NCAT Report 08-03

STONE SKELETON ASPHALT: FIELD TRIAL U.S. 331, LUVERNE, ALABAMA

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ABSTRACT

Alabama Department of Transportation (ALDOT) developed Section 426, Stone Skeleton Asphalt (SSA), based on results from a laboratory concept study. The concept of stone skeleton asphalt was a mixture that would have similar performance characteristics to typical stone matrix asphalt (SMA) mixtures, but without some elements contained in SMA mixtures that increase its cost, such as modified asphalt binders, fibers, and mineral fillers.

A trial project was let on U. S. Route 331 in Luverne, Alabama. A neat PG 67-22 binder was specified instead of the PG 76-22 specified in ALDOT's SMA mixes. Fiber was included in the design, but incrementally removed during placement. Samples of the produced mix were taken and results from the volumetric, draindown, and performance testing were gathered and analyzed. From these results, several conclusions were made. The removal of fibers reduced the VMA below the minimum specification for SSA during production. The rutting potential of the stone skeleton mixtures was generally not affected by the removal of fibers and reduction in asphalt content. All test sections had rut depths below the maximum specified value. Four out of the six test sections had TSR values that were slightly below the minimum specified value of 0.80. This matched observations from the mix design verification. None of the test sections had any issues with asphalt draindown. Field permeability values for the test sections correlated very well to in-place densities. In order to ensure an impermeable stone skeleton asphalt mixture, in-place densities should be approximately 95 percent of the theoretical maximum density. The stone skeleton mixes exhibited acceptable friction values.

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INTRODUCTION

The concept of stone skeleton asphalt is a mixture having similar performance characteristics to typical stone matrix asphalt (SMA) mixtures, but without some elements contained in SMA mixtures that increase its cost, such as modified asphalt binders, fibers, and mineral fillers. A rut resistant, durable asphalt mixture without these particular components will reduce the overall cost of the pavement.

It has been suggested that stone skeleton asphalt produced with fractionated aggregates would also allow better overall utilization of aggregate production (*1*, *2*). An initial laboratory evaluation by the National Center for Asphalt Technology was performed to determine the performance of stone skeleton asphalt (*3*). This was conducted by systematically removing cost increasing ingredients of stone matrix asphalt and measuring the performance of the resulting stone skeleton asphalt mixture. Conclusions from that analysis were:

- The inclusion of fibers increased the mixture's voids in mineral aggregate (VMA) and optimum asphalt content,
- Eliminating fibers increased the amount of draindown compared to the mixtures containing fibers, but the draindown did not exceed the maximum specified limit,
- Rutting results from the mixtures containing performance grade (PG) 67-22 and fibers, and particularly the additional percentage of fly ash, indicated similar results to those of the mixtures with a modified PG 76-22 asphalt binder, and
- At typical in-place densities, stone skeleton asphalt mixtures appear to be permeable. Densities would have to be above 95 percent of maximum theoretical density to produce an impermeable pavement.

The objective of this research study was to construct and evaluate the performance of field trial sections of stone skeleton asphalt. Different combinations of ingredients (asphalt content and fiber) were adjusted to determine their effect on performance.

RESEARCH APPROACH

Mix Design

Before this field evaluation of stone skeleton asphalt could be conducted, a preliminary mix specification needed to be developed. This new specification was entitled ALDOT Section 426, Stone Skeleton Asphalt (SSA). Among the differences between stone matrix asphalt and Stone Skeleton Asphalt are: 1) SSA mixes use unmodified asphalt binders (such as PG 67-22) instead of polymer modified binders (e.g. PG 76-22), 2) SSA mixtures can be designed using a compactive effort of 65 gyrations in the Superpave Gyratory Compactor (SGC), 3) both mineral filler and mineral fiber may not be necessary in SSA mixes, 4) SSA mixes have slightly coarser gradation limits on the fine aggregate sieves, and 5) the maximum rut depth has been increased from 4.50 mm to 5.75 mm for SSA mix, when tested according to ALDOT 401, Rutting Susceptibility Determination of Asphalt Paving Mixtures Using the Asphalt Pavement Analyzer.

The mix design used for the field evaluation of stone skeleton asphalt was a 19.0 mm maximum aggregate size design based on ALDOT Section 426 developed by the APAC-Southeast, Inc. Gulf Coast Division, Dothan area office. An unmodified PG 67-22 asphalt binder was used. The mix design contained six percent fly ash and 0.2 percent mineral fiber by total mix weight. A liquid anti-stripping agent was also included in the mix design, at a percentage of 0.5 percent by weight of asphalt binder.

The job mix formula, containing the design gradation and optimum asphalt content, is presented in Table 1. Since one of the primary objectives of this study is to try and develop a less expensive stone matrix asphalt type mixture, NCAT verified the original job mix formula with and without fiber. For the mix design with fiber, an optimum asphalt content of 6.2 percent was determined, 0.4 percent higher than the optimum asphalt content submitted by the contractor. This may be the result of a slightly different gradation or a difference in specific gravity values used in the volumetric calculations. For the mix design verification without the mineral fiber, the optimum asphalt content was determined to be 5.5 percent, a 0.3 decrease from the original mix design. This decrease in asphalt content will decrease the overall cost of stone skeleton asphalt compared to typical SMA mixes. Figure 1 illustrates the difference in the appearance of the asphalt mix with and without the presence of mineral fiber.

Table 1. Stone Skeleton Asphalt Mix Design Gradation and Optimum Asphalt Content

Sieve Size, mm	JMF	Spec. Range
19.0	100	100 - 100
12.5	95	90 – 100
9.5	68	26 – 78
4.75	27	20 – 28
2.36	19	15 – 24
1.18	16	12 – 21
0.600	14	10 – 18
0.300	12	10 – 15
0.150	10	--
0.075	8.1	6 – 10
AC, %	5.8	5.7 min.
Fiber, %	0.2	--

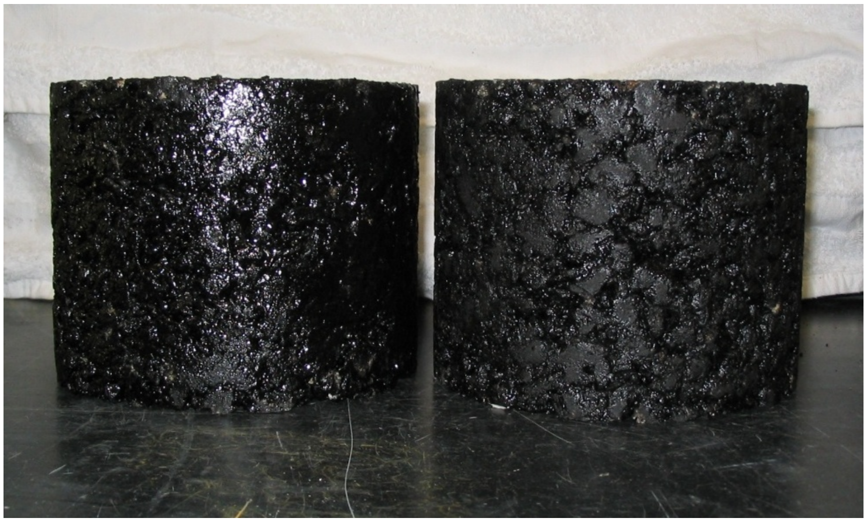

Figure 1. Stone Skeleton Asphalt Sample With (right) and Without (left) Mineral Fiber

A control SMA mix meeting the requirements of ALDOT Section 423 was not included in the project. The SSA designs did not use PG 76-22 as specified in Section 423. The SSA mixture with fibers had a minimum voids in mineral aggregate of 16.5 percent, which is lower than the minimum VMA of 17.0 percent for SMA in accordance with ALDOT Section 423. The Asphalt Pavement Analyzer rut depth results for the SSA mixture with- and without fibers were 4.63 and 3.87 mm, respectively. The rut depth for the mixture with fibers exceeds the maximum rut depth of 4.5 mm specified in Section 423.

Field Test Sections

The field test sections were constructed from November 1 to November 8, 2005, on US 331, just north of Luverne, Alabama. The test sections were constructed in both north and south lanes. A schematic of the different test sections is presented on Figure 2. The linear distances in Figure 2 are from the project limits along the direction of traffic. The ovals in the figure represent locations of the core samples that were taken from each of the test sections. A total of seven different test sections were constructed. Table 2 describes the different test sections. Weather problems on the first day prevented sampling from Test Section 1.

Table 2. Test Section Mixture Descriptions

Test Section	Mix Description
1	Original SSA job mix formula (did not evaluate)
2	Original SSA job mix formula (5.8% AC, 0.2% Fiber)
2A	Decreased percentage of #7 stockpile by 3%
3	Gradation same as 2A, 5.6% AC, 0.2% Fiber
4	Same gradation, 5.6% AC, 0.1% Fiber
5	Same gradation, 5.6% AC, No Fiber
6	Same gradation, 5.4% AC, No Fiber

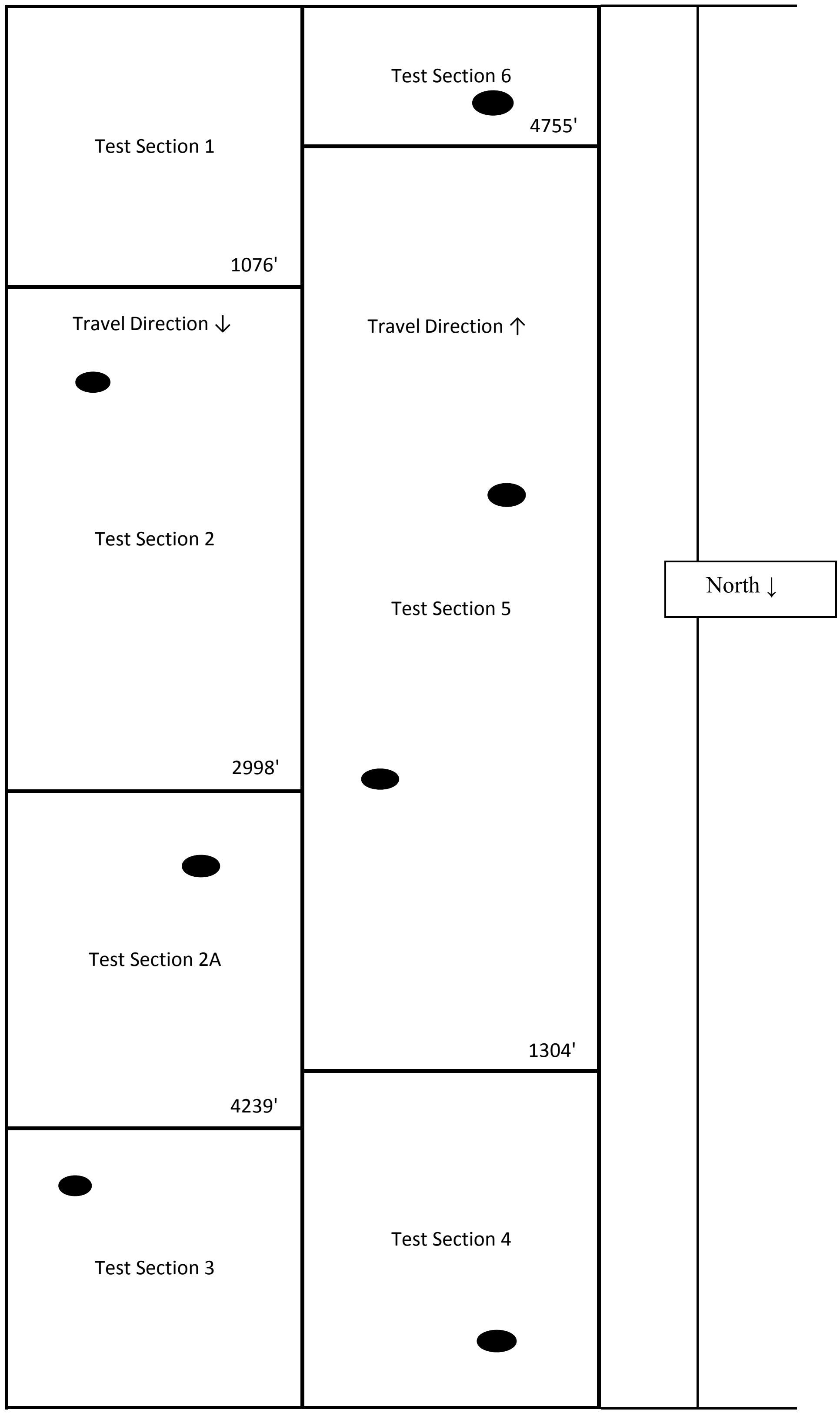

Figure 2. Test Section Locations for Stone Skeleton Asphalt Field Evaluation

CONSTRUCTION

The mix was produced using a CMI PVI-400 parallel-flow drum plant, rated at 400 tons per hour. The haul distance from the plant to the site was approximately 15 miles. The paving train consisted of a Blaw-Knox MC-30 mobile conveyor and Blaw-Knox PF-3200 Paver. Breakdown rolling consisted of three vibratory passes with an Ingersol Rand DD-110 HF roller. Breakdown rolling was followed by five static passes with an Ingersoll Rand DD-118 HA. The mix was delivered to the job site at temperatures ranging from 290 to 325°F (143 to 163°C). Typical surface temperatures immediately behind the paver screed ranged from 280 to 290°F (138 to 143°C). The mix was very stable under the rollers; the breakdown roller typically changed directions very close to the paver screed (Figure 3). The compacted lift thickness was 1.5 inches (38 mm). No draindown was observed in the trucks for any of the trial sections (Figure 4). The surface texture of the compacted mix appeared typical of SMA with a high degree of macrotexture (Figure 5).

Figure 3. Paving Train with Breakdown Roller Close to Paver Screed

Figure 4. Typical Clean Truck Bed During Production Without Fibers

Figure 5. Typical Surface Texture, No Fibers

TEST RESULTS AND DISCUSSION

For each of the test sections, mix was sampled and split into smaller samples for testing. The testing protocol included determining mixture volumetric properties, draindown tests, Asphalt Pavement Analyzer testing, and moisture susceptibility testing. Density measurements and field permeability tests were performed on the roadway. Friction testing was conducted after construction was completed. The following sections discuss the results obtained for each of these test procedures.

Mixture Volumetric Properties

The original mix design had a design laboratory compactive effort of 65 gyrations in the Superpave Gyratory Compactor (SGC). Therefore, each of the test sections was compacted at this compaction level. Table 3 presents the entire set of test results obtained from the tests performed for each of the test sections. Regarding the voids in mineral aggregate (VMA) of the different test sections, it can be observed that as the fiber was removed from the mixture, the VMA tended to decrease. This matches the findings of the concept study (3). This may be due to the mineral fiber soaking up asphalt binder. Also observed was the decrease in air voids as the mineral fiber was removed from the mixture. The asphalt content was decreased in section six in an effort to increase the air voids when the fibers were removed.

Voids in coarse aggregate (VCA) are measured in SMA type mixes to ensure stone-on-stone contact (4). First, the VCA of the dry rodded condition (DRC) is determined using the coarse aggregate fraction. For a 19.0 mm (3/4 inch) NMAS mix, the coarse aggregate fraction is defined as the material retained on the 4.75 mm (No. 4) sieve. The void space between the coarse aggregate in a compacted HMA sample can be calculated and is termed the VCA_{Mix}. Since only coarse aggregate particles are used when calculating the VCA_{DRC}, they represent a condition where stone-on-stone contact is assured. If the $VCA_{Mix} < VCA_{DRC}$ then there should be stone-on-stone (coarse aggregate) contact in the compacted mix samples, creating a “stone skeleton.” All of the VCA ratios shown in Table 3 are less than 1.0, indicating that all of the mixes achieved a stone skeleton.

Asphalt Draindown

One of the primary concerns with Stone Skeleton Asphalt was the potential for increased asphalt draindown due to fiber not being included in the mixture. Therefore, draindown tests were conducted on the different test sections. Test results are presented below in Table 3. As can be observed, no draindown was measured for any of the test sections except for section 6, which had only 0.1 percent. This still met the maximum draindown requirement of 0.3 percent. This confirmed the observations from the field and indicates that asphalt draindown should not be a problem with Stone Skeleton Asphalt mixtures.

Table 3. Test Results for the Different Stone Skeleton Asphalt Test Sections

Test Strip	JMF	1	2	2A	3	4	5	6	Spec. Range
Compactive Effort	65	65	65	65	65	65	65	65	65
19.0 mm (3/4")	100	100	100	100	100	100	100	100	100
12.5 mm (1/2")	95	95	95	96	95	95	96	97	90 - 100
9.5 mm (3/8")	68	61	63	68	65	67	69	68	26 - 78
4.75 mm (#4)	27	20	22	27	25	27	28	28	20 - 28
2.36 mm (#8)	19	14	16	18	18	19	19	20	15 - 24
1.18 mm (#16)	16	12	13	15	15	16	17	17	12 - 21
0.60 mm (#30)	14	10	11	13	13	14	14	15	10 - 18
0.30 mm (#50)	12	8	9	10	11	12	12	12	10 - 15
0.15 mm (#100)	10	6	8	8	8	9	10	10	
0.075 mm (#200)	8.1	4.3	5.8	6.3	6.3	6.9	7.6	7.9	6 - 10
% AC	5.80	5.67	5.70	6.27	5.87	5.90	5.67	5.65	min 5.70
Target % AC	5.80	5.60	5.80	5.80	5.60	5.60	5.60	5.40	--
Fiber, %	0.2	0.2	0.2	0.2	0.2	0.1	0.0	0.0	--
Air Voids @ Ndesign, %	4.0	NA	5.4	3.8	5.2	3.7	2.9	3.3	4.0
VMA, %	16.7	NA	17.2	17.1	17.2	15.3	14.5	14.7	min 16.0
VCAmix/ VCAdrc	NA	NA	0.84	0.83	0.84	0.81	0.80	0.80	< 1.0
Rut Depth, mm	NA	NA	3.40	3.43	5.38	4.71	4.49	4.80	max 5.75
TSR	0.94	NA	0.90	0.70	0.75	0.80	0.74	0.76	min 0.80
Draindown, % @ 300F	max 0.3	NA	0	0	0	0	0	0.1	max 0.3

NA = No Data was determined for this test strip.

Asphalt Pavement Analyzer

Once the volumetric data was determined, the test samples were subjected to testing in the Asphalt Pavement Analyzer (APA). This was to determine whether or not Stone Skeleton Asphalt was more susceptible to premature rutting than a typical SMA mixture. It should be noted that the samples tested in the APA were compacted to N_{design}(65 gyrations), so their air voids varied from section-to-section. The APA results are presented in Table 3 and shown in Figure 6. ALDOT specifications for a standard SMA mix limits the APA rutting to a maximum of 4.50 mm; however, as stated earlier, the preliminary specification for the design of Stone Skeleton Asphalt states that rutting cannot exceed 5.75 mm. APA testing was conducted at a temperature of 67°C (146°F) using a load and hose pressure of 100 pounds and 100 psi, respectively. From the results, it can be seen that mixes from some of the test sections were just above the SMA limit, but all met the SSA maximum requirement. This indicates that a Stone Skeleton Asphalt would have a slight increase in rutting potential over typical Stone Matrix Asphalt. It should be noted that standard SMA in Alabama uses PG 76-22 asphalt binder, which reduces rutting potential.

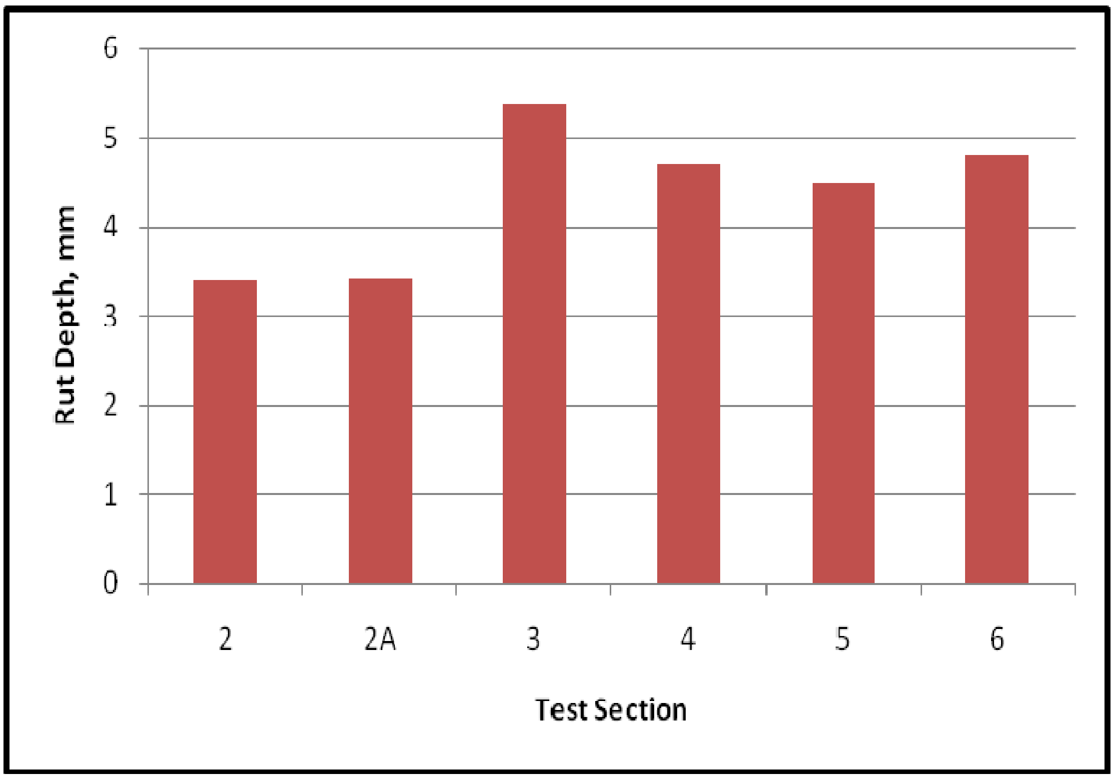

Figure 6. Asphalt Pavement Analyzer Results for the Field Test Sections

Moisture Resistance

To determine if the different stone skeleton asphalt test sections were more susceptible to moisture damage than typical SMA mixes, samples were compacted to perform tensile strength ratio testing. TSR tests were also performed during the mix design verification. Testing was done according to ALDOT-361. ALDOT-361 is similar to AASHTO T283, except that the extended aging times have been eliminated. This specification requires a minimum tensile strength ratio (TSR) 0.80. From the test results, only two test sections (sections 2 and 4) satisfied this minimum requirement. However, as seen in Figure 7, all other test sections were just under the minimum tensile strength ratio requirement. The values from the plant produced mix were slightly higher than the TSR tests performed during the mix verification. The mix design verifications tests produced TSR ratios with and without fiber of 0.61 and 0.63, respectively. Typically, SMA type mixes are not expected to be susceptible to moisture damage due to the thickness of the binder mastic. Although Alabama Department of Transportation specifies a minimum TSR of 80 percent for SMA, some agencies allow 70 percent. The reduced binder content in some of the SSA sections may make it more susceptible to moisture damage, particularly if it is permeable.

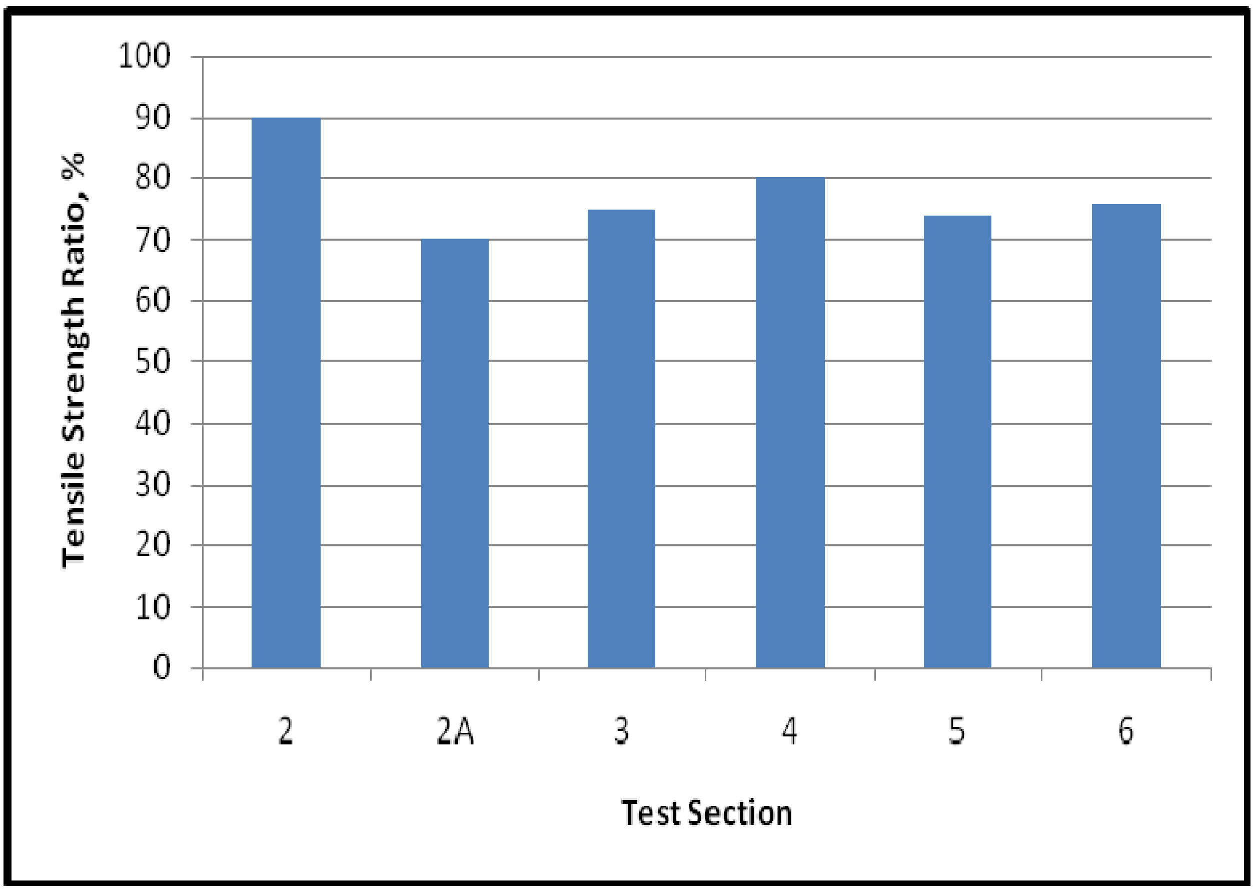

Figure 7. Tensile Strength Ratio Results for the Field Test Sections

Field Permeability

Field permeability testing on the different stone skeleton asphalt test sections was conducted using the NCAT Field Permeameter. This device has been shown to compare reasonably well with the Florida DOT lab permeameter and produce a good relationship with in-place air voids in a compacted pavement (5). The field permeameter uses a silicone-rubber sealant and a flexible rubber base in conjunction with a metal base plate to secure the device to the pavement surface. It also incorporates a three-tier system to make the permeameter more sensitive to the flow of water through the pavement. The NCAT Field Permeameter is shown in Figure 8. The test procedure is described in reference (6).

Test results for the different test sections are presented in Table 4 and graphically shown in Figure 9. From these results, a very good relationship can be seen between field permeability and in-place air voids. Test results for Test Section 2A were not included on Figure 9 because they were determined to be an outlier. It can also be seen from the data that to ensure an impermeable stone skeleton asphalt pavement, in-place air voids must be approximately five percent (95 percent in-place density). This closely approximates the findings of the concept study, which suggested that the in-place density would need to be between 94.2 and 97.2 percent, depending on the combination of binder, fiber, and filler, for the pavement to be considered impermeable (3).

Table 4. Field Permeability Results

Test Section	Air Voids, %	Avg. Perm., 10^{-5} cm/s
2	7.3	686
2A	7.9	29
3	6.1	719
4	4.7	122
5	7.6	1084
6	8.6	2588

Figure 8. NCAT Field Permeameter

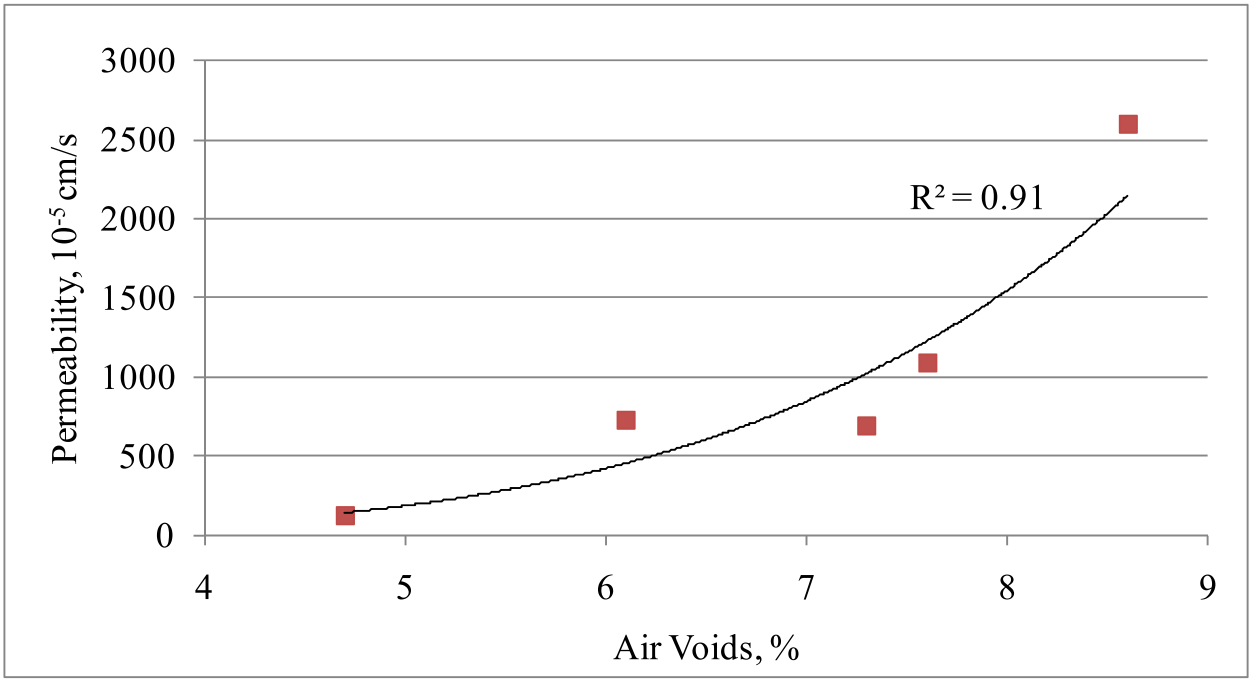

Figure 9. Field Permeability versus In-place Air Voids

Friction Number

Friction testing was conducted by ALDOT using their ASTM E-274 locked-wheeled skid trailer with a ribbed tire. The friction testing took place on July 27, 2006. This testing was conducted to determine if the surface friction would be reduced by using Stone Skeleton Asphalt. The test sections were tested approximately nine months after construction. Friction testing was conducted at 40 miles per hour. Test results for the sections are shown in Figure 10. The section with the coarsest gradation, section 2, has the lowest friction number.

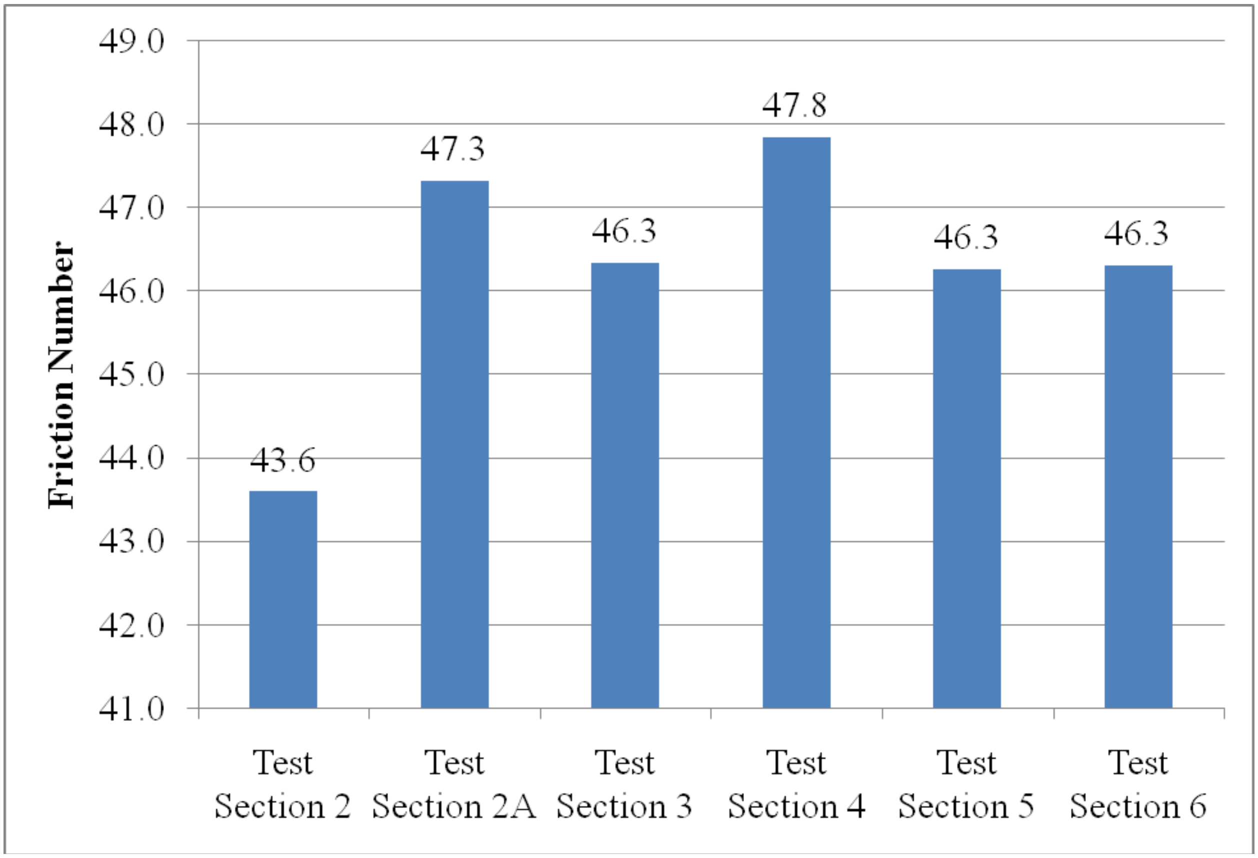

Figure 10. Friction Number Results for the Test Sections

CONCLUSIONS

A field evaluation was conducted for the Alabama Department of Transportation to determine the field performance of stone skeleton asphalt. APAC-Southeast, Inc. Gulf Coast Division designed and constructed six stone skeleton asphalt test sections, in which mineral fiber and asphalt binder was systematically removed to assess the pavement's performance in terms of asphalt draindown, rutting potential, moisture damage, field permeability, and friction properties. Volumetric properties were also determined for the test sections. The following conclusions were determined from the results:

- The removal of fibers reduced the VMA below the minimum specification for SSA during production. The measured VMA still exceeded the minimum for dense-graded mixtures.
- The rutting potential of the stone skeleton mixtures was generally not affected by the removal of fibers and asphalt content. All test sections had rut depths below the maximum specified value.
- Four of the six test sections had TSR values that were slightly below the minimum specified value of 0.80. This matched observations from the mix design verification.
- None of the test sections had any issues with asphalt draindown. Therefore, asphalt draindown should not be a concern with stone skeleton mixtures.
- Field permeability values for the test sections correlated very well to in-place densities. In order to ensure an impermeable stone skeleton asphalt mixture, in-place densities should be above approximately 95 percent of the theoretical maximum density.
- The stone skeleton mixes have acceptable friction values.

RECOMMENDATIONS

Based on the concept study and this field study, pavement permeability is a potential problem with stone skeleton asphalt. Consistently achieving an in-place density greater than 95 percent is unlikely. There are two potential solutions to this problem. First, smaller maximum aggregate size mixtures tend to be less permeable at a given density level. Therefore, a 12.5 mm maximum aggregate size stone skeleton asphalt mixture should be less permeable than a 19.0 mm maximum aggregate size stone skeleton asphalt mixture. The second option is to use a gritting process, which is routinely used on SMA mixes in Germany. Schreck (*7*) states 2-5 mm grit is applied at a rate of 3-5 lbs per square yard on 0/11 mm and larger nominal maximum aggregate size (approximately 16.0 mm maximum aggregate size SMA. The grit is typically precoated with 0.8 percent asphalt binder to control dust. This is not enough binder to cause the particles to stick together and it can be stockpiled. Grit is applied to the mat surface while it is still hot, typically in the range of 150 to 200°F and then rolled in. If the mat is too cold, the grit will not stick. Figure 11 shows the grit being applied, and Figure 12 shows the difference in surface appearance before and after gritting. The grit acts to absorb excess binder on the surface of the SMA, improving early skid resistance and reducing permeability. The application of grit to the surface of a stone skeleton asphalt project should be evaluated for it potential to reduce pavement permeability. The applications of grit to stone skeleton asphalt would increase its cost.

Figure 11. Application of Grit to SMA on Autobahn 3, near Passau, Germany

Figure 12. Gritted (Foreground) and Non-Gritted SMA Surface

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