EVALUATION OF STONE MATRIX ASPHALT (SMA) FOR AIRFIELD PAVEMENTS

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INTRODUCTION

Stone Matrix Asphalt (SMA) was developed in Germany over 30 years ago. Its success has led to its usage throughout Europe on both highway and airfield pavements. In 1990, an AASHTO led European Asphalt Study Tour introduced SMA to the United States (U. S.) SMA has demonstrated good performance on highway pavements in the U. S., but has seen little use on airfields. Recently, there has been resurgence in interest in SMA in the U. S. as a more durable paving option than Superpave or other dense-graded mixes.

SMA is a gap-graded asphalt mixture with a high percentage (> 70 percent) of coarse aggregate. Gap-graded refers to the fact that SMA mixtures typically have very little material retained on the sand size sieves (e.g. between 2.36 mm and 0.075 mm). SMA is differentiated from dense-graded mixes by its coarse aggregate skeleton, consisting of a limited number of particle sizes, which carries the load. Mastic, consisting of mineral filler, fibers, and asphalt binder, fills the voids between the coarse aggregate skeleton. The percentage by weight passing the 0.075 mm sieve is typically greater than 8 percent. Asphalt contents range from 6 to 7.5 percent by weight of total mix. Fiber, either cellulose or mineral, is generally added to prevent draindown of the binder during construction.

SMA has been used extensively on airfields in both China [1] and Norway. Additionally, airfields have been constructed using SMA in Australia, Belgium, Germany, Italy, Mexico, and the United States (U.S.). Additional details on specifications and individual projects are provided in reference [2]. The U.S. Air Force constructed SMA runways in Germany and Italy [3, 4].

OBJECTIVE AND SCOPE

This project evaluated SMA for use on airfield pavements. There are several unique differences between highway and airfield pavements which may affect the performance of SMA on airfields. Specific concerns include potential for acceptability of grooving, foreign object damage (FOD), resistance to deicing chemicals, resistance to fuel spillage, rubber build up, skid resistance, and winter maintenance requirements. Where possible, these concerns were addressed within the research. Performance of the SMA was compared to dense-graded P401 mixes designed using the same aggregate sources.

MATERIALS

The coarse aggregate for SMA mixtures needs to be angular (crushed), cubical, and hard. Although some specifications require 100 percent crushed particles, AASHTO MP-8 [5] only requires 90 percent two-crushed faces, determined according to ASTM D5821. This seems to be a reasonable specification since it would potentially allow the use of crushed gravel sources.

There is an interaction between the percent of flat and elongated particles and aggregate breakdown. With the exception of Georgia DOT, all of the specifications which specified flat and elongated particles specified a maximum of 5 percent 5:1, and 20 percent 3:1 for the maximum to minimum dimension. Georgia DOT's specification is slightly more restrictive (based on the measurement technique).

The FHWA SMA Technical Working Group (TWG) [6] specified a maximum L.A. Abrasion loss of 30 percent. Stuart [7] recommended a maximum L.A. Abrasion loss of 40 percent based on his review of European practice. States, such as Georgia and Wisconsin, have allowed aggregates with up to 45 percent L.A. Abrasion loss, although Schmiedlin and Bischoff [8] noted an increased rate of reflective cracking with increased L.A. Abrasion loss. Higher L.A. Abrasion loss specifications would allow the use of more locally available aggregates and thus reduce cost. However, the higher tire pressures found on large commercial and military aircraft may cause a breakdown of the aggregate contact points under load. The maximum L.A. Abrasion loss allowed may impact the required gradation limits. When considering the breakpoint sieve (the 4.75 mm (No. 4) sieve for 12.5 mm (1/2 inch) NMAS SMA), it is anticipated that coarser mixes would be required for aggregates with higher L.A. Abrasion loss values and finer mixes for aggregates with lower L.A. Abrasion loss values.

Aggregates with a range of properties were selected for this study. Some of the aggregates had properties which were outside typical specifications for SMA. These aggregates were included to assess the effect of the aggregate properties on performance. The aggregate properties are summarized in Table 1.

Table 1.
Coarse Aggregate Properties.

Aggregate Source	L.A. Abrasion Loss, ASTM C131, %	Flat and Elongated Particles ASTM D4791, %		Coarse Aggregate Angularity ASTM D5821,%		Voids in Coarse Aggregate_{DRC}, %[b]
		3:1	5:1	≥ 1FF[1]	≥ 2FF[a]	
Diabase	18	9.7	0.4	100	100	46.2
Columbus Granite	37	7.8	0	100	100	42.3
Ruby Granite	20	3.3	0	100	100	40.6
Gravel	30	49.3	9.8	97	77	42.2
Limestone	25	10.1	0	100	100	41.5

[a]FF = Fractured Faces
[b]Voids in Coarse Aggregate_{DRC} for 50-blow Marshall gradation

German guidelines for the use of asphalt on airfields specify 8 or 11 mm nominal maximum aggregates size mixtures (NMAS), with 11 mm NMAS being used for heavier loading conditions [9]. The FHWA SMA TWG [6] gradation specification was for a 16 mm NMAS. Norway reports moving toward smaller NMAS SMA mixtures for airfields with time. The current Unified Facilities specifications are for a 12.5 mm NMAS SMA mixture [10]. China uses both 13 and 15 mm NMAS SMA mixtures on airfields. The 12.5 mm NMAS SMA was selected for the laboratory portion of this study.

A variety of mineral fillers have been used in SMA. Limestone fillers are most commonly used in Germany. The modified Rigden voids tests can be used to assess the stiffening potential of various fillers. A limestone filler was used for the majority of the mixes in this study. Fly ash was used for the Ruby Granite mixtures. All of the mixtures contained 1 percent hydrated lime as an anti-stripping agent. Fibers are typically added to SMA mixes at the rate of 0.3 percent by total weight of mix to prevent draindown of the binder prior to laydown. All of the SMA mixtures tested in this study contained 0.3 percent of cellulose fibers by total weight of mixture.

Both Germany and the U.S. have trended towards increased use of polymer modified binder in SMA. The Unified Facilities guide specification (UFGS) requires a two-grade high temperature bump from the recommended climatic grade determined with LTPPBind [10]. PG 64-22 is the most common base climatic binder grade in the U.S. Therefore a PG 76-22 would meet the UFGS requirements. Two binders were used in the study, a PG 76-22 and PG 64-22. The true grades were PG 82.5-24.1 and PG 68.2-23.2, respectively. Only limited testing was conducted with the PG 64-22.

MIX DESIGNS

The 50-blow Marshall compaction effort has been the standard for the design of SMA in Europe and early U.S. projects. Airfield pavements are still primarily constructed with mixes designed using the Marshall method. However, many U.S. paving contractors are losing their experience base with the Marshall method. Research is being conducted to adapt the Superpave mix design system, including the gyratory compactor, for the design of airfield pavements. Therefore, when developing specifications for SMA for airfields, SGC laboratory compactive efforts were considered as well as the Marshall method.

The 50-blow Marshall compaction effort is used in Germany and China. Italy specifies a 75-blow Marshall compaction effort for SMA for airfields. Numerous research studies have been conducted to determine an appropriate laboratory compaction effort using the Superpave Gyratory Compactor (SGC). NCHRP 9-8 recommended 100 gyrations for aggregates with L.A. Abrasion loss values less than 30 percent and 70 gyrations for aggregates with L.A. Abrasion loss values greater than 30 percent [11]. A recent study for Georgia DOT recommended a design compactive effort of 50 gyrations for the SGC [12]. This recommendation has been adopted in Georgia DOT's specifications (as an alternative to a 50-blow Marshall compaction effort). The Marshall hammer generally causes more aggregate breakdown than the SGC. Aggregate breakdown increases with increasing gyration levels.

Design air voids are generally specified between 3 and 4 percent for SMA. A minimum voids in mineral aggregate (VMA) of 17 is generally specified for SMA. Research conducted as part of NCHRP 9-8 recommended the use of voids in coarse aggregate (VCA) to ensure that a stone-on-stone skeleton is achieved [11]. The VCA_{Mix} should be less than the VCA_{DRC} (dry-rodded condition) determined according to AASHTO T19. This specification ensures stone-on-stone contact.

Trial blends were established using stockpile gradations for each of the aggregate sources. Although some of the stockpile gradations were not ideal for the production of SMA, the gradations were not artificially altered in the laboratory to produce an ideal gradation as it was felt that contractors may face similar difficulties in production. Typically in an SMA mix design, the percent passing the 4.75 mm (No. 4) sieve is varied with a relatively constant percentage of material passing the 0.075 mm (No. 200) sieve to determine a design with the lowest acceptable VMA which meets the VCA requirements. For instance trial blends may be produced with 24, 28, and 32 percent passing the 4.75 mm (No. 4) sieve and the mineral filler adjusted to provide approximately 10 percent passing the 0.075 mm (No. 200) sieve.

SMA designs were initially performed with each aggregate source using 50-blow (on each face) Marshall compaction effort. P401 control mixes were compacted with a 75-blow Marshall effort. Automatic hammers with flat faces and fixed bases were used for the designs. The selected SMA design gradations are shown in Table 2. Once a blend was determined with acceptable volumetric properties using the Marshall method, samples were compacted with the SGC, starting with 50 gyrations. It was expected that as gyrations increased, mixtures would fail volumetric properties and require adjustments to the design blend. This only occurred for the Columbus Granite source. The diabase blend falls outside the specification design range presented in Table 2 on the 9.5 mm (3/8 inch) sieve. This is because the diabase mixture was designed as a 9.5 mm (3/8 inch) NMAS SMA.

Table 2.
SMA Design Gradations

Sieve Size	Diabase	Columbus Granite		Ruby Granite	Gravel	Limestone	Target Design Range
	Blend 2	Blend 2	Blend 1	Blend 8B	Blend 1	Blend 4	
19.0 (3/4)	100	100	100	100	100	100	96-100
12.5 (1/2)	100	97	94	100	95	90	70-100
9.5 (3/8)	95	68	62	69	65	64	45-85
4.75 (No. 4)	32	29	25	26	28	23	20-43
2.36 (No. 8)	22	24	18	20	22	12	16-30
1.18 (No. 16)	20	21	17	17	20	10	14-22
0.600 (No. 30)	18	19	13	15	16	9	12-19
0.300 (No. 50)	16	17	11	13	15	9	10-16
0.150 (No. 100)	13	15	10	12	13	8	9-14
0.075 (No. 200)	9.8	12.5	8.7	11.0	9.4	7.8	7-13

Since higher design VMA values result in higher design asphalt contents, contractors in low-bid systems tend to design toward the minimum VMA value. Thus, attempts were made to design mixtures with VMA values approximately 1.0 percent above the minimum to account for breakdown, but less than 19 percent. This was not possible in all cases.

In-place air voids are critical to the performance of SMA. If in-place density is not achieved, the SMA may be permeable. Initially, 3 percent design air voids were targeted for determining optimum asphalt content. It was felt that the lower design air voids would correspond to improved density in the field.

Optimum asphalt content, VMA, and VCA_{Ratio} (VCA_{Mix} / VCA_{DRC}) for the SMA blends are presented in Table 3. The properties are presented at both 3 and 4 percent design air voids. Several trial blends for different aggregate sources were prepared with trial asphalt contents which initially produced air void contents above 3 percent. The rule of thumb used for Superpave mixes is that a 0.4 percent change in asphalt content will produce a 1 percent change in air voids. This approximation seems to be fairly good for other mixes too. However, for some of the SMA mixes, large increases in asphalt content did not produce 3 percent design voids and as the asphalt content was increased, the mixture would reach a point where it would

Table 3.
Summary of Volumetric Properties for SMA Mixtures

Aggregate	Blend	Lab Compaction	3% Air Voids			4% Air Voids		
			AC, %	VMA, %	VCA_{Ratio}	AC, %	VMA, %	VCA_{Ratio}
Columbus Granite	2	50-Blow	6.8	17.5	0.99	5.9	16.6[a]	0.97
	2	50 Gyration	6.4	16.6	0.97	NA	NA	NA
	2	65 Gyration	6.3	16.4	0.97	NA	NA	NA
	1	50-Blow	7.7	19.6	0.93	7.1	19.0	0.92
	1	50 Gyration	7.6	19.4	0.93	7.1	19.1	0.92
	1	65 Gyration	7.3	18.9	0.92	6.5	18.1	0.90
	1	80 Gyration	7.1	18.5	0.91	6.7	18.4	0.91
	1	100 Gyration	6.8	17.6	0.90	6.4	17.8	0.90
Gravel	1	50-Blow	8.0	19.4	1.00	7.6	19.4	1.00
	1	50 Gyration	7.2	18.3	0.98	6.8	18.2	0.98
	1	65 Gyration	7.0	17.8	0.97	6.4	17.3	0.96
	1	80 Gyration	6.7	17.2	0.96	6.2	16.9[a]	0.95
	1	100 Gyration	6.4	16.6[a]	0.95	6.0	16.5[a]	0.94
Limestone PG 76-22	4	50-Blow	7.4	19.5	0.88	6.9	19.3	0.88
	4	50 Gyration	7.8	20.3	0.90	7.3	20.2	0.90
	4	65 Gyration	7.2	19.1	0.88			
	4	80 Gyration	7.0	18.6	0.87	6.6	18.5	0.86
	4	100 Gyration	6.5	17.6	0.85			
Limestone PG 64-22	4	50-Blow	7.4	19.6	0.89			
	4	50 Gyration	7.6	19.9	0.89	7.2	19.8	0.89
	4	65 Gyration	7.2	19.1	0.88			
Diabase	2	50-Blow	8.0	22.0	0.85	7.5	21.7	0.85
	2	50 Gyration	8.5	23.1	0.87	8.1	23.0	0.86
	2	65 Gyration	8.1	22.1	0.85	7.6	22.1	0.85
	2	80 Gyration	8.2	22.4	0.86	6.4	19.0	0.80
	2	100 Gyration	7.5	21.0	0.83	6.7	20.0	0.81
Ruby Granite	8-B	50-Blow	7.8	20.0	1.01[b]	7.3	19.6	1.00
	8-B	50 Gyration	8.4	21.4	1.03[b]	7.5	20.2	1.01[b]
	8-B	65 Gyration	8.1	20.6	1.02[b]	7.4	19.8	1.00
	8-B	80 Gyration	8.3	21.0	1.02[b]	7.0	19.1	0.99
	8-B	100 Gyration	7.2	18.6	0.98	6.6	18.3	0.97

[a]Fails minimum VMA
[b]Fails VCA_{Ratio}

fail VCA_{Ratio}. Closer examination indicated that the mixtures were on the so-called "wet side" of the VMA curve. This is illustrated in Figures 1 and 2. For the 50-gyrations samples in Figure 1 the air void content at 7 percent asphalt is 4.4 percent and at 8 percent asphalt the air void content only decreases to 3.9 percent. At the same time, the VMA has increased from 19.4 to 21.0 percent. This indicates that the additional asphalt is pushing the aggregate skeleton apart, creating more VMA. This is also indicated by an increase in the VCA_{Ratio} from 0.997 to 1.027. Examination of Table 3 indicates that the VMA is higher at 3 percent design voids in every case except the Columbus granite mixture with the 100 gyration compaction effort. The measured VMA is the same at 3 and 4 percent air voids for the 50-blow gravel mixture and 65 gyration diabase mixture. All of the remaining combinations of aggregate source and laboratory compaction were selected on the wet side of the VMA curve.

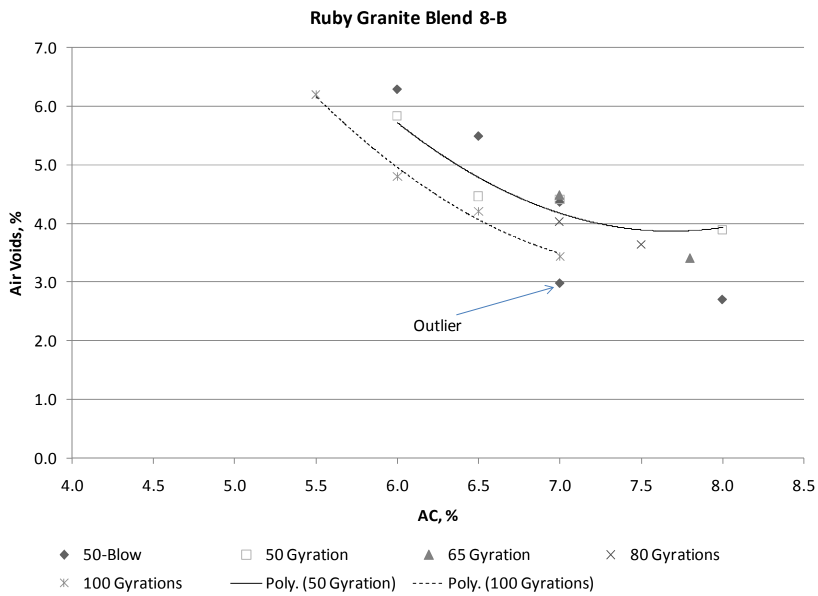

Figure 1. Air Voids as a Function of Asphalt Content for Ruby Granite.

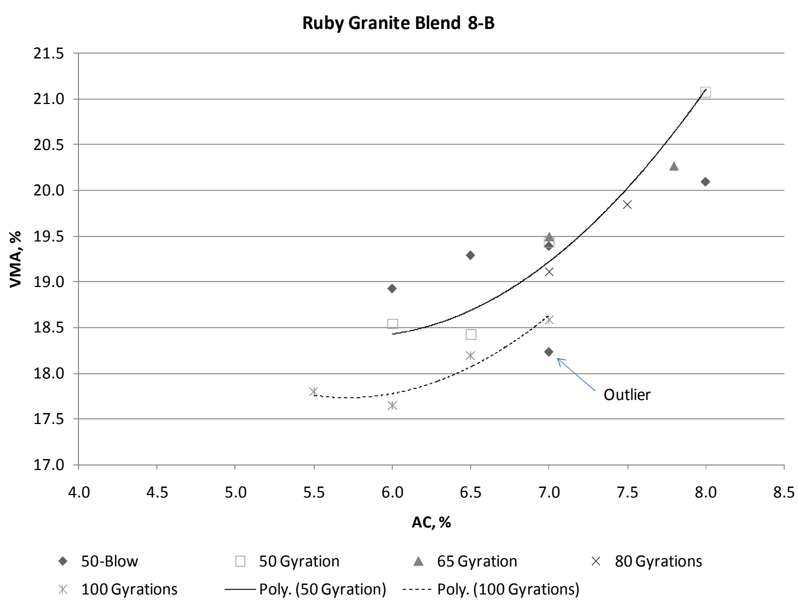

Figure 2. VMA as a Function of Asphalt Content for Ruby Granite.

RUTTING SUCEPTIBILITY

SMA mixes have proven to be resistant to shear flow rutting in the field, even though the optimum asphalt content of SMA mixes is typically 1.0 percent or more higher than dense-graded mixes. Laboratory testing has typically shown SMA mixtures to have comparable performance to dense-graded mixtures [13]. Therefore, the objective in this study was to demonstrate that SMA mixtures produced comparable performance to dense-graded mixtures even with the higher contact pressures associated with commercial and military aircraft. A modified binder, PG 76-22, was used in the majority of the SMA and P401 control mixes. The use of a modified binder is expected to improve rutting performance compared to an unmodified or “neat” binder.

The rutting susceptibility of the SMA mixtures and P401 control mixtures was assessed in three ways: stability and flow, repeated load permanent deformation, and Hamburg wheel-tracking. Stability and flow tests are the historic method used in the Marshall design procedure to assess rutting potential. The repeated load permanent deformation test was first used by Ahlrich [14] to evaluate the influence of aggregate properties on the rutting performance of asphalt mixtures for airfields. A version of this test was recommended as one of the simple performance tests (SPT) for asphalt mixtures [15] The Hamburg wheel-tracking tests were conducted wet. Wet Hamburg wheel-tracking tests provide information about both the rutting susceptibility and moisture susceptibility of asphalt mixtures.

P401 mixes with the Columbus Granite and limestone aggregates were produced with both PG 64-22 and PG 76-22. The average stability is 910 lbs higher with PG 76-22 as compared to PG 64-22 for the Columbus granite and limestone P401 control mixtures. The P401 specifications note that the flow values may need to be modified for polymer modified binder such as PG 76-22. The flow (measured in 0.01 inches) of the control mixes produced with PG 76-22 average 13 compared to 10 for the PG 64-22. The average stability of the diabase and Columbus granite SMA mixtures exceed the minimum requirements for P401 mixtures for aircraft with gross weights in excess of 27,200 kg (60,000 lbs) or tire pressures in excess of 689 kPa (100 psi). All of the SMA mixture’s flow values exceed the P401 specifications. The German specifications note that stability and flow are not applicable to SMA mixtures. The NCHRP 9-8 research also concluded that stability and flow was not appropriate for SMA mixtures [11]. The stability and flow results are not indicative of field performance.

The confined, repeated-load deformation test was one of the tests selected for assessing the performance of Superpave mixtures [15]. Some changes, however, were recommended to the test procedure used by Ahlrich [14]. In this study, samples were prepared according to the draft AASHTO test procedure [16]. The samples were 150 mm (6 inches) in height by 100 mm (4 inches) in diameter, cored and sawed from an oversize SGC sample. The SMA samples were prepared at 5 ± 0.5 percent air voids. As noted previously, SMA must be compacted to a high degree of in-place density to prevent permeability. A sample density of 95 percent of theoretical maximum density is representative of required field in-place densities. The P401 mixtures were prepared at 6 ± 0.5 percent air voids. Using a typical standard deviation of core densities of 1.1 percent, 94 percent of theoretical maximum density should provide 100 percent pay when using the P401 specifications. Gauge points to mount LVDTS were glued to the samples to produce a 100 mm (4-inch) gauge length. Three LVDTs were mounted on each sample. The samples were encased in a latex membrane to provide confinement. A greased latex disk was used on each end of the sample to reduce friction. The samples were tested at 58 °C (136.4 °F) with a 276 kPa (40 psi) confining pressure. Three different deviator stresses were initially used: 689, 1,379, and

2,413 kPa (100, 200, and 350 psi). The deviator stresses are consistent with tire pressures on general aviation, commercial, and military aircraft, respectively.

The data were analyzed for three primary parameters: flow number, secondary creep slope and number of cycles to 2 percent accumulated strain. The flow number was determined using the Franken Model. The Franken Model is a composite mathematical model which allows primary consolidation, secondary creep, and tertiary flow to be modeled [17]. The Franken Model is represented by the following equation:

$$\varepsilon_p(N) = AN^B + C(e^{DN} - 1) \quad (1)$$

where:
$\varepsilon_p(N)$ = permanent deformation or permanent strain,
N = number of loading cycles, and
A, B, C, and D = regression constants.

The regression constants were determined by a non-linear regression, least-squares procedure using Microsoft Excel Solver. The Francken Model is differentiated once with respect to N to determine the strain slope. The model is differentiated a second time to determine the gradient of the strain slope. The flow number is the point where the gradient of the strain slope changes from a negative to a positive value. The regression constant "B" represents the secondary creep slope on a log scale.

Statistical analyses of the data were conducted using analysis of variance (ANOVA). From these analyses, a number of conclusions can be drawn:

- Francken flow number was the response from the repeated load test which was most sensitive to experimental factors such as deviator stress.
- Deviator stress was altered between 689 and 2,413 kPa (100 and 350 psi) to simulate different aircraft tire pressures. Increased tire pressure, as evidenced by deviator stress, has a significant effect on permanent deformation.
- Repeated load tests were performed on samples from three aggregate sources: Columbus granite, gravel and limestone. Aggregate source was not a significant factor for either the P401 or SMA mixes. This indicates that rut resistant mixes can be designed for airfield pavements using gravel aggregate sources with as low as 77 percent two crushed faces. The high flat and elongated particle content may have contributed to the gravel mixture's performance.
- Design gyrations were somewhat significant in the rutting performance of the SMA mixtures based on the Francken FN and number of cycles to 2 percent permanent strain. Higher gyrations provided better rutting performance. It should be noted that the optimum asphalt content selected using 100 gyrations at 3 percent air voids is approximately equivalent to the asphalt content which would be selected between 71 and 85 gyrations using 4 percent design air voids.
- The permanent deformation performance of SMA mixtures designed at 3 percent air voids using 100 design gyrations and P401 mixtures were not significantly or practically different.

- At 689 kPa (100 psi) deviator stress, there was no significant difference in the rutting performance of the limestone P401 and SMA mixes produced with either PG 64-22 or PG 76-22. This suggests that modified binders are not required to produce mixes with good rutting performance for general aviation fields serving aircraft with tire pressures less than 689 kPa (100 psi).

The Hamburg wheel-tracking device (HWTD) was developed in the 1980's to assess both the rutting and moisture damage potential of asphalt mixtures. In this study, samples were tested for 20,000 passes (10,000 cycles) at a temperature of 50 °C (122 °F). The SMA test samples were produced at 5 ± 0.5 percent air voids and the P401 samples at 6 ± 0.5 percent air voids. Samples were not tested for every laboratory compaction level due to the fact that some of the optimum asphalt contents were very close together. Primarily three results were analyzed to determine the existence of a stripping inflection point, the secondary creep slope, and the total rutting after 10,000 cycles (20,000 passes).

Figure 3 shows the average rutting rates as a function of asphalt content. A lower rate indicates better performance. Figure 3 shows that the SMA mixes generally have similar rutting rates across a range of asphalt contents. The one exception is the Columbus granite P401 mix, which has a higher rutting rate, most likely due to moisture damage. The thicker asphalt film of the SMA mixes should improve moisture resistance. It is interesting to note that the rutting rate increases at the extremes of the SMA asphalt contents. The low asphalt contents represent a 100 gyration lab compaction effort at 3 percent design voids or approximately an 80 gyration lab compaction effort at 4 percent design voids. The higher asphalt contents generally represent the 50 gyration lab compaction effort at 3 percent air voids.

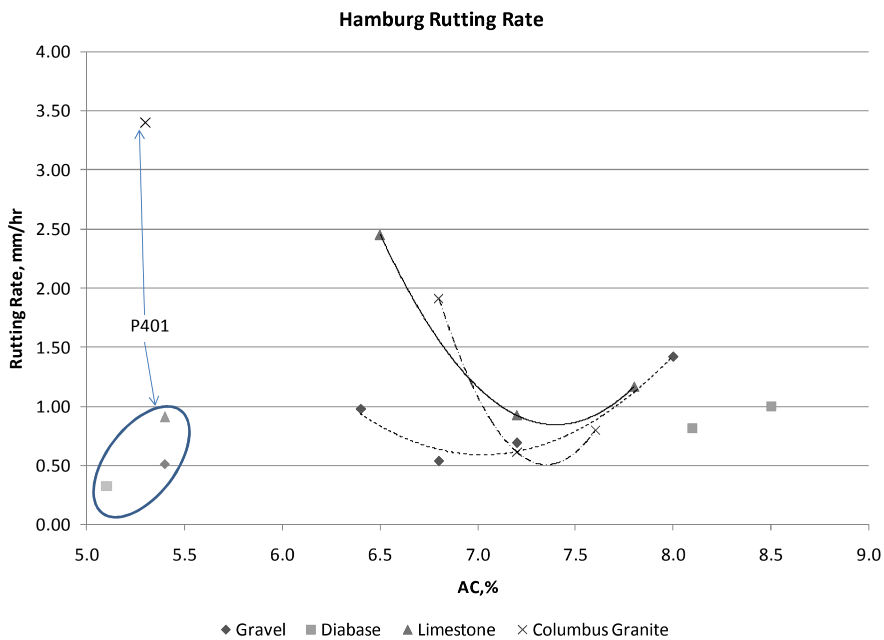

Figure 3. HWTD Rutting Rates as a Function of Asphalt Content.

Figure 4 shows the average total rutting at 10,000 cycles for the PG 76-22 mixes as a function of asphalt content. If the test was stopped prior to 10,000 cycles, the rut depth was extrapolated using a best-fit polynomial regression. The diabase and gravel P401 mixes provide better performance (less total rutting) than the SMA mixtures and the Columbus granite and limestone mixes provide worse performance than the SMA mixtures. The total rutting response of the SMA mixtures appears to be relatively insensitive to asphalt content. Overall, the total rutting of the SMA mixtures is more consistent, regardless of aggregate source, whereas the performance of some P401 mixtures was better and others worse as described previously.

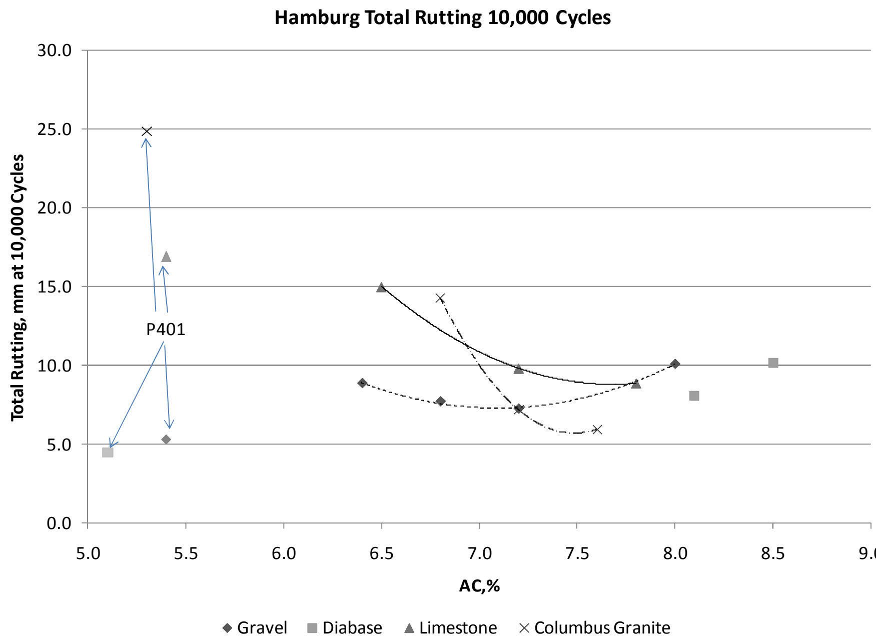

Figure 4. Total HWTD Rutting as a Function of Asphalt Content.

Finally, comparisons were made between the limestone SMA and P401 mixtures produced with PG 76-22 and PG 64-22. In an SMA mixture, the aggregate skeleton is expected to carry the load. Therefore, it may be expected that SMA mixtures would be less sensitive to binder grade than dense graded mixes are. However, previous experience with SMA mixtures suggests they may be sensitive to slow speed or turning movements with softer binders. The average rutting rate for the PG 64-22 limestone SMA mixture was 10.4 times that of the PG 76-22 mixture. Recall that the PG 76-22 used for this work graded in excess of a PG 82-22. By comparison, the rutting rate of the PG 64-22 limestone P401 mixture was only 4.8 times that of the PG 76-22 mixture. On average, the PG 64-22 mixtures have a rutting rate 7.6 times that of the PG 76-22 mixtures.

OVERLAY TESTS FOR CRACKING RESISTANCE

Historically, resistance to age related and fatigue cracking has been difficult to quantify in the laboratory. A device called the overlay tester was developed to test the cracking resistance of asphalt mixtures. The device, shown in Figure 5, simulates the opening and closing of a joint in a hydraulic cement concrete pavement or existing crack in an asphalt pavement due to environmental stresses. The device does not simulate the bending associated with traffic loads on flexible pavements or load transfer across joints in composite pavements. However, the device was used to correctly rank the fatigue performance of flexible pavement test sections from the Federal Highway Administration's Accelerated Load Facility (ALF) [18].

Test samples of the 50-blow Marshall SMA and P401 control mixes were prepared in the SGC at 5 ± 0.5 and 6 ± 0.5 percent air voids, respectively. The test sample is sawed out of the

SGC sample using a double-bladed wet saw. The samples were tested according to Texas Department of Transportation Test Method Tex-248-F at 25 °C (77°F) using a maximum cracking opening (deflection) of 0.64 mm (0.025 inches).

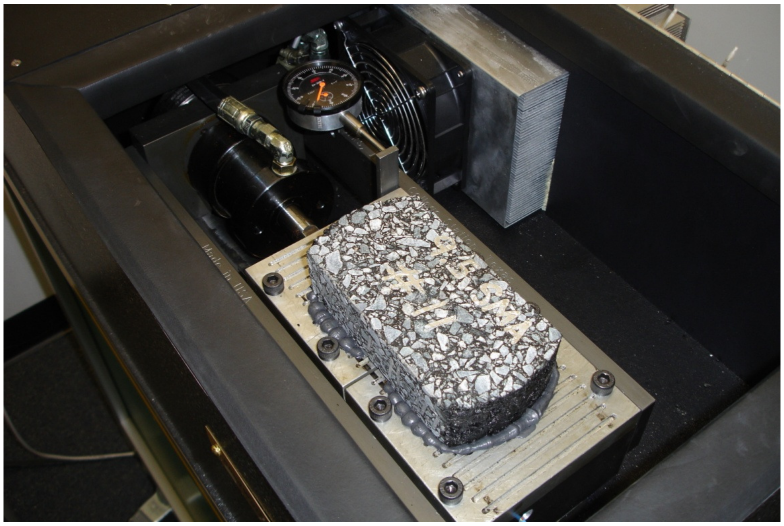

Figure 5. Overlay Tester.

Test results for the overlay tester are presented in Figure 6. All of the mixes were produced with PG 76-22. The limestone mixture was also produced with PG 64-22. Both the SMA and P401 mixes lasted considerably longer than the Superpave mixes previously tested by Rutgers University (Personal communication with Tom Bennert). On average for the mixtures containing PG 76-22, the cycles to failure for the SMA mixtures were 435 percent higher than for the P401 mixtures. This increase clearly demonstrates the potential benefits of SMA in terms of durability. ANOVA indicated that both mix and aggregate type were significant factors (p = 0.000 and 0.017, respectively).

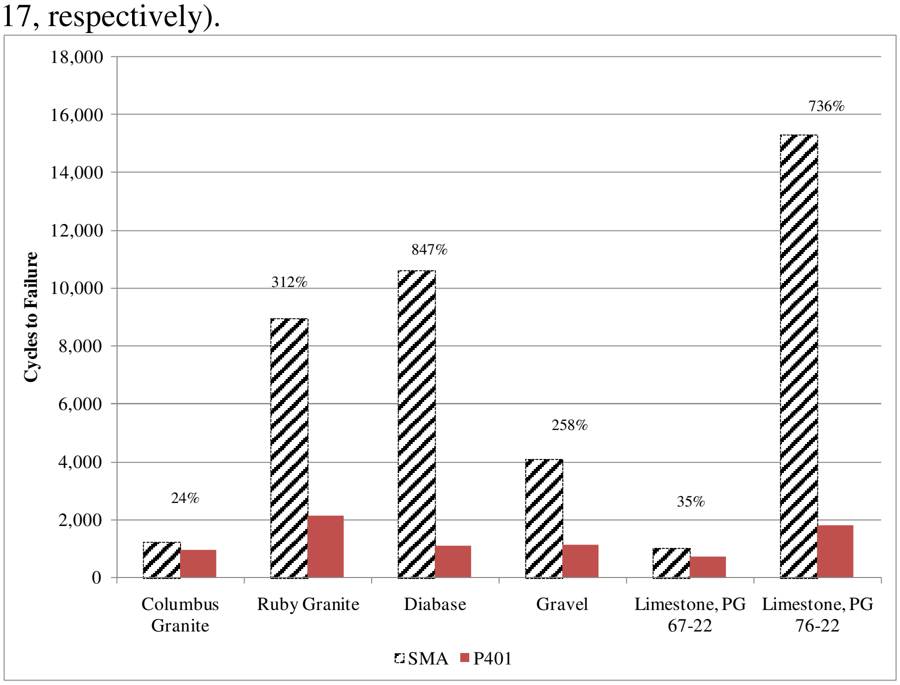

Figure 6. Overlay Tester Results.

FUEL RESISITANCE TESTING

In order to evaluate Stone Matrix Asphalt's resistance to fuel-induced failures, samples were prepared and evaluated according to the CITGO Fuel Soak Test Procedure [19]. The only variations were in the sample air voids and method of producing the test samples. The CITGO Fuel Soak Test calls for test samples to have an air void content of approximately 2.5 percent; samples for this project were compacted to an air void content of approximately 5 ± 0.5 percent for the SMA samples and 6 ± 0.5 percent for the control P401 mixes. Test samples for this project were also produced with the Marshall hammer instead of a Superpave gyratory compactor. A PG 76-22 grade binder was also used for this evaluation.

Figure 7 shows a sample after it has been evaluated by the CITGO Fuel Soak Test. It can be seen from the photo that the fuel did not fully saturate the sample, but rather only affected the outer portion of the test sample. This allowed the sample to retain approximately 80 percent of its original strength. Table 4 presents the test results from the CITGO Fuel Soak Tests. The SMA mixtures resulted in 42 and 43 percent less mass loss for the Columbus granite and gravel, respectively. Previous studies suggest that a mixture with a maximum mass loss of 5 percent should be resistant to damage from fuel spills (*Personal communication with Doug Hanson*). The granite SMA mixture meets this criterion. The retained tensile strengths for the SMA and P401 control mixtures were similar.

Figure 7. Lab Gravel Fuel Resistance Samples After Immersion.

Table 4
CITGO Fuel Soak Test Results

Aggregate	Mix Type	Treatment	Mass Loss, %	Avg. Failure Load, N (lbs)	Avg. Tensile Strength, kPa (psi)	Tensile Strength Retained, %
Columbus Granite	P401	Fuel	7.8	6717 (1510)	645 (93.5)	51.2
		Control	--	13015 (2926)	1260 (182.8)	--
	SMA	Fuel	4.5	5849 (1314)	542 (78.6)	59.8
		Control	--	9826 (2209)	906 (131.4)	--
Gravel	P401	Fuel	11.6	5667 (1274)	544 (78.9)	79.6
		Control	--	7019 (1587)	684 (99.2)	--
	SMA	Fuel	6.6	4079 (917)	351 (50.9)	73.6
		Control	--	5400 (1214)	476 (69.1)	--

DEICER EVALUATION

Based on prior evaluations conducted as part of AAPTP Project 05-03 [20], test samples were produced and submerged in a potassium acetate solution to evaluate the SMA's resistance to DIAIC-related damage. DIAIC-related damage refers to the damage caused by deicing and anti-icing chemicals. From the research performed as part of AAPTP Project 05-03, the Immersion Tension Test (ITT) was established.

Table 5 presents the data obtained from the ITT testing conducted on both the P401 and SMA mixes. In the table, both the average indirect tensile strength values as well as the retained tensile strength/deicer treatment (TSR/D) values for each of the mixes are reported. TSR/D values of less than 80 percent indicate that the pavement may be susceptible to DIAIC-related damage. From the data, it is seen that neither the SMA nor the P401 samples demonstrated any DIAIC-related damage.

Table 5
Immersion Tensile Test (ITT) Results

Aggregate	Mix Type	Sample Set	Avg. Failure Load, N (lbs)	Avg. Tensile Strength, kPa (psi)	TSR/D, %
Lab Granite	P401	Dry Control	13015 (2926)	1260 (182.8)	--
		Soaked Control	8136 (1829)	782 (113.4)	--
		2% Potassium Acetate	7931 (1783)	765 (111.0)	97.8
Lab Gravel	P401	Dry Control	7059 (1587)	684 (99.2)	--
		Soaked Control	10017 (2252)	938 (136.0)	--
		2% Potassium Acetate	10066 (2263)	947 (137.4)	101.0
Lab Granite	SMA	Dry Control	9826 (2209)	918 (133.2)	--
		Soaked Control	8447 (1899)	794 (115.1)	--
		2% Potassium Acetate	8176 (1838)	765 (111.0)	96.3
Lab Gravel	SMA	Dry Control	5400 (1214)	482 (69.9)	--
		Soaked Control	6303 (1417)	546 (79.2)	--
		2% Potassium Acetate	6788 (1526)	591 (85.7)	108.2

CONCLUSIONS

A literature review and laboratory study were conducted to evaluate the use of SMA for airfield pavements. The laboratory study evaluated susceptibility to rutting, moisture damage, reflective cracking, fuel resistance, and deicer resistance. The ability of SMA to be grooved was also studied, but is not reported herein. Overall, the performance of SMA compared to P401 control mixtures is summarized in Table 6. The performance summary is based on the literature review, performance of in-service airfields, and the laboratory testing. SMA performs similar to dense-graded P401 mixes in terms of rutting susceptibility and deicer resistance. SMA is superior in all other areas, particularly resistance to reflective cracking. SMA is expected to have a higher initial cost than dense-graded P401 mixes. Performance data from highway pavements indicates the increased cost is justifiable on a life-cycle basis. A draft FAA Advisory Circular for SMA on Airfields has been prepared and is presented in reference [2].

Table 6
Summary of SMA and P401 Performance Comparison

Property	Performance worse than P401	Performance similar to P401	Performance better than P401
Permanent Deformation		✓ [a]	✓ [b]
Moisture Damage			✓
Cracking			✓
Fuel Resistance			✓
Deicer Resistance		✓	
Texture			✓ [b]

[a]Based on laboratory tests performed as part of this study.
[b]Based on review of the literature or in-service performance.

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