COMMONWEALTH OF VIRGINIA'S (USA) IMPLEMENTATION OF STONE MATRIX ASPHALT

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ABSTRACT

Like most transportation agencies, the Virginia Department of Transportation (VDOT) strives to provide a smooth, long-lasting, cost-effective highway system. For decades, research funds have been spent on developing and/or enhancing pavement structures and paving materials. In the last 15 years, VDOT's asphalt program has evolved from the Marshall process to the SUPERPAVE® Mix Design system. Prior to implementation of the SUPERPAVE® system, VDOT began experimenting with Stone Matrix Asphalt (SMA). VDOT's first SMA specifications were based on the American Association of State Highway and Transportation Officials (AASHTO) guide specifications developed after American transportation officials toured Germany in the early 1990's. These early specifications were used on several demonstration sections in various parts of the state. In 1995, VDOT had its first successful high-profile SMA project on Interstate 95. Later in 1995, a second high-profile project was constructed over deteriorated jointed concrete pavement. These projects and their performance set the stage for a large-scale implementation effort. In 2002, a full implementation plan was outlined and in 2003 over 181,000 tonnes of SMA was placed on Virginia's Interstate and Primary road networks. Since then, vast amounts of performance and material information has been collected. This paper will outline the performance of SMA, the changes in material specifications, and the lessons learned. Clearly, SMA is a superior asphaltic material. The additional binder provides long-term durability; the stone skeleton resists deformation. However, great care must be taken in each stage of SMA deployment – planning, producing and placing SMA. A lack of attention to detail in any stage will result in an unacceptable product.

1. INTRODUCTION

Like most transportation agencies, the Virginia Department of Transportation (VDOT) has strived to provide a smooth, long-lasting, cost-effective highway system. For decades, research funds have been spent on developing and/or enhancing pavement structures and paving materials. Through the Strategic Highway Research Program sponsored by the United States and Canadian governments, numerous advances with hot mix asphalt (HMA) and Portland cement concrete were made. The more prominent advances in HMA were the performance graded (PG) binder system and the SUPERPAVE® mix design system. With these new approaches to HMA, VDOT's asphalt program evolved from the Marshall process to the SUPERPAVE® Mix Design system. At the same time PG binder and SUPERPAVE® implementation began nationally, North American pavement and materials engineers were looking for the next "new" material.

1.1 Background

In 1990, a European Asphalt Study Tour was organized to identify technologies that could be transferred to the United States. While in Germany, the tour participants discovered a relatively new asphalt material – Stone Matrix Asphalt (NAPA, 1994). Used on German roads such as the Autobahn for decades, this material "show(ed) promise as a tough, stable, rut-resistant surface mix in certain applications." Intrigued by the reported properties of SMA, VDOT and other transportation agencies began experimenting with SMA on demonstration projects using guideline specifications developed by the American Association of State Highway and Transportation Officials (AASHTO).

The first SMA trail section in the Commonwealth of Virginia was placed in 1992. With no experience and only a guide specification, this section was a failure. Problems with production and placement plagued the initial project. However, instead of walking away from SMA, VDOT and industry officials learned from this experience. In 1993, a second SMA demonstration project was conducted on an interstate highway. Deemed successful (planning, production and placement), VDOT developed two major contracts for the 1995 paving season. One contract was to overlay SMA on a deteriorated composite pavement (HMA on jointed concrete) and the other was to overlay a deteriorated jointed reinforced concrete pavement. Again, these projects were successful and over the next seven years, VDOT awarded contracts for more than 545,000 tonnes of SMA for placement on deteriorated interstate pavements (Clark, 2006).

1.2 Scope of Paper

By 2002, VDOT had implemented the PG binder and SUPERPAVE® system. Initial problems with these new systems were rectified by modifying specifications to meet Virginia's materials. In contrast, except for a specification change in 1999 from the Marshall hammer to the SUPERPAVE® gyratory compactor, SMA had seen little change since the early 1990's. Nonetheless, this "new" material was outperforming conventional dense-graded HMA. This paper presents the evolution of the specifications, discusses the performance of SMA (new and older mixes), and offers some lessons learned in SMA production and placement.

2. EVOLUTION OF THE SPECIFICATIONS

With any new process, a set of specifications were required. This was no different with SMA. After the European Asphalt Study Tour, a set of guidelines were produced by AASHTO and later published in a document by the National Asphalt Pavement Association in 1994 – *Guidelines for Materials, Production, and Placement of Stone Matrix Asphalt (SMA)*. This document was used by many transportation agencies experimenting with SMA. Based on the Marshall hammer compaction approach, specifications on aggregate properties, minimum asphalt content, and volumetrics (Voids in Total Mix and Voids in Mineral Aggregate) were provided. To help ensure material durability, an asphalt content of 6 percent minimum was required. For the aggregate, gradation ranges and minimum flat to elongated ratios were specified to create a stone skeleton for rut resistance. Finally, only one mix was provided – a SMA surface mix. By today's standards, a very-coarse surface mix with 85 to 95% passing the 12.5 mm sieve. This AASHTO specification, modified for Virginia conditions in 1995, was used until 1999 on nine different projects. Table 1 contains some of the important design aspects of the SMA mixes.

Unique to Virginia in the 1990's was the development of a SMA intermediate or binder mix. The AASHTO specification only contained a surface mix; no intermediate SMA mixes were known to be used in Germany. However, with the impending overlay of a deteriorated jointed reinforced concrete pavement, VDOT wanted a SMA style intermediate mix in addition to the surface mix. The desire was to reduce the effects of reflective cracking and raveling common with conventional HMA. Following the SMA design philosophy, a larger-stone mix was specified with a minimum AC content of 5.5%. (See Table 1 for more details).

In 1999, VDOT was in the process of transitioning from the Marshall hammer to the SUPERPAVE® gyratory compactor for dense-graded HMA. To reflect this shift in mix design, the SMA specifications were modified. Only three major changes were made – replacing the 50 blow compaction with 100 gyrations, adding a minimum VMA for the intermediate mix, and requiring cores for determination of density. (See Table 1)

Soon after these changes, VDOT began examining the stone gradations. As noted earlier, the initial SMA surface mix was very coarse and prone to permeability problems. Using material obtained in Germany after a 1995 trip, the Maryland State Highway Administration (MDSHA) adjusted their gradations to create a 12.5mm and a 9.5mm maximum nominal aggregate size surface mix. Seen as a lead state (Maryland) in SMA implementation, VDOT started adjusting their specifications to mirror Maryland. In 2002, VDOT changed the existing surface mix gradations as well as added a second, finer surface mix similar to the MDSHA mixes (Schreck, 2005). With these changes, the AC content was increased to fill void space and the minimum VMA was increased (see Table 1). Finally, SMA mixes were designated based on the maximum nominal aggregate size and the PG binder specified. For example, a surface mix with a 12.5mm maximum nominal aggregate size and a PG 76-22 binder would be designated as SMA-12.5(76-22).

As will be discussed later in this paper, several problems occurred during the 2003 SMA paving season. Some of these problems were related to VDOT’s and contractor’s inexperience with SMA; however, some issues arose from the 2002 specification. The main issue with the specification was the minimum design AC content. For many aggregates in Virginia, having a design AC content of 6.5 or 6.8 percent was not a problem given the specific gravity of the material (2.400 – 2.600). But, in the northern part of the state, aggregates are much heavier (2.900 – 3.000) and achieving the minimum AC content without jeopardizing other volumetric properties was a challenge. Several contractors had to reduce the amount of material passing the 4.75mm (#4), 2.36mm (#8) and 75µm (#200) sieves to meet the minimum AC requirement. With a lack of fine material to bond to the liquid asphalt, a stable mastic was not formed and flushing occurred. Therefore, the specification was changed to allow for lower AC contents when heavier stone was used. (See Table 1, 2003 column).

During the 2004 paving, fewer problems during production and placement were encountered. This was a reflection on the experience gained in 2003. However, VDOT and Industry officials were still concerned with the AC content and gradation of many SMA mixes. It was decided to reduce the AC content for all surface mixes to 6.3 percent. This would give the contractor freedom to design a mix based on their aggregates and not risk mix durability. In addition to AC content, several sieve gradation bands were adjusted to increase the fines in the mix – particularly the 75µm sieve. Extra fine material and dust was desired to bond with the liquid asphalt to minimize flushing and improve skid resistance (initial and long term). Finally, the number of design gyrations was reduced from 100 to 75. This was done to better replicate common practice during mix production. With a 15 percent or greater penalty for not meeting the minimum field density, many contractors would produce SMA at 2.0 percent VTM (design VTM was 3.0 percent). For VDOT, this created concerns with flushing and reduced skid resistance. By reducing the design gyrations and adjusting the aggregate gradations, contractors would not have to produce a “tighter” mix during production compared to design (See Table 1, 2004 column).

Table 1. SMA Specification Summary.

Mix Parameter	1995	1999	2002	2003	2004
Asphalt Content Surface Intermediate	6.0 5.5	6.0 5.5	6.5(12.5mm) 6.8(9.5mm) 5.5	6.3(12.5mm) 6.5(9.5mm) 5.5	6.3(12.5mm) 6.3(9.5mm) 5.5
Compaction	50 Blows	100 Gyrations	100 Gyrations	100 Gyrations	75 Gyrations
Design VTM	3.5	3.5	3.0	3.0	3.0
Production VTM Range Surface Intermediate	2.5 - 4.5 -	2.5 – 4.5 -	2.5 – 4.5 2.0 – 4.0	2.5 – 4.5 2.0 – 4.0	2.5 – 4.5 2.0 – 4.0
Design VMA Surface Intermediate	17.0 -	17.0 16.0	18.0 17.0	18.0 17.0	18.0 17.0
Air Temperature	10º C	10º C	10º C	10º C	10º C
Density	94%	94%	94.0 %	94.0 %	94.0 %
Density Test Mode	Nuclear/Core	Core	Core	Core	Core
Number of Tests Rolling Mode Number Speed	10/4 Static 3 Rollers (95) 3 MPH	4 Static 3 Rollers 3MPH	5 Vibratory or Static 3 Rollers 3 MPH	5 Vibratory or Static 3 Rollers 3 MPH	5 Vibratory or Static 3 Rollers 3 MPH
Mineral Filler	70% Passing 75µm	70% Passing 75µm	55% Passing 75µm	55% Passing 75µm	55% Passing 75µm

Clearly, VDOT’s SMA specifications have evolved over a decade. In the last five years, rapid changes based on field data, laboratory results, and expert opinion have been made to address production and placement problems. However, it is important to remember, the number of changes were expected given the growth of the SMA program. Between 2003 and 2005, SMA placement increased from just less than 180,000 tonnes to over 410,000 tonnes.

3. PERFORMANCE OF SMA

The average life of a dense-graded HMA surface was approximately 8 years in Virginia. Of course, the actual life varied based on the traffic levels experienced by the pavement. On the interstate system, many dense-graded mixes last less than 8 years due to fatigue cracking, reflective cracking, and/or rutting. Given the short life of dense-graded HMA and the need to reduce user delay/cost, SMA had been selected for use on most high-volume routes (AADT > 20,000).

To monitor the performance of SMA, VDOT has been tracking the ride quality and skid resistance of several sites for many years. Sites paved prior to 2003 were monitored as part of a statewide pavement assessment program; sites paved from 2003 on have been tested on a routine basis to track incremental changes and seasonal effects.

3.1 Pre-2003 SMA Mixes

Prior to 2003, SMA had only been used on interstate routes as a maintenance overlay to improve structural and functional pavement performance. SMA had not been used on any new construction projects. Of the initial 16 projects, only three have been replaced. The first interstate test section (laid in 1994) was replaced in 2005 as part of a larger reconstruction project; the second section (laid in 1995) was milled and replaced in 2005; the last section (laid in 1995) was partially milled and replaced in 2004. All three sections had exceeded the average HMA service life and none of the remaining 13 projects were planned to be removed or overlaid.

In July 1996, VDOT overlaid a section of continuously reinforced concrete pavement (CRCP) near Richmond (I-295) in two lifts – 50mm dense-graded intermediate HMA and 37.5mm SMA surface mix. Over 29,000 tonnes of SMA was placed over 8 travel lanes. The CRCP was in poor condition due to numerous structural failures. Since the patching and overlay, the SMA has remained in “very good” to “excellent” condition. Cracking sealing of the longitudinal joints and patching CRCP failures has been the only maintenance performed. Figure 1 tracks the ride quality for this section from initial construction to 2004. While the roughness has increased 23 percent since placement, the overall ride quality has remained excellent.

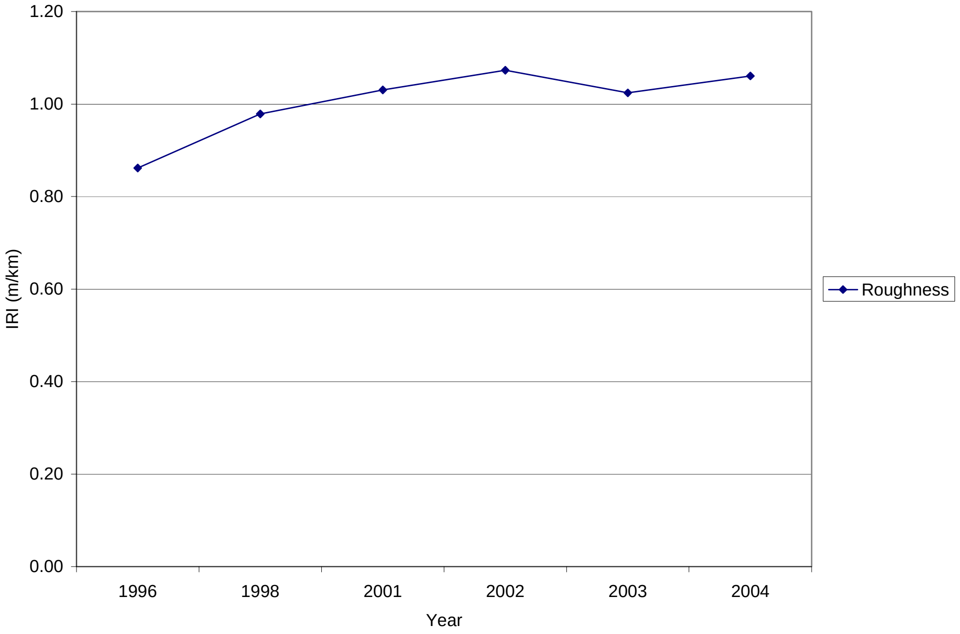

Figure 1. I-295 SMA Ride Quality.

With the implementation of SUPERPAVE® mixes in the late 1990’s and specification modifications in 2000, VDOT was concerned about the skid resistance due to the higher AC content. VDOT began a routine testing program to monitor the changes in friction over seasons and time. When this program began, several SMA projects had been recently completed and were added to the testing schedule. VDOT uses an ASTM E-274 locked-wheel trailer with an ASTM E-524 blank/smooth tire for friction testing. Figure 2 compares the skid resistance of SMA to conventional SUPERPAVE® mixes (Clark, 2006). SM-9.5A, SM-9.5D, SM-12.5A and SM-12.5D are SUPERPAVE® surface mixes. Values less than 20 are considered a safety concern. Despite the higher film thickness that is a SMA characteristic, it provides skid resistance equivalent to dense-graded HMA.

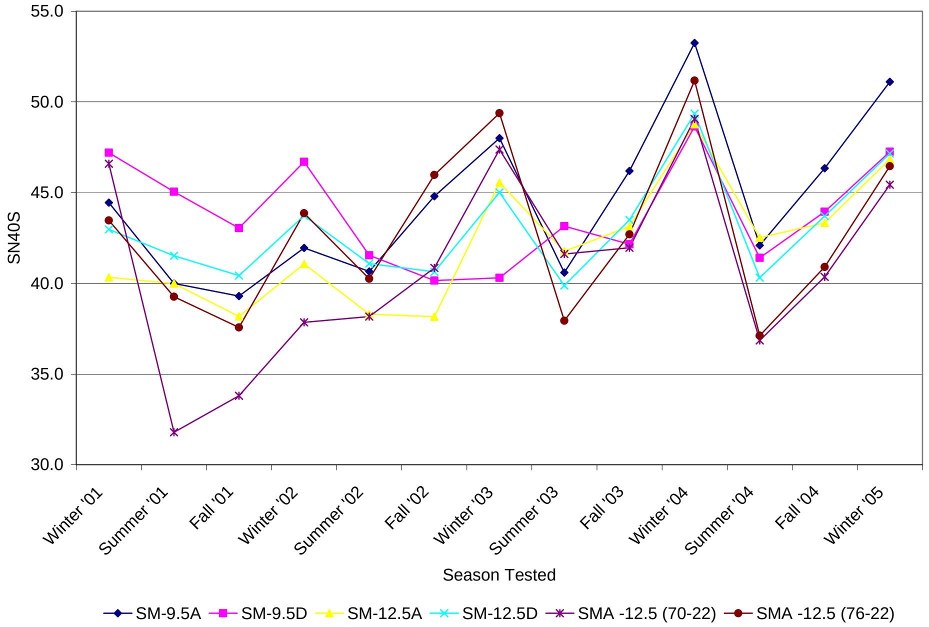

Figure 2. SMA and SUPERPAVE® Friction Change.

3.2 New SMA Mixes (2003 – 2005)

As discussed earlier, VDOT made major specification changes starting in late 2002. A vast amount of laboratory testing was conducted by VDOT and contractors developing mix designs and testing aggregate sources. However, once the mix designs were approved and trial sections accepted at the project, field testing was initiated. Two main elements affected the contractor's pay for SMA – field density and ride quality. These two elements were used to adjust the percentage of payment. A third element, skid resistance, could also be used for material acceptance. If a section of SMA was found to have unacceptable skid properties, then the contractor would have to remove and place at their expense. While the field density will not be covered in this paper, the skid resistance and ride quality of these new SMA mixes will be summarized.

In 2003, the initial concern was skid resistance due to the higher minimum AC content. A recurring question was "Would the pavement be slick?" The visual appearance (shiny and glaring depending on the angle of the Sun) of the first few projects led to immediate friction testing activities. These activities were expanded initially to all SMA sites. As expected, no sites exhibited dangerously low initial surface friction and as the asphalt film wore off, the skid resistance continued to increase. However, concerns still existed with some of the friction results. In particular, the SMA-9.5 mixes had much lower initial friction values and showed a larger seasonal shift compared to the SMA-12.5 mixes (see Table 2). These concerns led to some of the specification changes discussed earlier.

Table 2. Skid Testing Results for 2003 SMA Sites.

	Month and Year Tested							
	2003			2004			2005	
SMA Mix	**Oct**	**Nov**	**Dec**	**Feb**	**May**	**Sept**	**Jan**	**Jul**
SMA 9.5(70-22)	34.0	38.3	46.4	46.1	49.4	39.5	45.3	37.8
SMA 12.5(70-22)	42.9	43.4	46.5	47.6	49.9	46.7	47.9	46.0
SMA 12.5(76-22)	45.7	44.9	47.4	50.6	52.2	46.2	51.2	49.7
All Mixes	42.1	43.5	47.0	49.0	51.1	45.7	49.4	46.9

Based on SMA projects prior to 2003, contractors demonstrated the ability to lay smoothly a coarse surface mix. Therefore, with the new finer gradations, VDOT anticipated similar or better results. For the SMA laid in 2003, the average International Roughness Index (IRI) value was approximately 1.0 m/km for the SMA-9.5(70-22) and the SMA-12.5(76-22) mixes. The ride quality was a little worse for the SMA-12.5(70-22), which averaged 1.2 m/km (see Figure 3), but all three mixes were equivalent in ride to dense-grade HMA. After further analysis of the data, contractor experience with SMA was the major factor in the ride quality. In 2004, most contractors had one or more years of experience producing and placing SMA. This experience was reflected in the overall roughness reduction from 1.04 to 0.98 m/km. Only the paving sites with SMA-9.5(70-22) were slightly rougher. The 2005 paving season saw a large expansion of the SMA program. More the 410,000 tonnes of SMA were contracted across the Commonwealth with several contractors placing SMA for the first time. Again, the overall initial ride quality was approximately 1 m/km – a slight increase from 2004. This increase was due to the jump in initial roughness on sites paved with SMA-12.5(76-22). In contrast, the sites paved with SMA-9.5(70-22) and SMA-12.5(70-22) were significantly smoother. For these mixes, the improvement was an indication of contractor's gaining knowledge of SMA production and placement. Further investigation of the SMA-12.5(76-22) sites discovered problems with the contractor's placement operations. Overall, SMA could be placed smoothly and subsequent testing by VDOT has shown these mixes remain smooth over time.

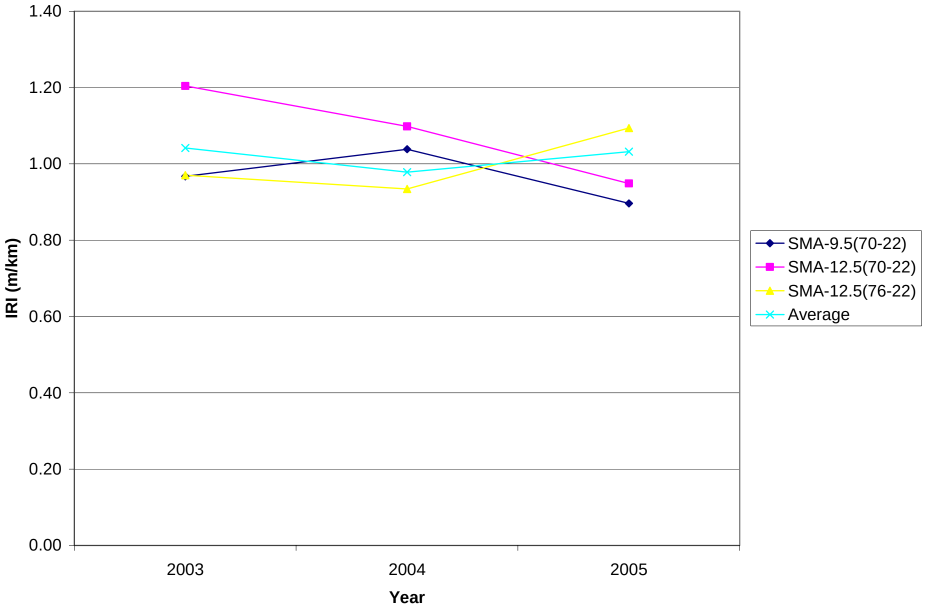

Figure 3. Average IRI by SMA Mix.

4. PROBLEMS ENCOUNTERED AND LESSONS LEARNED

The expanded implementation of SMA since 2003 has included numerous success stories. The overall ride quality has been "very good" to "excellent" and the surface friction has not been a concern. While each project may have experienced one or two localized glitches, only a few problems were encountered on a more general basis. The following sections identify those global problems, list probable/possible causes for each problem, and the lessons VDOT and the paving industry learned to eliminate/mitigate those problems.

4.1 Production Issues

4.1.1 Additive

The high liquid asphalt content of SMA mixtures typically requires the use of a fiber additive to suspend the addition liquid during transport and placement (i.e., prevent drain-down). Adding fiber at the plant presents a unique challenge. It requires the use of a “fiber dispersion” machine that was interlocked into the plant control system. Essentially, when the fiber machine either runs out of fiber material or breaks, the plant was shutdown automatically. This creates two distinct problems. One problem was equipment breakdown, which could be expected but resulted in lost production. The other problem encountered was clogging of the feed line for the fibers. The cause was typically the result of a “kinked” line, which would not allow flow of the fibers. In order to reduce the possibility of this happening, it was recommended that the amount of bends in the line be minimized. In addition, a clear piece of tube can be strategically placed in the line to assure visually that the fibers were flowing freely.

Reduction or loss of fiber additive to the mix resulted in excess liquid asphalt in the mix not able to bind to the aggregate – effectively reducing the mixes AC content. In the field, this resulted in two different conditions. One, “drain down” or excessive asphalt binder flowing to the bottom of the mix in the truck or on the mat occurred. When the gate of the truck was released, the excess asphalt binder flowed onto the ground. Once placed on the ground, the asphalt binder puddled around the mix. The second problem was flushing. After placement, the excess liquid rose to the surface and created a safety problem due to reduced skid resistance. Picture 1 illustrates the results of fiber loss in the mix.

Picture 1. “Drain Down” Due to Lack of Fibers.

4.1.2 Mineral Filler

Mineral filler was used in conjunction with the binder to form an asphalt mastic/mortar. The material was a very fine graded material that had a tendency to retain moisture. Therefore, it was very important to store this material in a manner to reduce the chance of moisture infiltration. Typically, Contractors used tarps to cover the mineral filler stockpile. Although the tarps work when covering the stockpiles, there were occasions when during production, a rainstorm occurred before the stockpile could be covered. Once the material became wet, it was very difficult and in some cases impossible to dry it to a point where it would not be detrimental to the mix. Wet mineral filler led to flushing of the asphalt (see Picture 2). Not only was this undesirable for the mix, but led to reduced friction properties and safety concerns. In many cases, the SMA was removed and replaced. For small areas, diamond grinding of the SMA was performed to remove the AC film and increase friction. To mitigate the possibility of having mineral filler become wet, some contractors utilized sheds to store the mineral filler.

Picture 2. Flushing Due to Wet Mineral Filler.

<u>4.2 Placement Issues</u>

4.2.1 Flushing Pavement

In producing SMA, it was common to have what are called “fat-spots” in the pavement. These “fat-spots” were evidence of localized flushing of the mix. As a general rule, an occasional fat-spot the size of a dinner plate was considered acceptable. If the fat-spots became larger than a dinner plate or excessive in number, then an investigation into the mix and placement operation was done to determine the cause. The immediate attention and correction, as warranted, of these areas was required due to the possibility of reduced skid resistance. A recommended practice when starting to produce SMA was to discard the first loads of material in order to allow the plant to “settle.” The number of loads that were discarded ranged from three to six before shipping material to the road.

As mentioned before, it was important to keep the mineral filler dry. If the mineral filler became wet and was introduced into the mixture, the moisture prevented the asphalt liquid from adhering to the mineral filler and the excess liquid worked upward and became part of the finished surface. The result was flushed areas of various extents, and a consequential loss in supplied friction. Based on a VDOT investigation of a flushed pavement as seen in Picture 2, wet mineral filler was determined to be the main cause.

4.2.2 Roller Pick-up

Roller pick-up with SMA can easily happen due to the “sticky” asphalt mastic and high mix temperature (150º C) at time of placement. Therefore, it was essential to have a properly operating spray bar on the roller and to ensure that there was adequate water supply. Some contractors indicated that they had added powdered soap to the water to prevent the mixture from sticking to the roller. Even in doing so, there were cases of roller pick-up on SMA. In these situations, it was important to stop the roller, clean it, and check the water supply. Continuing on without cleaning resulted in additional pickup and a marred surface.

4.2.3 Fractured Aggregate

Currently, VDOT specifications allow for no more than three vibratory passes in the highest frequency, lowest amplitude mode. For most projects, the standard number of vibratory passes was two. There were some cases where the roller was set in the high frequency, high amplitude setting or more than three vibratory passes were used to try to achieve density. In these cases, the result was fractured aggregate. If the fracturing of the aggregate penetrates beyond the surface, then the load carrying capability of the mix has been compromised through destruction of the stone skeleton.

5. CONCLUSIONS

Over the last 15 years, the stone matrix asphalt technology transferred from Germany to the United States has had a tremendous influence on transportation agencies. In the Commonwealth of Virginia, this impact has been seen on interstate highways and other high-volume routes. The initial SMA specifications provided surface mixes with service lives that significantly exceeded conventional HMA mixes. With subsequent trips to Germany and review of other transportation agency specifications, major revisions to the specifications started in 2002 with the adjustment of aggregate gradations and the addition of a second surface mix. Over the next three years, VDOT and industry made several more improvements to the specifications. These enhancements addressed the problems documented during production and/or placement of the new SMA surface mixes. Even with these problems, contractors demonstrated the ability to provide a superior asphalt product. SMA ride quality was as good as or better than dense-graded HMA. Friction properties of SMA, like dense-graded HMA, fluctuated with the seasons – but remained well above the minimum threshold. Based on these functional properties and long-term (demonstrated and expected) structural performance, SMA has become the premier asphalt paving material in Virginia.

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