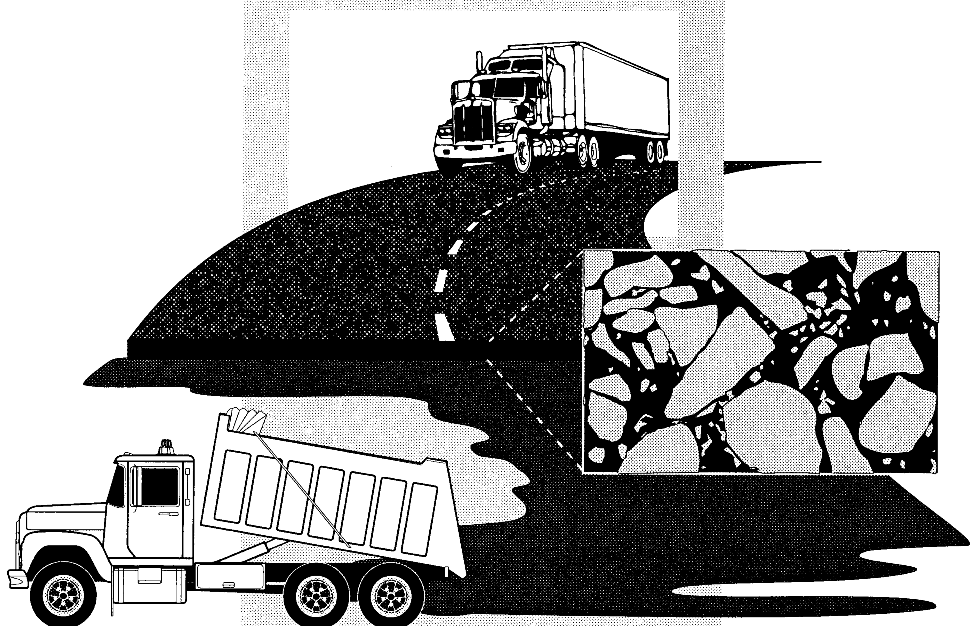
FINAL REPORT

CONSTRUCTION AND PERFORMANCE OF A STONE MATRIX ASPHALT MIX TEST SECTION IN VIRGINIA



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16. Abstract

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During construction, better equipment was necessary to control the amount of fines contained in SMA mixes. Lack of control in the mix gradation caused variability on the roadway and on routine mix tests conducted during construction.

The mix containing the cellulose fiber, Arbocel, has rutted more at stop-lights than the mix containing the polymer, Vestoplast, or the high-stability control mix. However, all mixes continue to perform well. Laboratory creep tests and gyratory shear tests predicted that the control mix and Vestoplast mix would be more resistant to rutting and consolidation under traffic.

This investigation and work in other states have improved the current Virginia specification for SMA. The gradation was coarsened, a stiffer asphalt cement was required, and plant equipment that can adequately handle the aggregates was used. With these changes, future installations will perform better than the current dense graded mixes.

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

SMA is a gap-graded mix filled with a rich asphalt-fines mastic developed in Europe. In 1991 five states constructed trial sections to determine if satisfactory mixes could be produced in the United States with current materials and high rates of production. This report discusses Virginia's first section, placed in 1992 near Lynchburg.

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INTRODUCTION

In 1990 a 21-member group representing AASHTO, FHWA, the Transportation Research Board, NAPA, SHRP, the Asphalt Institute, industry, and state DOT's conducted a 14-day tour of six European countries. The objective was to obtain information on the design, production, and placement of asphalt pavements. They were particularly interested in innovative European processes that would extend the service life of U.S. pavements.

The resulting report (1) described the mission of the tour (2) described activities observed in each country (3) summarized innovative technology pertaining to materials, construction practices and construction equipment and (4) presented a plan for implementing these innovations in the United States.[1] One of the innovative technologies common to several of the countries was a gap-graded mix known as stone mastic asphalt (SMA). This mix was widely used in Germany, the Netherlands and Scandinavia to resist load-induced rutting, a common problem in the United States. In 1990 the largest user, Germany, used approximately one million tons. Sweden placed almost 300,000 tons.

The stone mastic asphalt mix, known as stone matrix asphalt in the United States, relies on stone-to-stone contact developed between the coarse aggregate particles to carry the tire loads. The open voids in the coarse aggregate skeleton are filled with an asphalt-rich mastic of fine aggregate and asphalt that should promote durability. The dense graded mixes used in the United States carry the load with fine aggregate-asphalt mastic, which floats the coarse aggregate particles. Carpenter[2] states that the mastic of the dense graded mixes "does not provide a positive structure to carry the wheel stress, and could possess less resistance to rutting than the SMA mixture" (Figure 1).

The implementation plan was to place test sections in several states, form a technical working group, and perform laboratory studies on the materials used in SMA and SMA design. In 1991 projects were constructed in five states.[3] A technical working group (TWG) representing FHWA, state DOT's, and industry was sponsored by the FHWA Office of Technology Applications. The TWG coordinated technical information from field projects; developed guidelines on design, construction, and use; investigated the feasibility of using generic fibers; and provided assistance to states. Guidelines were released in August of 1994.[4] The TWG is still active.

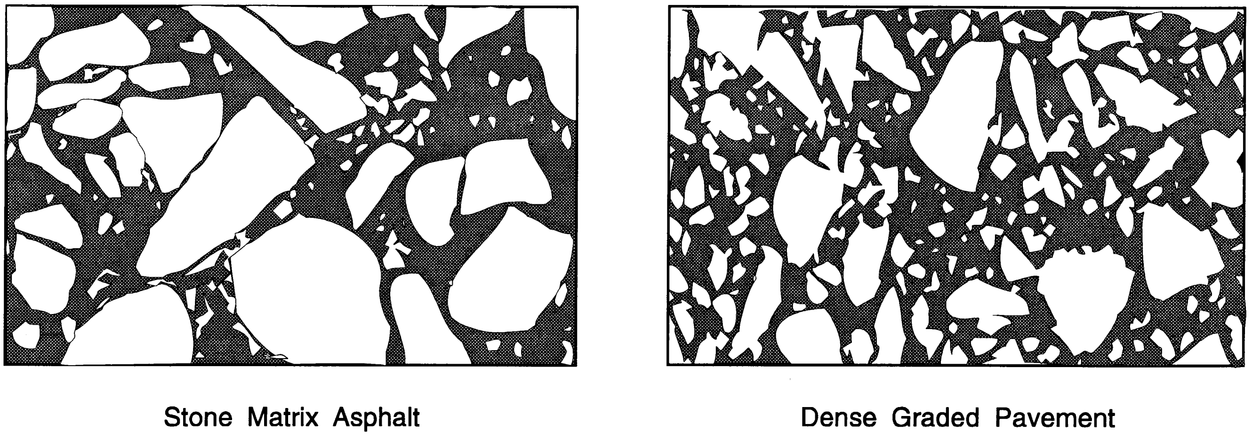

Figure 1. Aggregate structures of SMA and dense-graded asphalt mixes

Europeans rely mostly on a recipe type of design because the same types of materials are used; however, materials vary widely in the United States, even within states, and a design procedure is necessary. Part of the plan for implementation was to investigate the laboratory design of SMA. The National Cooperative Highway Research Program contracted (project 9-8) with the National Center of Asphalt Technology in 1994 to develop a design procedure. A tentative design procedure has since been developed, which will be refined as the project progresses. The Virginia Department of Transportation (VDOT) recently adopted the tentative design procedure for SMA contracts to be constructed in 1995.

As part of the national initiative to accumulate data on the performance and construction of SMA and to gain local experience, a test section was constructed in 1992 near Lynchburg, Virginia. This report deals with the construction of the test section and its performance.

PURPOSE AND SCOPE

The purpose of this investigation was to monitor the construction of a test section of SMA and measure its performance over a short period. A control mix was also placed on an adjoining section for comparison. In addition, some laboratory tests were performed on mix sampled during construction to develop an indication of predicted performance.

METHODOLOGY

General

The SMA mixtures were compared to a conventional control mixture designed to produce rutting resistance. Three areas were evaluated: construction of the test sections, performance of the test sections, and the engineering properties of the mixtures produced.

Evaluation of construction was a combination of subjective and quantitative ratings. The ease of construction and problems encountered because of the type of mix used were observed and noted. Quantitative measurements of gradation, asphalt content, and Marshall properties indicated how well the contractor controlled the production process. Measurements of in-place voids indicated whether the mix had been produced and placed as designed. Performance was measured primarily by rut depths, skid resistance, and general surface distresses such as cracking and bleeding.

Engineering properties were measured to get an idea of the difference between the potential performance of the mixes. For example, the gyratory shear test should indicate if some mixes tend to consolidate more than others. Shear strength is probably the most important material property that determines whether a mix will or will not rut. Mixes with high shear strengths and low strains should be less susceptible to rutting. Creep tests should show whether some mixes are more resistant to rutting. The creep test produces permanent deformation that does not recover when the test load is removed. It should simulate the mechanism of rutting and be another indicator of rutting susceptibility.

Tests and Measurements

Gyratory Shear Test

The gyratory shear test was performed in accordance with ASTM D 3387(5), except for the number of total revolutions and angle of gyration. The angle of gyration was 1.309×10^{-2} rad and the vertical pressure was 827 kPa. The mixture was heated to 149 C before loading into the mold. Compaction was terminated when the change of density decreased to 16 kg/m^3 per 100 revolutions. Shear strength, gyratory shear index (GSI), and final voids were used to evaluate the mixes. Shear strength should be greater than 260 kPa, the GSI should be less than 1.0, and final voids should not be less than 3 percent.

Creep Test

Uniaxial creep tests were performed at 40 C on cylindrical specimens 100 mm by 100 mm in diameter, which were constructed on the gyratory shear testing machine (GTM). The specimens were preloaded for 2 min with an axial pressure of 203 kPa, unloaded, allowed to rest for 5 min, and reloaded for 60 min at 203 kPa. Axial deformation was recorded from dial gauges at set intervals after the load was applied and again for 60 min after the load had been released. The total strain during the load application and permanent strain remaining after the load had been removed for 60 min was used to compare the mixes.

Creep modulus was also used to evaluate the rutting potential. Creep modulus was computed according to the following formula.

$$\textit{Creep Modulus} = \frac{\sigma}{\epsilon}$$

where:

Creep modulus = modulus, kPa
σ = stress, kPa
ϵ = strain, m/m

Routine Tests

The routine laboratory tests used to monitor the consistency of the mix and the ability of the contractor to control the operation were extraction and Marshall volumetrics.

Extraction tests were performed according to the reflux method (ASTM D2172)[5] and the vacuum method (VTM-91).[6] These results were not reported because there was concern that the polymer influenced the accuracy of some of the results. The nuclear asphalt content gauge (VTM-93) was also used by the Lynchburg District materials laboratory to obtain quick results during construction, and these results are reported.

Marshall design tests were performed according to VTM-57 and VTM-58[6] on various combinations of raw materials before construction and on field samples during construction.

Field Dipstick Measurements

Transverse profiles were measured with an electronic leveling device (Dipstick), and the rut depths were estimated from the profiles. The device, which was walked across the pavement, measures the difference in elevation of the two attached "walking" supports. When the pavement was constructed measurements were made with an early version that required a long time for the computer to record each measurement. Measurements were read manually to speed up the process and the built-in rutting from the paver screed was estimated by spreadsheet calculations. Measurements were also made with an improved version of the Dipstick when the pavement was approximately 29 months old. The improved version recorded each measurement automatically.

Friction Tests

Friction tests were performed with a full-scale skid trailer at 64 km/hr (ASTM E 274-90) using a standard smooth tire (E 524-88).[5]

Test Section

A test section containing two SMA mixes and a control mix was constructed on Route 29 south of Lynchburg in October of 1992 (Figure 2). It was assumed that traffic loading was approximately equal in the northbound and southbound lanes. Loading may have been slightly heavier in the northbound lanes because of loaded trucks entering from Route 683. However, much of the loading is contributed by trailer trucks traveling through on Route 29. Approximately 940 metric tons of SMA containing Arbocel and 820 metric tons of SMA containing Vestoplast were placed 38 mm thick, covering 5.7 lane-km of roadway.

The SMA's containing Arbocel and Vestoplast were paved on October 1-2, 1992. The control mix was placed October 14-15, 1992. There was not enough Vestoplast polymer to complete the northbound passing lane; a conventional SM-2C surface mix was used to complete the last 120 m of the passing lane.

The existing pavement surface was rutted at several of the intersections. Approximately 110 mm of pavement was removed by milling at the intersections of Routes 683 and 678 to ascertain that any underlying unstable material would not contribute to future rutting. Seventy-five millimeters of BM-2 base mix with a maximum aggregate size of 38 mm were placed before the surface mix was applied. Thirty-eight millimeters of surface were milled from the control section before the control mix was placed.

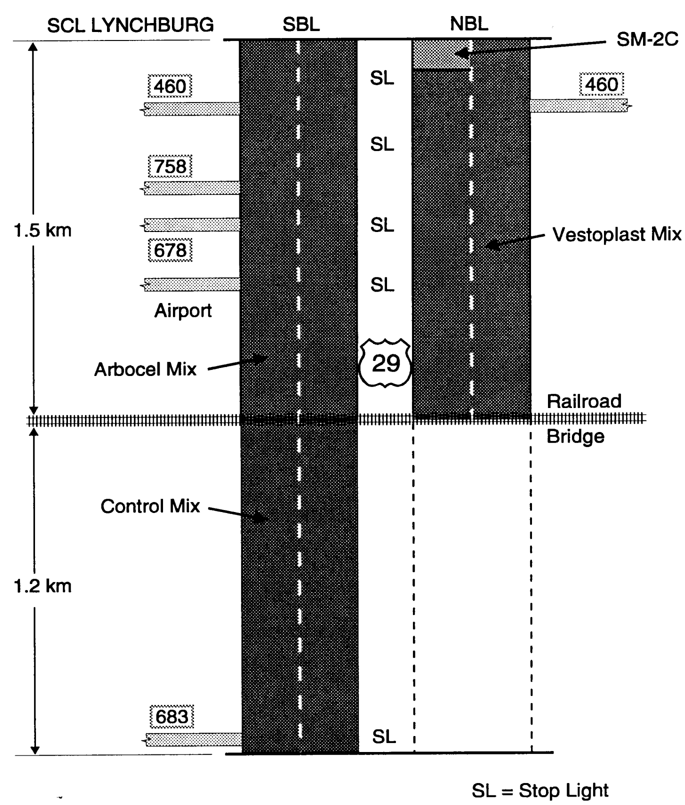

Figure 2. Test section location

Materials and Mixes

One SMA mix contained a cellulose fiber (Arbocel) and the other SMA mix contained a polymer additive (Vestoplast). The control mix was a high-stability dense graded mix containing Gilsonite that has been used in situations in Virginia where rutting is a problem.

Initial specifications for the SMA required that the aggregates be supplied in four sizes in addition to a mineral filler. It was then thought that the gradation could not be controlled adequately unless several sizes of aggregates were used. This was the practice in Europe and also on one of the first jobs in the United States (the previous year in Michigan). After a small amount of the material had been crushed it was evident that the gradation could be achieved using only two of the four aggregates and the agricultural lime filler material (Table 1).

Table 1: Sources and proportions of materials for SMA mixes

Percentage	Type	Source
60	19 mm x 9.5 mm	W. W. Boxley Inc.; Piney River, Va.
23	9.5mm x 4.75 mm	W. W. Boxley Inc.; Piney River, Va.
16	Agricultural Lime	W. W. Boxley Inc.: Piney River, Va.
1	Hydrated Lime	APG; Ripplemead, Va.
0.3	Cellulose - Arbocel	Scan Road; Waco, Texas

The Research Council lab, the district materials lab and the central office materials lab did several mix designs using various combinations of aggregates. It was difficult to get consistent results between labs for the void contents at the design binder content. Finally, after many designs, and production and placement of about 320 metric tons on a secondary road prior to the test section construction, it was decided to aim for the proportions and gradation shown in Tables 1 and 2 respectively. This target design gradation was not within the original specified design range. The design voids in total mix (VTM) was 4.5 percent, which was somewhat higher than recommended. The Europeans normally aimed for approximately 3 percent VTM, but it was feared that the mix would be susceptible to bleeding and rutting if it was made at this low void content. The design binder content of the SMA mix containing Vestoplast was less than that of the SMA mix containing Arbocel. The void contents (VTM) were generally about 0.5 percent lower for the mix containing Vestoplast than for the mix containing Arbocel at comparable asphalt contents. Possibly the stabilizers affected the lubrication and compaction of the aggregate particles.

Table 2: SMA mix design gradation and binder content

Sieve, mm	Percent Passing	
	Target	Original Design Range
19	100	100
12.5	89	92 - 100
9.5	65	70 - 76
4.75	26	30 - 35
2.36	18	20 -24
0.6	15	12 -18
0.075	9.1	7 - 11
AC, percent	6.5 Arbocel; 6.0 Vestoplast	6 - 8

Note: Target was shifted outside original design range after trial section was placed.

The control mix was a high-stability mix designed with a 75-blow Marshall compactive effort. It contained a powdered additive, Gilsonite, to increase the stiffness of the asphalt and prevent permanent deformation. The sources of materials and mix design are listed in Table 3 and Table 4 respectively. The design void content (VTM) was 4.7 percent at the selected asphalt content.

Table 3: Source of materials and proportions for high stability control mix (SM-2CH HS-2)

Percentage	Type	Source
45	# 78	Blue Ridge Stone; Mt. Athos, Va.
10	# 8	Blue Ridge Stone; Mt. Athos, Va.
20	Natural Sand	Otter River
24	# 10	Blue Ridge Stone; Lawyers Rd. Quarry; Lynchburg, Va.
1	Hydrated Lime	APG Lime Corp.; Ripplemead, Va.
8 % of AC	Gilsonite	Valley Asphalt; Dayton, Ohio
	AC-30 asphalt cement	Exxon

Table 4: Gradation for high stability control mix (SM-2CH HS-2)

Sieve, mm	Percent Passing	
	Target	Design Range
19	100	100
12.5	97	97 - 100
9.5	87	82 - 94
4.75	56	48 - 62
0.6	21	18 - 24
0.075	5	4 - 8
AC, percent	5.3	-------

RESULTS

Construction

Lawhorne Brothers, Inc. of Lynchburg produced and placed the SMA mix and control mix during the first two weeks of October, 1992. Ambient temperatures were mild, with average lows of 7 C at night and average highs of 23 C during the daytime when paving took place.

A Simplicity 2.25 metric ton batch plant approximately 2-3 km from the job site was used to produce the mixes. Aggregates, including the agricultural mineral filler, were introduced from cold bins. The hydrated lime, which was used as an antistripping agent, was metered onto the cold feed belt through a system especially constructed for introduction of hydrated lime into the hot mix.

Early in the production of the SMA a problem was encountered with the control of fine material from the No. 1 (fine) hot bin. Because of the extreme fineness of the material contained in this bin it leaked through the bin gates, resulting in excessive amounts in the mix. A plate had to be welded to the bin gates to correct the problem. Subsequently, another problem was discovered where the fine material in the No. 1 bin would temporarily clog and then release suddenly, resulting in inconsistent flow. Air tubes had to be installed in the bin to prevent the build-up of fines on the sides and the cold feed rate was decreased so that only enough material accumulated in the bin for each batch.

Both SMA's required a 5-10 sec dry mix time and 35-40 sec wet mix time. The mixing time was slightly longer than that used for conventional mixes in order to properly disperse the stabilizing agents. Mix temperature averaged 154 C for the SMA containing Arbocel and 135 C for the SMA containing Vestoplast. These temperatures were based on prior experience of other states and recommendations by the polymer supplier. Both stabilizers, Arbocel and Vestoplast, were introduced into the mix by hand through a door located above the mixing box. No drainage of the binder was observed during construction. Drainage, which can be a problem with SMA mixes, was minimized because of the short haul distance.

Paving was accomplished with minimal problems. Two 10-ton tandem steel wheel rollers were used to compact the mixes. A number of roller patterns were tried in an attempt to achieve the desired density (6 percent voids or less). The optimum roller pattern was one vibratory pass and 4 static passes. Some concern has been expressed about using vibratory rollers on SMA because of the chance of crushing aggregate or drawing the rich mastic to the surface.[4] An article in Roads and Bridges states that "...with caution, vibratory rollers can be used with success."[7]

Texture differences behind the paver seemed to indicate that some loads of mix had more fines than others. In fact, the surface texture was so smooth at several areas that possible low tire friction was a concern when the section was opened to traffic. The friction was monitored and sand was applied before the mix containing Arbocel was rolled. Some European countries take similar precautions against possible safety problems. The Vestoplast mix had less binder and a better surface texture appearance. The binder content of the passing lane was lowered to 5.8 percent on the recommendation of a Vestoplast consultant present on the job. The mix containing Vestoplast was stiff and somewhat harder to work by hand than the mix containing Arbocel.

Routine Tests

Gradations of truck samples from reflux extractions are listed in Table 5. Examination of these gradations reveals significant variation between samples for two critical sieves, 4.75 mm and 0.075 mm. The percentage passing the 4.75 mm sieve ranged from 24 to 31 for five samples. Other investigations have shown that variability for this sieve "... of only a few percent may alter the optimum asphalt content by as much as 0.5 percent."[4] If the optimum asphalt content is changed the voids in the mix also change.

Another obvious source of high variability within the mixes was the amount of material passing the 0.075 mm sieve. This amount ranged from 5.1 to 12.5 percent for five samples. The asphalt content seems to have been controlled very well.

Table 5: Extraction gradations of SMA

Mix	Job Mix	Vestoplast		Arbocel		
Sample No./ Sieve, mm		1	2	1	2	3
19	100	100	100	100	100	100
12.5	89	82.7	82.5	79	84	82.2
9.5	65	64.5	63.8	60	64	61
4.75	26	29.9	24.9	24	31	26.8
2.36	18	20.2	13.3	15	20	19.6
0.6	15	16.5	9.9	13	17	17.2
0.3		15.4	9.3	12	16	16.6
0.15		13.5	8.2	11	15	15.3
0.075	9.1	10.1	5.1	8.6	12	1
AC, percent*		6	5.8	6.4	6.4	100

* By nuclear asphalt content gauge

It can be seen from voids measured in cores (Table 6) that the Arbocel mix was slightly more dense (less air voids) than the mix containing Vestoplast. Neither mix met the requirement of six percent pavement voids that was specified. The voids were not different for the two mixes in the traffic lanes; however, the voids in the passing lane for the Vestoplast mix were slightly higher. This difference was probably caused at least partially by the change in binder content described below.

Table 6. Voids measured from cores immediately after construction

Mix	Average Voids Total Mix (Number of cores)	Range
Arbocel (Traffic lane)	7.8 (16)	4.9 - 12.1
Arbocel (Passing lane)	6.2 (4)	4.8 - 8.1
Vestoplast (Traffic lane)	7.9 (5)	6.1 - 10.1
Vestoplast (Passing lane)	8.5 (3)	7.9 - 9.4

The effect of variability in gradation can be seen in the voids results, especially VTM, listed in Table 7. The VTM ranged from 4.1 to 7.2 percent for the Vestoplast mix and 3.6 to 6.9 percent for the Arbocel mix. All VMA values were above the minimum specified value of 16 percent.

Table 7. Field Marshall Voids and Stability During Construction

Mix	Sample No.	VTM	VMA	VFA	Stability, kN
Vestoplast	1	4.1	17.1	75.8	6.10
	2	4.6	17.3	73.3	5.87
	3	4.3	16.9	74.4	6.45
	4	7.1	18.9	62.3	6.10
	5	7.2	19.4	62.8	5.74
	6	5.5	17.8	68.8	7.03
Arbocel	1	4.2	18.1	76.6	5.43
	2	3.5	18.0	-----	7.16
	3	5.9	19.6	70.0	4.63
	4	3.6	17.6	79.8	5.43
	5	3.6	17.4	79.2	6.94
	6	6.9	19.9	65.6	3.96

Laboratory Tests

Gyratory Shear

Results of the gyratory shear tests are in Table 8. All values are within acceptable limits. Shear strength is greater than 260 kPa and the GSI value is not greater than 1.0. VTM are not less than 3.0 percent. Over-densification under traffic should not be a problem. However, the voids results do indicate that the Arbocel mix may densify more than the other two mixes.

Some asphalt technologists are concerned about whether the gyratory shear test is applicable to gap-graded mixes such as SMA. However, a Florida study using the gyratory shear test indicated that it may be suitable to test SMA mixes.[8,9]

Table 8. Gyratory Shear

Mix	VTM, percent	Shear Strength, kPa	GSI	Revolutions
Vestoplast	4.7	340	0.89	245
Arbocel	3.7	320	0.91	240
Control	5.9	290	0.89	150

Creep

The creep test results appear in Table 9 and Figure 3. An attempt was made to test samples of both SMA mixes at two levels, high and low voids. Tests at these two levels should cover the range of values encountered on the roadway as the mix densifies under traffic. The control mix was only tested at low voids since this is the void level that usually produces more permanent deformation for dense graded mixes.

Table 9. Creep test results

Mix	VTM, percent	Total Strain, percent	Permanent Strain, percent
Vestoplast (Low)	3.4	0.22	0.08
Vestoplast (High)	6.6	0.30	0.15
Arbocel (Low)	3.4	0.28	0.11
Arbocel (High)	5.2	0.32	0.14
Control	3.9	0.20	0.07

Figure 3 shows that SMA mixes with low void levels had less permanent strain and apparently better rutting resistance, with the control mix being the best. There was a significant difference at a 5 percent confidence level between the average permanent strain for mixes with low void content and mixes with high void content. Also, there was a significant difference between either the control mix or the mix containing Vestoplast made with low voids and each of the other mixes. The control mix was a very "dry" mix because it was designed with the 75-blow effort and also contained the Gilsonite additive that tends to harden the binder; therefore, it could be susceptible to cracking. The SMA mixes are richer in binder and should be less susceptible to cracking, although still possessing good rutting resistance.

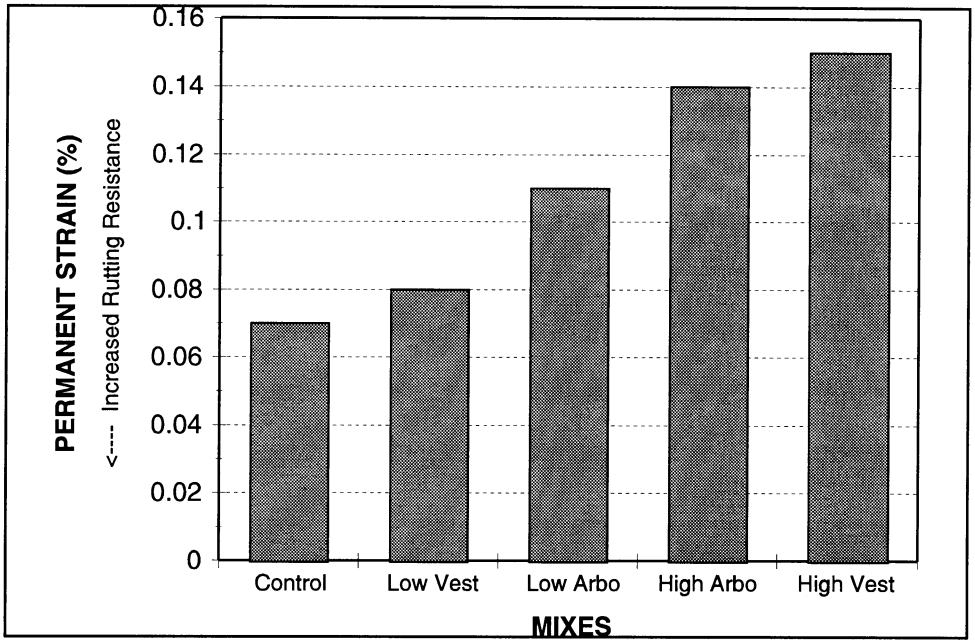

Figure 3. Creep test results at low and high air void levels

Figures 4 and 5 compare the mixes on a rutting plot developed in the NCHRP Asphalt-Aggregate Mixture Analysis System (AAMAS) study.[10] All mixes had less rutting potential at low voids than at high voids. There was a significant difference at a 95 percent confidence level between moduli values for the mixes at a specific creep time, with the exception of the mix containing Arbocel and the mix containing Vestoplast at a high void content. The control mix

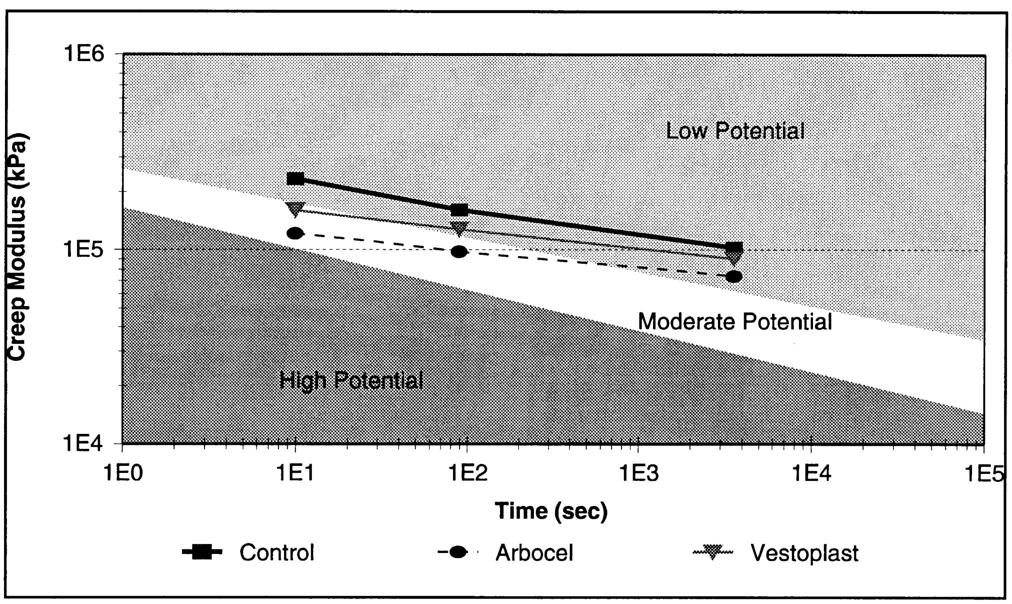

Figure 4. Rutting potential for mixes with high air voids on AAMAS plot

plotted in the area of low rutting potential at both high and low void levels. The Vestoplast mix was primarily in the area of low rutting potential at the low void level, but it was borderline. The Arbocel mix was primarily in an area of moderate rutting potential.

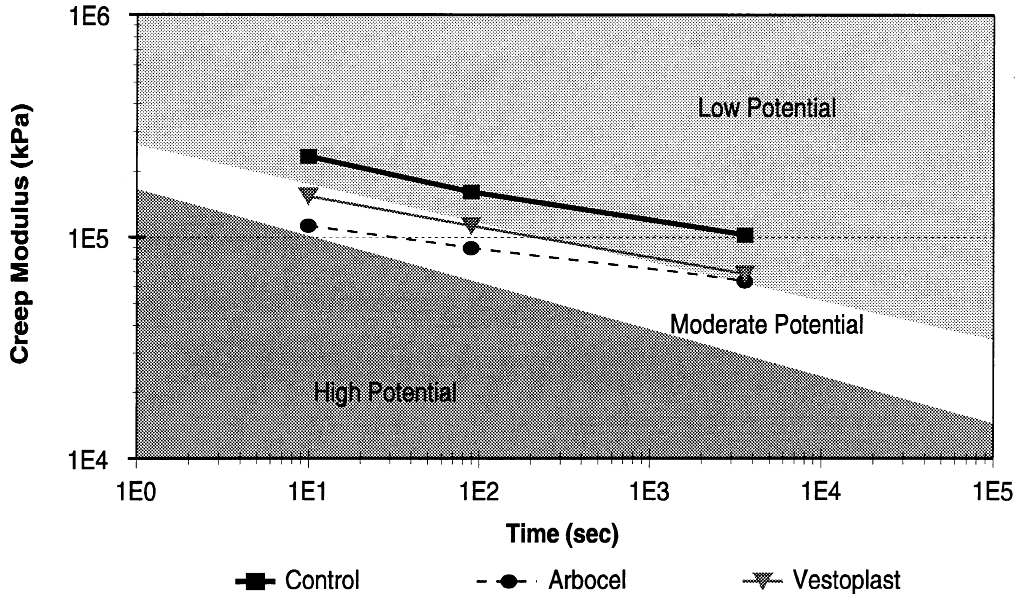

Figure 5. Rutting potential for mixes with low air voids on AAMAS plot

Field Tests

Dipstick

Profile measurements were made with a Dipstick from which rut depths were calculated. Measurements were made immediately after paving to determine if the paver screed left humps or dips. The average hump was less than 1 mm; therefore it was not used to adjust subsequent measurements.

The results of subsequent measurements made after 29 months are shown in Tables 10 and 11. Table 10 shows that the Arbocel mix had more rutting at stop-lights than either the Vestoplast mix or control mix. The maximum rut depths were 16 mm, 4 mm, and 6 mm for the Arbocel, Vestoplast, and control mixes respectively. Rutting between stop-lights was not great for any of the mixes but it was slightly more for the Arbocel mix than for either of the other mixes.

Table 10. Rut Depths Before Stop-Lights Computed from Dipstick Profiles After 29 Months

Mix	Number of meas.	Average, mm		Range, mm	
		Left WP	Right WP	Left WP	Right WP
Arbocel	5	7	8	1 - 10	1 - 16
Vestoplast	4	2	2	0 - 4	0 - 4
Control	2	3	3	2 - 5	0 - 6

Table 11. Rut Depths Between Stop-Lights Computed from Dipstick Profiles After 29 Months

Mix	Number of meas.	Average, mm		Range, mm	
		Left WP	Right WP	Left WP	Right WP
Arbocel	23	3	2	0 - 7	0 - 7
Vestoplast	18	0	1	0 - 2	0 - 4
Control	18	2	1	0 - 4	0 - 7

Friction Tests

Results of friction tests are shown in Figure 6. The friction resistance (number) seemed to gradually increase during the winter and spring of the first year, possibly because of the asphalt film being worn from the aggregate particles by traffic. After the first summer the friction resistance dropped slightly, probably because the mixes densified during high ambient temperatures and lost some of the surface texture. The Vestoplast mix has retained its friction resistance slightly better and visibly has better surface texture than the Arbocel mix.

Performance

Some loss of surface texture started to occur at stop-lights after the first summer of traffic. The problem appeared to be worse in the Arbocel section than in the Vestoplast section. No problem was observed in the control section.

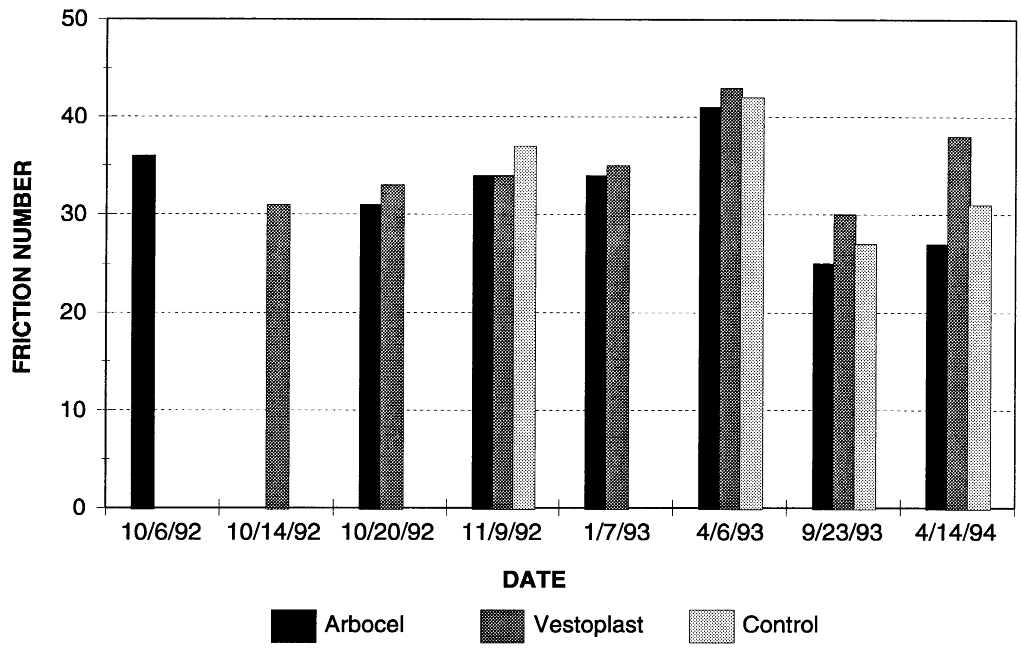

Figure 6. Friction test results

Even though some rutting has developed at stop-lights in the Arbocel test section, all sections are performing well. No cracking was visible in the Arbocel section. Some longitudinal cracking along the center-line of the traffic lane was visible in the control section. This cracking has reflected through from the underlying structure and is not particularly objectionable. Very minor alligator cracking was visible along the shoulder edge for approximately 60 m of the Vestoplast section. This cracking was undoubtedly caused by poor underlying structure.

NCAT Investigation

After one year the SMA developed some bleeding at several of the stop-lights. The co-chairman of the national TWG, E. R. Brown, who is also Director of the National Center of Asphalt Technology, offered to conduct a short investigation in an attempt to determine the cause.

Sets of cores were extracted from both SMA mixes in areas where the surface texture was good and where the surface texture seemed to have diminished by over-densification. NCAT labs tested half of the cores and the state materials lab tested the other half. Brown concluded that the asphalt contents and gradations compared favorably with the job mix.[11] However, the author noted that the gradation was finer than the job mix gradation on all sieves.

Also, voids in the cores and recompacted specimens measured by NCAT were lower than those measured by VDOT. Despite these differences, it is not likely that the three VDOT labs would have all produced faulty measurements during construction. The investigation reported that an AC-20 asphalt cement was used. Asphalt paving experts postulated that possibly a harder asphalt cement was needed. Europe uses soft asphalt but the ambient temperature is lower than in most of our southern states. Most southern states are now using AC-30 or polymer modified asphalt cements.

SUMMARY

Problems were encountered during production that are not experienced with conventional mixes. There was excessive variability of the fines, which could have been prevented by having proper equipment to introduce the fines into the mixture. It has been suggested by the TWG in the SMA guidelines that appropriate equipment should be furnished to accurately proportion the large amounts of mineral filler present in SMA mixtures.

The routine tests indicated excessive variability in the gradation, especially for the 4.75 mm and 0.075 mm sieves. Control of both sizes are critical to production of a consistent mix. The variation in gradation produced variability in the voids of Marshall specimens and created the potential for variability in the finished pavement. Some rutting in the Arbocel mix probably was caused by a combination of high amounts of minus 0.075 mm material and a high design asphalt content.

The gyratory shear test and creep test both indicated that the control and Vestoplast mixes would perform better than the Arbocel mix with respect to rutting. However, all mixes were predicted to have low to moderate rutting potential.

The Arbocel mix has developed more rutting at stop-lights than the other two mixes. Up to 16 mm was observed in the Arbocel mix, while the other mixes had maximum rut depths of 4 to 6 mm. In retrospect, the Arbocel mix would perform well on the open highway but standing loads probably require changes in the mix design as discussed above.

Although some rutting has developed, all mixes are performing well. Minor cracking believed to be caused by the underlying structure is present in the control and Vestoplast sections; however, it may have been accelerated somewhat by the lower binder contents in these mixes.

The friction resistance has decreased due to the loss of surface texture but it is still satisfactory. The Vestoplast mix has the best friction resistance and best surface texture.

Since the construction of this test section, improvements have been made in the specification based upon these findings and the experience of other states. Several of the significant changes have been to coarsen the original specified gradation, require a stiffer asphalt cement than an AC-20, and require plant equipment to adequately handle fines and fibers. A current specification is included in the Appendix. With these changes and additional experience the SMA mix could be more durable than the conventional rut resistant mixes such as the control mix used in this study.

CONCLUSIONS

1. SMA was difficult to produce properly with inadequate equipment to introduce the fine aggregate.

2. Gyratory shear tests and creep tests indicated that the control mix would perform best with respect to consolidation and rutting, followed by Vestoplast and Arbocel mixes.

3. Rut depths were approximately 3 to 4 times greater in the Arbocel mix than in the Vestoplast or control mixes.

4. All mixes continue to perform well although some rutting has developed, particularly in the Arbocel mix. Based upon subsequent experience by Virginia and other states and improvements in the current specification, future installations should perform as well or better than the present dense graded mixes.

ACKNOWLEDGEMENTS

Appreciation is expressed to John K. McEwen, D. H. Grigg, Jr., Robert Wilson and their staff for arranging construction of the test section, providing traffic control, and performing many of the tests contained in this report.

C. R. Abbott and his staff at Lawhorne Bros. Inc. were also very cooperative in trying to provide a quality product, considering it was a new experience for both VDOT and the asphalt paving industry in Virginia.

Michael C. Dudley at the Research Council is commended for conducting the testing and reporting the results in a timely and accurate manner. Special thanks go to R. D. Horan for his encouragement and help throughout the investigation.

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APPENDIX

Current VDOT SMA Specifications

February 23, 1995

Virginia Department of Transportation
Special Provision for the Production and Installation of Stone Matrix Asphalt (SMA)

1. Description:

This work shall consist of furnishing Stone Matrix Asphalt (SMA) bituminous mixture in accordance with Sections 211 and 315 of the current VDOT Road and Bridge Specifications and this Special Provision.

2. Materials:

(a) Coarse Aggregate: Coarse aggregate shall conform to the following requirements:

(1) Los Angeles Abrasion	40% max.
(2) Flat and Elongated Particles	
ASTM D4791 (Measured on No. 4 retained)	
3 to 1	20% max.
5 to 1	5% max.
(3) Magnesium Sulphate Soundness Loss (5 cycles)	15% max.
(4) Particles retained on the No. 4 sieve shall have at least -	
one fractured face	100% min.
two fractured faces	90% min.
(5) Absorption, AASHTO T-85	2% max.

(b) Fine Aggregate: Fine aggregate shall consist of a blend of 100% crushed aggregate. The magnesium sulphate soundness loss in 5 cycles shall not exceed 20 percent.

In addition the liquid limit shall not exceed 25 as determined by AASHTO T-89.

In addition the liquid limit shall not exceed 25 as determined by AASHTO T-89.

(c) Asphalt Binder: Asphalt binder shall be Strategic Highway Research Program (SHRP) Performance Graded (PG) Binder PG76-22. The supplier shall certify to the Department that the binder meets all the properties of that grade. This certification shall be based on testing performed on samples of the binder that is provided to the paving contractor for incorporation into the mixture. Certification based on testing performed on laboratory produced binders will not be acceptable. The formulation and PG grading of the binder will be submitted to the Department's Central Materials Division by the supplier at least 15 days prior to production of the SMA mixture for approval. The information supplied shall include the following:

(1) the source and the PG grade of the base asphalt (prior to modification)

(2) a general description of the modifier that will be used and the dosage

(3) a description of the blending, hauling and storage procedure

(4) test results for each of the standard specification properties for the modified binder.

During production, independent third party testing to determine the PG grade will be performed on samples taken from storage at the hot mix asphalt plant as directed by the Engineer. The Department will be responsible for selecting the independent laboratory from the Department's approved list and paying for all shipping and testing expenses. The contractor will be responsible for obtaining the sample of binder when requested. In the event that it is determined that the binder does not meet the requirements further testing indicates that the problem has been corrected.

(d) Mineral Filler: Mineral filler shall consist of finely divided mineral matter such as rock or limestone dust or other suitable material. At the time of use it shall 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. Baghouse fines added to the mixture will be limited to only fines produced during the production on the SMA.

(e) Fiber Additive: An approved fiber, either cellulose or mineral, shall be utilized unless the specified minimum draindown can be routinely maintained using a modified binder without the addition of fiber. Dosage rates for cellulose is 0.3% by weight of the total mixture, and for mineral fiber is 0.45 by weight of total mixture. Allowable tolerances of fiber dosage shall be ± 10% of the required fiber weight.

Fibers will be accepted based on the manufacturer's certification.

CELLULOSE FIBER PROPERTIES

- Sieve Analysis

Method A: Alpine Sieve[1] Analysis		
Fiber Length:		0.25" (max.)
Passing No. 100 Sieve	70%	(± 10%)
Method B: Mesh Screen[2] Analysis		
Fiber Length:		0.25" (max.)
Passing: No. 20 Sieve	85%	(± 10%)
No. 40 Sieve	65%	(± 10%)
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) x fiber weight
- Moisture Content[6]		< 5%

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[1] Method A: Alpine Sieve Analysis. This test is performed using an Alpine Air Jet Sieve (Type 200 LS). A representative five gram sample of fiber is sieved for 14 minutes at a controlled vacuum of 22 inches (± 3) of water. The portion remaining on the screen is weighed.

[2] Method B: Mesh Screen Analysis. This test is performed using standard No. 20, 40, 60, 80, 100, and 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.

[3] Ash Content: A representative 2-3 gram sample of fiber is placed in a tared crucible and heated between 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 let 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 five 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 ten minutes (approximately 1 1/4 inch motion at 20 shakes/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 250 F forced air oven for two hours. The sample is then reweighed immediately upon removal from the oven.

MINERAL (BASALT) FIBER PROPERTIES

- Size Analysis:

Fiber Length[7]	10.04 inches (average)
Thickness[8]	0.0002 inches (average)

- Shot Content[9]:

No. 60 Sieve	90% passing (minimum)
No. 230 Sieve	70% passing (minimum)

3. Composition of the SMA Mixture:

The SMA mixture shall conform to the requirements listed in Table A and Table B. One percent hydrated lime shall be required as an antistripping additive. An alternative antistripping additive can only be used if approved by the Engineer.

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

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

[9] 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.

TABLE A. SMA DESIGN RANGE AND PRODUCTION TOLERANCE

Sieve	Design Range - Percent Passing		Production Tolerance ± %
	Surface Mixture	Intermediate Mixture	
1"	100	100	---
3/4"	100	85-95	5 (Intermediate only)
1/2"	85-95	50-60	5
3/8"	75 max.	3-45	5
No. 4	20-28	---	3 (Surface only)
No. 8	16-24	16-24	3
No. 30	12-16	12-16	3
No. 200	8-10	8-10	2
0.020 mm	3.0 max.	3.0 max.	*
Asphalt Content	6.0% min. **	5.5% min. **	0.3
* Samples of the material shall be tested by VDOT periodically during production to ensure compliance with the 0.020 mm specification.			
** During production, the plant shall be calibrated and operated to produce the design asphalt content.			

TABLE B. SMA MIXTURE REQUIREMENTS

	Design Values		Production Tolerances
	Surface Mixture	Intermediate Mixture	
VTM, percent	4.0	4.0	2.5 - 5.5
Asphalt content, percent	6.0 min.	5.5 min.	
VCA, percent	$< VCA_{DRC}$	$< VCA_{DRC}$	
VMA, percent	17.0 min.	16.0 min.	
Stability, lbs.	1400 min.	1400 min.	
Flow, 0.01 inch	8 - 16	8 - 16	
Compaction, # blows on each side	50	50	
Draindown, percent	0.3 max.	0.3 max.	
Note: Mix design procedures and calculations of stability, flow and volumetrics in accordance with VTM-57, 58, and 99 (Design of SMA Mixtures). Draindown testing in accordance with VTM-100 (Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures).			

4. SMA Mixing Plant:

Plants used for the preparation of the SMA mixture shall conform to the following:

(a) Handling Mineral Filler:

Adequate dry storage shall be provided for the mineral filler that will, at a minimum, consist of a waterproof cover that will completely cover the stockpile(s) at all times. Provisions shall be made for metering of 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 in the drum mixer. Equipment shall be capable of accurately and uniformly metering the large amounts of mineral filler (up to 25 percent of the total mix).

(b) Fiber Addition:

Adequate dry storage shall be provided for the fiber additive, and provisions shall be made for accurately and uniformly metering fiber into the mixture at plus or minus 10% of the desired quantities.

Introduction of loose fiber shall require a separate supply system that can accurately proportion, by weight, the required quantity of fiber in such a manner to ensure a consistent, uniform blending into the mixture at all rates of production and batch sizes. This supply system shall be interlocked with the other feeding devices of the plant system and sensing devices shall provide for interruption of mixture production if the introduction of fiber fails.

Batch Plant:

Loose fiber or pelletized 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. Therefore, dry mixing time shall typically be increased 5 to 15 seconds. Wet mixing time shall typically 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.

When loose fiber is used, the fiber supply system shall include low level and no flow indicators and a printout of the date, time and net batch weight of fiber.

Drum Mix Plant:

Pelletized fiber shall be added directly into the drum mixer through the RAP inlet. Operation of the drum mixer will be such to ensure complete blending of the pelletized fiber into the mix.

When loose fiber is used, the fibers shall be added so as not to be entrained into the exhaust gases of the drum plant. The fiber supply system shall include low level and no flow indicators and a printout of status of feed rate in lb./min.

(c) Hot Mix Storage:

When the hot mixture is not to be hauled immediately to the project and placed, suitable bins for storage 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 longer than 12 hours.

(d) Mixing Temperatures:

Typical plant mixing temperature shall be 310 - 325 F and at no time shall the mixing temperature exceed 350 F.

5. Weather Restrictions:

Placement of the SMA mixture shall be permitted only when the ambient and surface temperatures are 50 F or above.

6. Placing and Finishing:

The mixture temperature, which shall be measured in the truck just prior to dumping into the spreader, shall not be less than 290 F.

Due to the nature of SMA mixtures, a continuous paving operation that provides for constant steady movement of the paver shall be maintained. In the event that excessive stop and go of the paver is occurring, production and laydown of the mixture shall be stopped until the contractor has made satisfactory changes.

A Materials Transfer Vehicle shall be used during the placement of the SMA surface mix.

7. Compaction:

Immediately after the mixture has been spread and struck off, it shall be thoroughly and uniformly compacted by rolling. After the first roller pass, the mixture shall be adequately stable such that subsequent rolling does not cause visually detectable materials movement. The SMA mixture shall be rolled immediately. The initial roller pass shall be accomplished with steel wheel rollers with a minimum weight of 10 tons operated in the static mode. Subsequent rolling shall be accomplished with steel wheel rollers operated in the static mode unless otherwise approved by the Engineer.

Rolling procedures should be adjusted to provide the specified pavement density. rollers shall move at a uniform speed not to exceed 3 mph with the drive wheel nearest the paver. Rolling shall be continued until all roller marks are eliminated and the minimum density has been obtained. 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.

To prevent adhesion of the mixture to the rollers, it shall be necessary to keep the wheels properly moistened with water possibly mixed with very small quantities of detergent or other approved material. Acceptance testing will be performed by the contractor by obtaining core samples of the compacted material and determining in-place density according to VTM-6. Four cores representing each day's production shall be taken by the Contractor at random locations specified by the Engineer. The average density of the four cores shall be at least 94% of maximum density as measured by VTM-6 and AASHTO

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In the event that the compaction operation is inadequate to provide for specified pavement densities or prompt compaction rolling, production may be stopped until the Contractor has made satisfactory changes to address these deficiences.

8. Trial Section:

Test sections, for both the intermediate and surface mixes, a minimum of 250 tons each, shall be constructed off site at least a week before roadway construction at the direction of the Engineer to examine the mixing plant process control, mix characteristics, placement procedures, SMA surface appearance, compaction patterns and to calibrate the nuclear density device.

The material placed in the trial sections will be at the specified application rate and shall be paid for at the contract unit price.

9. Prepaving Conference:

A prepaving conference shall be held prior to starting production. Those attending shall include the Contractor's production supervisor and laydown supervisor and a representative of the fiber supplier.

10. Measurement and Payment:

The measurement and payment of the stone matrix asphalt will be measured in tons and paid for at the contract unit price in tons, which shall include all materials, additives, and equipment as described herein. Placement and compaction shall be in accordance with Section 315 of the Road and Bridge Specification except as amended herein.