieved, rolling operations should cease, as over-rolling may cause migration of asphalt cement and filler to the compacted pavement surface.

Traffic should not be placed on the newly compacted surface, until the mat has cooled to 60°C (140°F) or lower.

Trial/Experimental Sections

Trial section(s), a minimum of 150 meters (500 feet) each, shall be constructed off site to examine the mixing plant process control, placement procedures, SMA surface appearance, compaction patterns and to calibrate the nuclear density device. (*See Notes To Engineer*.)

Notes to the Engineer:

Surface Preparation—SMA has been used as a high quality pavement surface, subjected to heavy traffic. To perform its function as a stable, rut-resistant, durable riding surface, it must be placed over properly prepared, structurally sound, new or existing pavement layers.

Asphalt Cement Content—The overwhelming emphasis of the German and Swedish experience with SMA has been to require a relatively high asphalt content. A high asphalt content is needed to ensure durability. To this goal, the approach with SMA projects constructed in this country has been to require at least a minimum of 6.0% effective asphalt content.

It has been proposed that technically it would be more precise to achieve the goal of a high asphalt content in SMA by control of VMA. Before VMA can completely replace asphalt content in SMA design and control, more data is needed on minimum acceptable values. Currently, a VMA value of 17 is used, based on practice in this country. VMA is not used in Germany or Sweden to describe SMA.

Marshall Stability—Values may be modified depending on other SMA mix considerations. Measurements are for information and should not be the sole reason to accept/reject an SMA design.

Draindown Test—The Asphalt Draindown Test shown is based on a proposed procedure developed by NCAT. It was developed as a field check as well as a lab design tool. It is intended that this test be applicable to a wide variety of stabilizers.

Aggregate Gradation—Current SMA projects utilize gradations that are within the extreme lower portion of the German 12.5 mm (1/2") gradation band. It is strongly advised that alternative gradations be limited to this practice when utilizing the German SMA gradation band.

Asphalt Cement Grade—European SMA experience is from the cooler climates of central and northern areas, typically corresponding to the northern tier of states in this country. These European areas do not have the extreme warm temperatures experienced in this country. Moderately stiff/hard asphalt cements typically 60 to 80 pen or AC-20 are used.

To account for temperature variations experienced around the United States, other grades of asphalt cement as appropriate for various climatic regions, may have to be used and mixing and placement temperatures adjusted accordingly. It is advisable that grades of asphalt cement currently utilized by states for heavy-duty pavements be investigated for SMA use.

Fiber Introduction—Manual and automated methods have been used to introduce SMA stabilizers at the asphalt mixing plant.

Manual Introduction Of Fiber Stabilizers—Manual introduction of fiber into batch plants is acceptable. Since fiber stabilizers typically are in a prepackaged condition, proper dosage overall can simply be determined by comparison of the amount of mixture produced to actual number of packages used. Close inspection during batching of the mixture can assure uniform introduction of the stabilizer. Just as with automated equipment, it is recommended that a device interrupt mixture production if the operator manually feeding the stabilizer fails to introduce it properly.

Automated Bulk Fiber Introduction (Batch Plant)—Methodology and equipment for metering bulk (loose) fibers into batch plants has been developed. Utilization of this method requires specialized equipment that can accurately proportion, by weight, the required quantity of fiber on a per-batch basis. Such proportioning devices should be locked with other feed devices of the plant system and be controlled to ±10% of the weight of fibers required. It is recommended that prior to project start, an equipment calibration report be presented which shows the ability of the equipment to accurately introduce fibers into the specific batch plant operation intended for use. Also on-site verification by direct inspection and monitoring of fiber usage during the batching operation can assure the metering device performs within the ±10% requirement. The specialized equipment should be interlocked with the plant operation for the interruption of the mixture production if the fiber introduction fails. The air-driven system which delivers the fibers to the pug mill is equally important as the metering device. Fibers should be added so as not to become entrained in the exhaust system of the plant. Close inspection of bag house fines before and after mixture production with fibers along with the mixture testing can identify if fibers are mixed properly.

Automated Bulk Fiber Introduction (Drum Plant)—Methodology and equipment for metering bulk (loose) fibers into drum plants has been developed. Utilization of this method requires specialized equipment that can accurately proportion, by weight, the required quantity of fiber in a steady and uniform manner. Such proportioning devices should be locked with other feed devices of the plant system and be controlled to ±10% of the weight of fibers required. It is recommended that prior to project start an equipment calibration report be presented which shows the ability of the equipment to accurately introduce fibers into the specific drum plant operation intended for use. Also on-site verification by direct inspection and monitoring of fiber usage during the mixture production can assure the metering device performs within the ±10% requirement. The specialized equipment should be interlocked with the plant operation for the interruption of the mixture production if the fiber introduction fails. The air-driven system which delivers the fibers to the drum mixer and mixing head inside a parallel flow drum plant are equally important as the metering device. Fibers should be added so as not to become entrained in the exhaust system of the plant. Close inspection of baghouse fines before and after fiber stabilized mixture production along with the mixture testing can identify if fibers are being picked up by the exhaust system.

Automated Pellet Introduction (Drum plants)—Stabilizers have used a methodology and equipment for metering pellets onto the RAP conveyor system and into drum mix plants producing SMA mixtures. In some cases the methodology consisted of controlling the RAP cold feeders to feed the extremely small portion of the mix (0.3%–0.6% by weight) onto a constant speed RAP conveyor system leading to the drum mixer, which must run at a constant TPH. In other cases, when the RAP cold feeders could not be used effectively, special metering equipment has been used to feed the pellets onto the RAP conveyor system. As with all metering devices, the pellet proportioning device and RAP conveyor system should be locked with other feed devices of the plant system and be controlled to the required tolerance of the weight of modifier required for the SMA mixture. It is recommended that prior to project start, an equipment calibration report be presented that shows the ability of the equipment and conveyor system to accurately introduce stabilizers into the specific drum plant operation intended for use. Also on-site verification by direct inspection and monitoring of stabilizer usage during the mixture production can assure the metering system performs within the specified requirement. Use of a typical weigh-bridge or totalizer on the RAP conveyor is not recommended for controlling the amount of stabilizer being added to the mixture. However, interlock of the feeder should allow for the interruption of the mixture production if the introduction system fails.

Some polymer modified asphalt cements have been delivered in a preblended condition or blended separately at the mixing plant, however modifiers are not covered by this note. Rather, the supplier of the polymer modifier must provide technical assistance regarding the manual introduction of its product.

Fiber Types—Initial SMA projects in this country utilized proprietary fiber stabilizers obtained from Europe. Generic properties for cellulose and mineral fiber have been developed. Fibers meeting the properties of these materials may be given consideration for evaluation. Critical fiber properties continue to be investigated and are considered "under development" and not in their final stage. The values shown are for general information.

Fiber/Polymer Stabilizers—Selection of the "better" approach of either fiber stabilization or asphalt polymer stabilization is under evaluation. SMA, as typically defined, requires a relatively high content of asphalt cement and mineral filler mastic to bind together the large aggregate particles. To retain the high amount of asphalt cement in the mix, some type of fiber stabilizer is generally utilized. Fiber stabilization is reported to be the German practice in over 90% of their projects and nearly all the Swedish SMA projects. The German government specifies that in order to have an SMA with sufficient durability, a minimum asphalt cement range of 6.0%–7.0% is required. The Swedish specification (Pub1 1988:42) requires a minimum asphalt content of 6.6% for its 12 mm SMA. SMA mixes not utilizing fiber but rather only asphalt cement polymer stabilization generally contain a lower asphalt cement content than a comparable fiber SMA.

If polymer stabilization is utilized, the individual manufacturer should be consulted for design and construction recommendations, as the traditional SMA guidelines will not be applicable to unique stabilizers.

Compaction—Rollers in a vibratory mode, with high frequency and low amplitude, may be used on a limited basis. However, care should be exercised so that the asphalt mastic does not migrate to the surface or that aggregate breakdown does not occur.

Trial Sections—Trial sections should be placed as specified approximately one week prior to placement of the project, not only to familiarize personnel with mixing and placement peculiarities of SMA but also to allow sufficient time for any required mixture adjustments, Trial sections shall be of sufficient tonnage to allow the mix plant to operate without the adverse effects of start up and shut down.

Appendix

SMA Asphalt Draindown Test Procedure

1. Scope

1.1 This test method covers the determination of the amount of draindown in an uncompacted SMA mixture sample when the sample is held at elevated temperatures comparable to those encountered during the production, storage, transport, and placement of the mixture.

1.2 The values stated in gram-millimeter units are to be regarded as the standard.

1.3 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents — AASHTO Standards, T 245 Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus and M 92 Standard Specification for Wire-Cloth Sieves for Testing Purposes.

3. For the purpose of this test method, draindown is considered to be that portion of the asphalt cement which separates itself from the sample as a whole and is deposited outside the wire basket during the test. (Note, any noticeable aggregate particles that are deposited outside the basket should be added back into the mixture and not counted as draindown. Alternatively, the test should be rerun.)

4. Summary of Method — A sample of the SMA mixture to be tested is prepared in the laboratory or obtained from field production. The sample is placed in a wire basket which is positioned on a pre-weighed paper plate. The sample, basket, and plate are placed in a forced-air oven for one hour at a preselected temperature. At the end of one hour, the basket containing the sample is removed from the oven along with the paper plate and the paper plate is weighed to determine the amount of draindown that occurred.

5. Significance and Use — This test method can be used to determine whether the amount of draindown measured for a given SMA mixture is within acceptable levels. It also provides an evaluation of the draindown potential of an SMA mixture produced in the field.

6. Apparatus

6.1 Oven, capable of maintaining the temperature in a range from 120°–175°C (250°–350°F). The oven should maintain the set temperature to within ±2°C (±3.6°F).

6.2 Paper plates of appropriate size. The paper plates used should be of appropriate durability to withstand the oven temperatures.

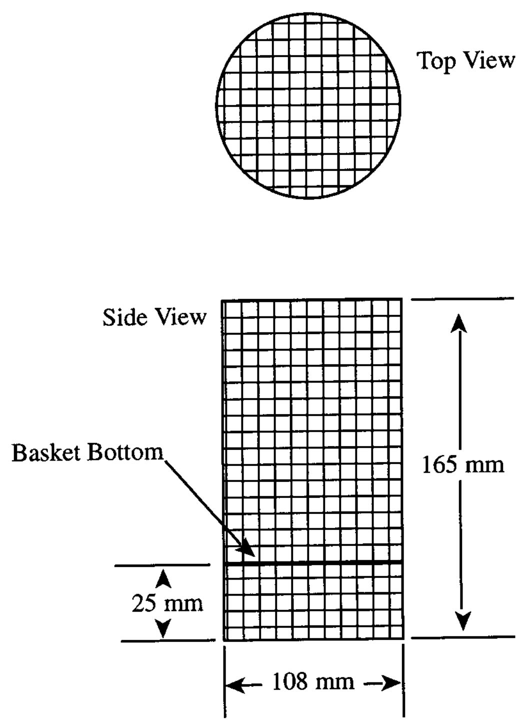
6.3 Standard cylindrical shaped basket meeting the dimensions shown in *Figure 1*. The basket shall be constructed using standard 6.3 mm (0.25 inch) sieve cloth as specified in AASHTO M 92.

6.4 Spatulas, trowels, mixer, and bowls as needed.

6.5 Balance accurate to 0.1 gram.

Figure 1

Wire basket assembly



7. Sample Preparation

7.1 Laboratory Prepared Samples

7.1.1 For each mixture tested, the draindown characteristics should be determined at the anticipated plant production temperature. Duplicate samples should be tested.

7.1.2 Dry the aggregate to constant mass and sieve it into appropriate size fractions as indicated in AASHTO T 245, section 3.2.

7.1.3 Determine the anticipated plant production temperature or select a mixing temperature in accordance with AASHTO T 245, Section 3.3.1. The asphalt cement supplier's recommendations should be sought when using modified asphalt cement.

7.1.4 Weigh into separate pans for each test sample the amount of each size fraction required to produce completed SMA mixture samples having a mass of 1,200 grams. The aggregate fractions shall be combined such that the resulting aggregate blend has the same gradations as the job mix formula. Place the aggregate samples in an oven and heat to a temperature not to exceed the mixing temperature established in 7.1.3 by more than approximately 28°C (50°F).

7.1.5 Heat the asphalt cement to the temperature established in 7.1.3.

7.1.6 Place the heated aggregate in the mixing bowl. Add any stabilizer (Note 1) as directed by the supplier and thoroughly mix the dry components. Form a crater in the aggregate blend and add the required amount of asphalt. The amount of asphalt shall be such that the final sample has the same asphalt content as the job mix formula. At this point, the temperature of the aggregate and asphalt cement shall be within the limits of the mixing temperature established in 7.1.3. Using a spatula (if mixing by hand) or a mixer, mix the aggregate (and stabilizer) and asphalt cement quickly, until the aggregate is thoroughly coated.

7.2 Plant Produced Samples

7.2.1 For plant produced samples, duplicate samples should be tested at the plant production temperature.

7.2.2 Samples may be obtained during plant production by sampling the mixture at the trucks prior to the mixture leaving the plant. Samples obtained during actual production should be reduced to the proper test sample size by the quartering method.

8. Procedure

8.1 Transfer the laboratory produced or plant produced uncompacted SMA mixture sample to a tared wire basket described in 6.3. Place the entire sample in the wire basket. Do not consolidate or otherwise disturb the sample after transfer to the basket. Determine the mass of the sample to the nearest 0.1 gram.

8.2 Determine and record the mass of a paper plate to the nearest 0.1 gram. Place the basket on the paper plate and place the assembly into the oven at the temperature as determined in 7.1.3 for 1 hour ±1 minute.

8.3 After the sample has been in the oven for 1 hour, remove the basket and paper plate. Determine and record the mass of the paper plate to the nearest 0.1 gram.

9. Calculations

9.1 Calculate the percent of mixture which drained by subtracting the initial paper plate mass from the final paper plate mass and divide this by the initial total sample mass. Multiply the result by 100 to obtain a percentage.

10. Report

10.1 Report the average percent drainage at the test temperature.

Note 1 — Some types of stabilizers such as fibers or some polymers must be added directly to the aggregate prior to mixing with the asphalt cement. Other types must be added directly to the asphalt cement prior to blending with the aggregate.

Appendix B

Example Mix Design

This appendix contains data from an actual SMA mixture design. The design method ensures that sufficient VMA, VCA, and air voids exist in the mixture. It also ensures that an aggregate skeleton with stone-on-stone contact is produced. The design is for a 19.0-mm nominal maximum aggregate size SMA which may be used for a binder course for heavy traffic. A step-by-step discussion of the mixture design is provided below.

Materials Selection

Materials available for this design are listed below and the aggregate gradations are shown in *Table B-1*.

Coarse Aggregate:	#78 Limestone
Fine Aggregate:	#810 Limestone
Mineral Filler:	Limestone Dust
Asphalt Cement:	PG 64-22
Stabilizer:	Cellulose Fiber (Dosage rate of 0.3 percent by total mix weight)

Materials Testing

The aggregates, mineral filler, PG 64-22, and cellulose fiber were tested for compliance with the applicable specifications. All materials were found suitable for use in SMA. The Los Angles Abrasion loss for the coarse aggregate was determined to be 25 percent.

Select Trial Gradations

Three trial gradations were chosen such that they were within the master gradation band for a 19 mm nominal maximum aggregate size SMA. The use of the 19 mm mix defines the coarse aggregate to be that retained on the 4.75 mm sieve (defined as the breakpoint sieve). The three trial blends were selected to be along the coarse and fine limits of the gradation band with one near the

Table B-1

Available Aggregate Gradations

Sieve Size		Percent Passing by Mass			
mm	inches	#78	#810	Mineral Filler	19 mm SMA Band
25.0	1	100.0	-	-	100
19.0	¾	96.7	-	-	90–100
12.7	½	61.2	100.0	-	50–74
9.5	⅜	44.0	99.8	-	25–60
4.75	#4	9.0	76.0	-	20–28
2.36	#8	5.0	65.0	-	16–24
1.18	#16	3.0	50.2	100.0	13–21
0.60	#30	2.0	37.6	98.8	12–18
0.30	#50	2.0	27.5	88.6	12–15
0.075	#200	1.0	10.0	77.6	8–10
G_{sb}		2.704	2.711	2.803	—

G_{sb} = bulk specific gravity of the aggregate middle. Because the bulk specific gravities of the different aggregates differ by more than 0.02, the blended trial gradations were based on volumetric percentages. These trial gradations are shown in *Table B-3*. The percentages of aggregates in each blend are shown in *Table B-2*.

Table B-2

Percent of Aggregates Used in Each of the Three Trial Blends

	Percent by Mass Used in Blend		
Blend No.	**#78**	**#810**	**Mineral Filler**
1	84	6	10
2	80	10	10
3	76	14	10

Table B-3

Gradations of the Three Trial Blends

Sieve Size		Percent Passing by Volume		
mm	**inches**	**Trial Blend 1**	**Trial Blend 2**	**Trial Blend 3**
25.0	1	100.0	100.0	100.0
19.0	¾	97.2	97.3	97.5
12.5	½	67.3	68.8	70.4
9.5	⅜	52.8	55.0	57.2
4.75	#4	21.8	24.5	27.2
2.36	#8	17.8	20.2	22.6
1.18	#16	15.2	17.1	19.0
0.60	#30	13.5	14.9	16.4
0.30	#50	11.9	12.9	14.0
0.075	#200	9.0	9.4	9.7
G_{sb}		2.715	2.715	2.715

G_{sb} = bulk specific gravity of the aggregate

Determination of Voids in the Coarse Aggregate—Dry-Rodded Condition (VCA_{DRC})

For each of the three trial blends, the VCA_{DRC} was determined for the coarse aggregate fraction according to AASHTO T 19. Two replicates for each test were performed. The average results are given in *Table B-4*.

Table B-4

Density and VCA_{DRC} for the Three Trial Blends

Blend No.	VCA_{DRC} (%)	Density (kg/m³)
1	40.8	1598
2	40.3	1610
3	39.9	1623

As an example, the calculation for VCA_{DRC} for blend 2 is shown below:

$$VCA_{DRC} = \left(\frac{G_{CA}\gamma_W - \gamma_S}{G_{CA}\gamma_W}\right)100$$

$$VCA_{DRC} = \left(\frac{(2.704)(998) - 1610}{(2.704)(998)}\right)100$$

$$VCA_{DRC} = 40.3\%$$

where,

γ_S—unit weight of the coarse aggregate fraction in the dry rodded condition (kg/m³),

γ_W—unit weight of water (998 kg/m³), and

G_{CA}—bulk specific gravity of the blended coarse aggregate.

As can be seen, the VCA_{DRC} does not vary much from blend to blend. This is because the coarse aggregate gradations are nearly identical for each of the three trial blends. In practice, this will nearly always be the case. The result is that the VCA_{DRC} may have to be determined for only one of the trial blends.

Compact Specimens

For each of the trial blends, three samples were produced at 6.5 percent asphalt cement by total mix mass using 100 gyrations of the SGC. This compactive effort was used because the Los Angles Abrasion loss was below 30 percent. The bulk specific gravities (G_{mb}) of these specimens were then determined according to AASHTO T 166. Also, for each trial blend the maximum theoretical specific gravity (G_{mm}) was determined for one sample according to AASHTO T 209. The air voids, VMA, and VCA were then determined. These results are summarized in *Table B-5*.

An example of the VCA calculation for the SMA mixtures is given here for blend 2. From *Table B-3*, the percent passing the 4.75 mm break point sieve was 24.5, which means that 75.5 percent is retained. For the 6.5 percent asphalt content, the following calculation is made:

$$P_{bp} = (P_S)(PA_{bp})\,100$$

$$P_{bp} = (0.935)(0.755)\,100$$

$$P_{bp} = 70.6\%$$

$$VCA = 100 - \left(\frac{G_{mb}}{G_{ca}}\right)P_{bp}$$

$$VCA = 100 - \left(\frac{2.383}{2.704}\right)70.6$$

$$VCA = 37.8\%$$

where,

P_{bp}—percent aggregate by total mixture weight retained on the breakpoint sieve,

P_S—percent aggregate in the mixture expressed as a decimal,

PA_{bp}—percent aggregate by total aggregate weight retained on the breakpoint sieve, expressed as a decimal.

G_{CA}—combined bulk specific gravity of the coarse aggregate (from *Table B-1*), and

G_{mb}—bulk specific gravity of compacted specimens (from *Table B-5*).

Only trial blends 1 and 2 meet both the VMA and VCA criteria (VMA > 17 percent and VCA < VCA_{DRC}). Trial blend 3 did not meet the VCA requirement. However, none of these blends meets the air voids requirement of 4.0 percent. Based on the combined bulk specific gravity of the aggregates (G_{sb}) of 2.715 (*Table B-3*), the minimum asphalt cement content is 6.1 per cent. From the trial blends, blend 1 has the closest air voids to 4.0 percent and was selected for determination of the optimum asphalt content.

Table B-5

Test Results for Three Trial Gradation Blends

Property	Trial Blend 1	Trial Blend 2	Trial Blend 3
G_{mb}	2.379	2.383	2.383
G_{mm}	2.468	2.460	2.455
Air Voids, %	3.6	3.1	2.9
VMA, %	18.1	17.9	17.9
VCA, %	35.7	37.8	40.1
VCA_{DRC}, %	40.8	40.3	39.9

Select Optimum Asphalt Cement Content

With the optimum gradation determined, the asphalt content is now varied to determine the optimum asphalt content. To do this, eight samples were prepared, four at an asphalt binder content of 5.7 percent and four at an asphalt binder content of 6.1 percent. The third asphalt binder content data point is 6.5 percent (already completed in the trial gradation). Three samples at each asphalt binder content were compacted while the remaining sample was used to determine the theoretical maximum specific gravity (G_{mm}). The average results are shown in *Table B-6*.

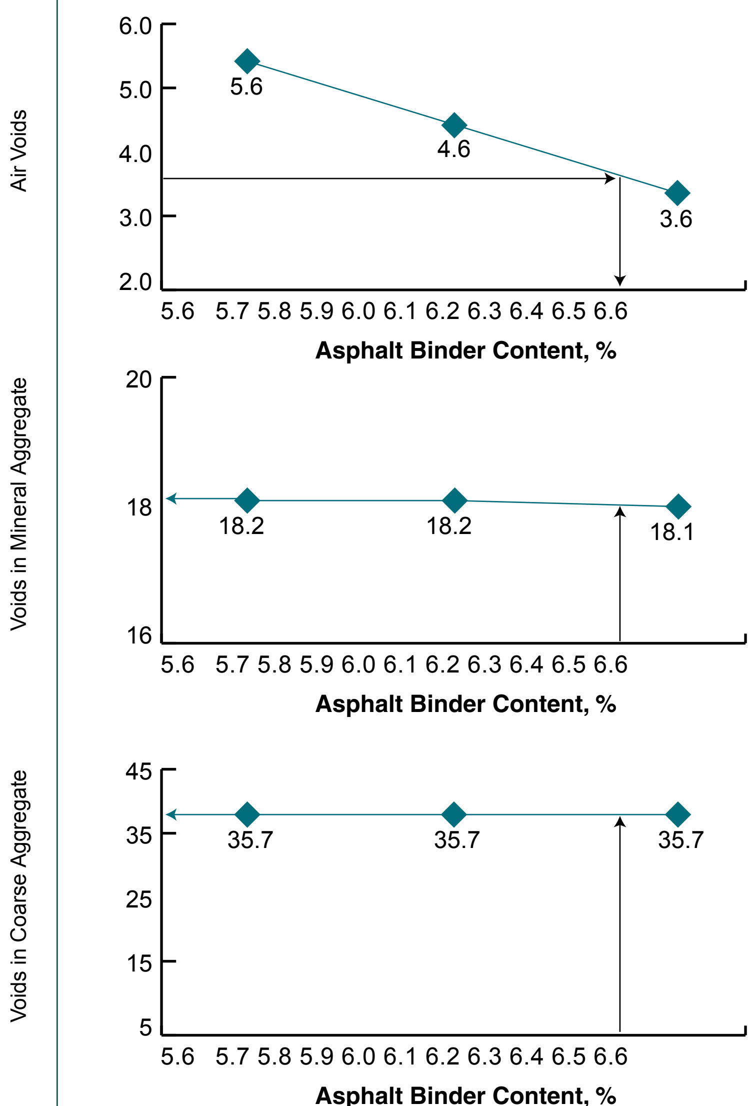
Table B-6

Test Results From Trial Blend 1 at Various Asphalt Binder Contents

Property	5.7% AC	6.1% AC	6.5% AC
G_{mb}	2.359	2.369	2.379
G_{mm}	2.498	2.483	2.468
Air Voids, %	5.6	4.6	3.6
VMA, %	18.2	18.2	18.1
VCA, %	35.7	35.7	35.7

The air voids, VMA, and VCA from *Table A-6* are plotted as a function of asphalt cement content in *Figure B-1*. Upon evaluation of the test results, it was determined that an asphalt binder content of 6.1% produced a mixture meeting all the requirements.

Figure B-1
Plots of Properties as a Function of Asphalt Content



Moisture Susceptibility

Moisture susceptibility, was determined in accordance with AASHTO T 283 using 100-mm specimens. The compactive effort necessary to produce an average of 6 percent air voids was determined. Eight samples were compacted to this average air void content and air voids of all samples were between 5 percent and 7 percent. Four of the specimens were tested for dry strength while the remaining four were tested for wet strength. A freeze-thaw cycle was not used. The average results are shown in *Table B-7*. The average TSR was measured to be 94.4 percent, well exceeding the 75 percent minimum requirement. The mixture therefore meets the moisture susceptibility requirements.

Table B-7
Moisture Susceptibility Test Results for the SMA Mixture

Ave. Dry Strength, kPa	445
Ave. Wet Strength, kPa	420
TSR, %	94.4

Draindown Testing

Draindown susceptibility was performed according to AASHTO T 305. Duplicate samples were tested at each of three temperatures, 137°C (280°F), 152°C (305°F) and 167°C (330°F). The test results are shown in *Table B-8*. For this project, the plant production temperature is anticipated to be 152°C (305°F).

Table B-8
Draindown Sensitivity Test Results for the SMA Mixture

Temperature°C (°F)	Average Draindown, %
137 (280)	0.05
152 (305)	0.06
167 (320)	0.09

Mortar Properties

It was decided to determine mortar properties for this mixture according to AASHTO TP 5 and TP 1, methods for the Dynamic Shear and Bending Beam Rheometer, respectively. The asphalt binder was a PG 64-22. The results of the testing are shown in *Table B-9*.

Table B-9

Mortar Properties

Test	Temperature °C (°F)	Result	Requirement
Unaged DSR, G*/sinδ(kPa)	64 (147)	6.23	5 min.
RTFO Aged DSR, G*/sinδ(kPa)	64 (147)	14.85	11 min.
PAV Aged BBR, Stiffness (MPa)	−12 (10)	895.0	1500 max.

Design Summary

The mixture properties for the designed mixture, gradation by both volume and mass, component percentages, and mortar properties are shown in *Tables B-10* through *B-l4*, respectively.

Table B-10

SMA Mixture Properties

Mixture Property	Test Result	Requirement
G_{sb}	2.715	—
Asphalt Content, %	6.4	6.1 min.
Fibers, %	0.30	0.30
Air Voids,%	4.0	4.0
VMA,%	18.1	17.0 min.
VCA_{MIX},%	35.7	41.8* max.
TSR,%	94.4	70.0 min.
Draindown @ 152°C (305°F),	0.06	0.30 max.

* VCA_{DRC}

Table B-11

Aggregate Gradation Based on Volume

Sieve Size mm	Sieve Size inches	Percent Passing
25.0	1	100.0
19.0	¾	97.2
12.7	½	67.3
9.5	⅜	52.8
4.75	#4	21.8
2.36	#8	17.8
1.18	#16	15.2
0.60	#30	13.5
0.30	#50	11.9
0.075	#200	9.0

Table B-12

Aggregate Gradation Based on Mass

Sieve Size mm	Sieve Size inches	Percent Passing
25.0	1	100.0
19.0	¾	97.2
12.7	½	67.4
9.5	⅜	52.9
4.75	#4	22.1
2.36	#8	18.1
1.18	#16	15.5
0.60	#30	13.8
0.30	#50	12.2
0.075	#200	9.2

Table B-13

Component Percentages in the Selected Mixture

Component	Percent by Mass of Aggregate	Percent by Total Mixture Mass
#78 Stone	84	78.4
#810 Stone	6	5.6
Mineral Filler	10	9.3
Cellulose Fiber	-	0.3
PG 64-22	-	6.5

Table B-14

Mortar Properties (optional)

Test	Temperature °C (°F)	Result	Requirement
Unaged DSR, G*/sinδ(kPa)	64 (147)	6.23	5 min.
RTFO Aged DSR, G*/sinδ(kPa)	64 (147)	14.85	11 min.
PAV Aged BBR, Stiffness (MPa)	−12 (10)	895.0	1,500 max.

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