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FEDERAL HIGHWAY ADMINISTRATION

# USE OF "SULPHUR" IN PAVEMENTS

BY

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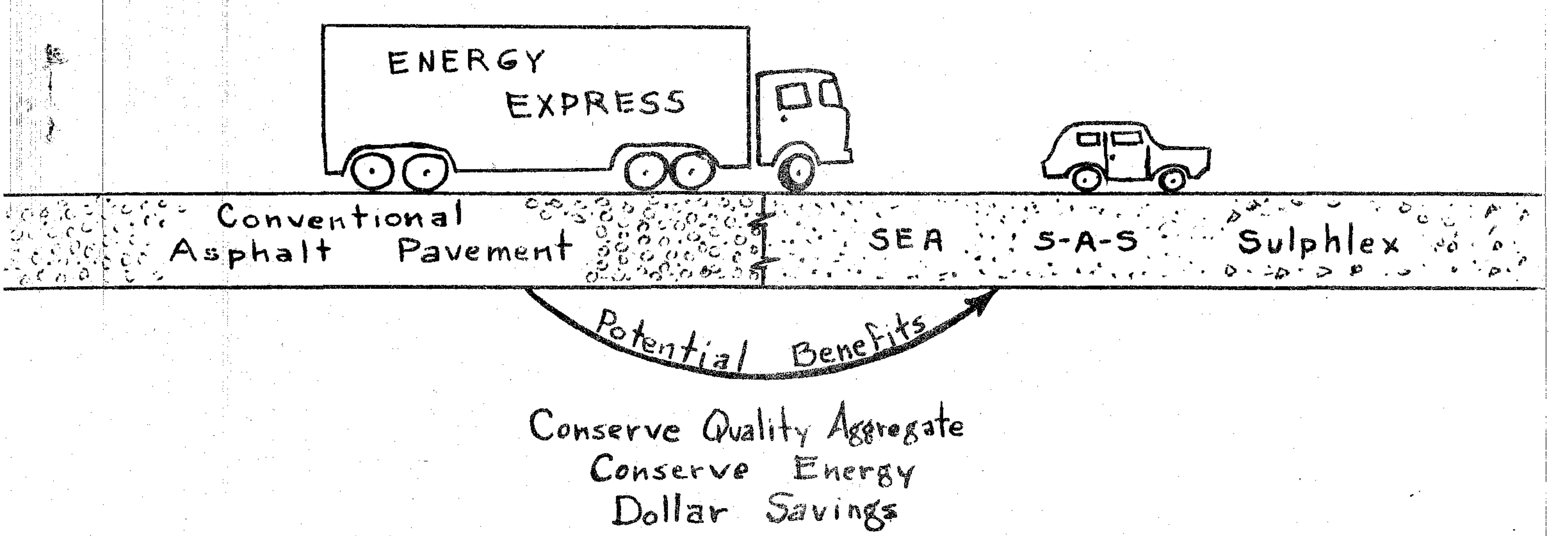


## CONTENTS

## FORWARD

An engineer considering the use of "SULPHUR" as an alternate to conventional paving materials must review as much published or unpublished information as possible so as to benefit from the experiences of others. In order to assist potential users of "SULPHUR" in their review of available information, this summary of the state-of-the-practice within FHWA Region 6 has been prepared.

Reported are the three experimental sections constructed in Texas and the two in Louisiana. These executive summaries highlight the design considerations, quality control, sulphur gas emissions, and post-construction evaluations of the five (5) projects within Region 6. Where appropriate, special design considerations and how these special problems were handled are highlighted. Under References, the available published research and construction reports for the experimental projects are listed for those desiring more detailed data.

The experience to date suggests that sulfur extended asphalt pavements may out-perform conventional asphalt pavements in terms of:

(1) a longer life,
(2) thinner sections,
(3) lower-quality aggregate, and
(4) a lower percent of asphalt (in SEA pavements).

## INTRODUCTION

Because of the need for conservation of petroleum products and high quality aggregates, the FHWA has recently placed major national emphasis on energy and material conservation and the utilization of available materials. One resource which has shown great potential in accomplishing the above and, in addition, possibly improving the pavement properties is "Sulphur." The following answers the question of Why Sulphur?

(1) Sulphur is an available resource which will need to be stored in the future when sulfur becomes a surplus material. Utilizing it as a construction material should offer an ecological benefit.

(2) Research and development work to date has demonstrated through laboratory work and field trials that adding Sulphur to asphalt could improve the pavement properties such as strength and stress fatigue and therefore make it possible to construct higher quality pavements.

(3) As asphalt becomes more costly and if the predicted surplus of Sulphur materializes, the economic benefits of using Sulphur in pavements should increase.

(4) In many parts of Region 6 and nationwide, mineral aggregate of a quality suitable for use in highway paving is not available locally and must be brought in from distant locations at considerable expense. By using Sulphur, locally available sand and lower quality aggregates can be utilized in highway paving, which could lead to considerable cost savings.

Two uses of sulphur in pavement construction have been explored and developed as follows:

(1) Sulphur Extended Asphalt (SEA) Pavements: Those in which elemental sulphur is used as a partial replacement for asphalt.

(2) Sand-Asphalt Sulphur(S-A-S) Pavements: Those in which sand and elemental sulphur are used as a replacement for high quality aggregate.

Strict temperature controls are required because of the effect of temperature on the sulphur solid-liquid-toxic gas emission relationship. The critical temperatures are as follows:

$245^{o}F$ = liquid-solid transition temperature of sulphur
$> 300^{o}F$ = potential for toxic gas emissions with increasing temperatures

The relationship between Hydrogen Sulfide ($H_2S$) and Sulphur Dioxide ($SO_2$) and human effects have been identified as follows:

Toxicity of $H_2S$

| Concentration (ppm) | Effect |
|---|---|
| 0.02 | Odor threshold ("rotten egg" odor) |
| 0.10 | Eye irritation |
| 5-10 | Suggested Maximum Allowable Concentration (MAC) for prolonged exposure |
| 70-150 | Slight symptoms after exposure of several hours |
| 170-300 | Maximum Concentration which can be inhaled for 1-hour without serious consequences |

Toxicity of $SO_2$

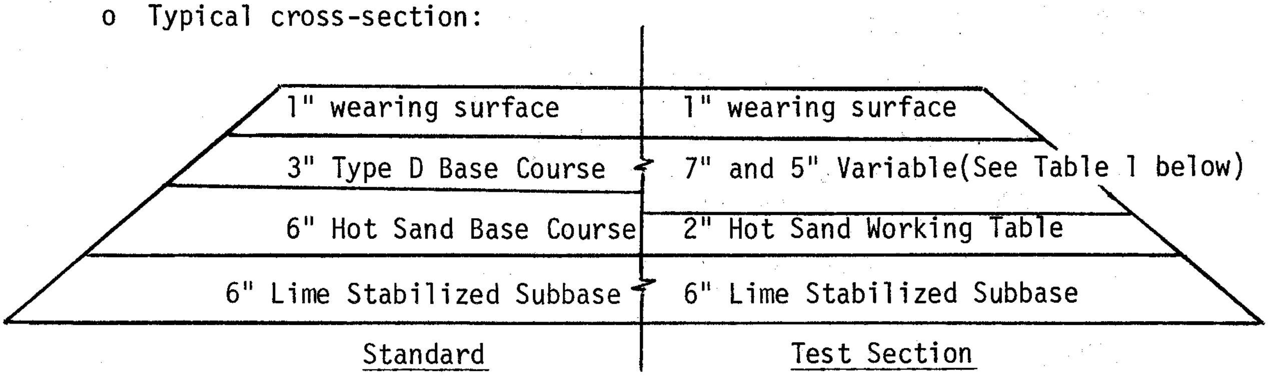
| Concentration (ppm) | Effect |
|---|---|
| 0.3-1 | Detected by taste |
| 3 | Noticeable odor |
| 5 | Maximum Allowable Concentration (MAC) |
| 6-12 | Immediate initiation of nose and throat |
| 20 | Irritation to eyes |

The following case histories illustrate that with proper standard construction control, the emission of sulphur gases is well below the MAC of 5 ppm and therefore caused no effect on construction personnel.

## Lufkin, Texas

General Information:

- o Two lanes of U.S. 69 in Angelina County
- o Constructed in September 1975
- o Concept used: (SEA) partial replacement for asphalt
- o Roadway use: Base course
- o Length of Experimental Section = 3650 feet
- o Traffic volume = 6,000 VPD with 15% trucks
- o Typical cross-section:




Note: Hot Sand = Hot-mix Sand Asphalt

Ten test sections were constructed with varying lengths, material, layer thickness and percent binder content as shown on Table 1 below.

Table 1

| Section | Length | Material | Layer Thickness | SEA Binder Content |
|---|---|---|---|---|
| 1* | 350' | Type D Asphalt Base | 3" } 7" | 4.8% |
| | | Hot Sand Asphalt Base | 4" | 5.4% |
| 2 & 3 | 700' | Type D (SEA) | 3" } 7" | 5.65% |
| | | Hot Sand (SEA) | 4" | 6.0% |
| 4 | 500' | Hot Sand (SEA) | 7" | 7.1% |
| 5 | 400' | Hot Sand (SEA) | 5" | 6.35% |
| 6 | 300' | Hot Sand (SEA) | 5" | 6.0% |
| 7* | 350' | Hot Sand Asphalt Base | 5" | 5.4% |
| 8 & 9 | 700' | Type D (SEA) | 3" } 7" | 5.65% |
| | | Type D (SEA) | 4" | 4.8% |
| 10* | 350' | Type D Asphalt Base | 7" | 4.8% |

*Control Sections

Laboratory SEA Studies:

Marshall test results with a varying content of a 30/70 sulphur-asphalt ratio for binder and a Lufkin sand and Lufkin Type D aggregate generated results with comparatively high stabilities relative to Asphalt Institute criteria. It was found that the optimum mixture is shifted to higher binder contents as more sulphur is incorporated into the emulsion.

The State of Texas uses Hveem rather than Marshall stability tests to optimize mixture designs. Comparable conclusions were derived from Hveem stability tests. Refer to reference number (1) for details on tests and test results.

Mix Design (SEA):

A 30/70 sulphur-asphalt ratio was used for the emulsion binder for all the test sections. See Table 1 above for binder content, layer thickness and type of material for the test sections.

Material Properties:

Asphalt Cement - AC 20 viscosity grade
penetration @ 77°F, 100 g ------- 58
Sulphur - supplied by Texas Gulf Sulphur
commercial grade --- 99.8% purity
SAE Binder (30/70 sulphur/asphalt)
specific gravity 60°F ------ 1.19
softening point ------------- 118°F
penetration 77°F, 100 g ----- 76

Aggregate Specifications:

Aggregate used in Hot Sand = Local Dune Sand
Aggregate used in Type D Mixes = 60/40 ratio of pea gravel and local sand
Gradations for these 2 aggregates are as follows:

| Sieve Size | Type D | Sand* |
|---|---|---|
| passing 1/2" sieve | 100 | -- |
| passing 3/8" sieve | 95 to 100 | -- |
| passing 3/8" sieve, retained on No. 4 sieve | 20 to 50 | -- |
| passing No. 4 sieve, retained on No. 10 sieve | 10 to 30 | -- |
| Total retained on No. 10 sieve | 50 to 70 | 0 |
| passing No. 10 sieve, retained on No. 40 sieve | 0 to 30 | 12.6 |
| passing No. 40 sieve, retained on No. 80 sieve | 4 to 25 | 59.3 |
| passing No. 80 sieve, retained on No. 200 sieve | 3 to 25 | 15.8 |
| passing No. 200 sieve | 0 to 6 | 7.7 |

*Specification gradation not provided, values given are "as extracted" gradation.

Equipment Modifications:

(1) The plant - a portable colloid mill was tied directly into the hot asphalt storage tank and into a hot sulphur truck tanker. The emulsion was prepared by a technician from a French company. Heated tracer lines, valves and storage to handle the emulsion were manufactured on-site.

Construction Procedure:

place 2-inch "Hot Sand" working platform
↓
prepare SEA emulsion in colloid mill
↓
prepare mix using standard pug mill
↓
haul mix 15 miles ± by standard trucks
↓
place with a standard Barber-Greene-Series 100 paver
↓
compact with a Hyster C-615A vibratory steel roller

Sulphur Emissions:

Instrumentation for measuring hydrogen sulfide ($H_2S$) emissions:

(1) Houston - Atlas ambient $H_2S$ Detection System - furnished for use on project by U. S. Bureau of Mines

(2) a portable Metronics "Rotorod Gas Sampler" - furnished by TTI.

Based on the recommended maximum allowable concentration (5-10 ppm) suggested by American Conference of Governmental Industrial Hygienist, the $H_2S$ concentrations measured in areas most frequented by construction personnel were well below the critical threshold. Measured emissions at some of the critical construction areas are as follows:

| Location | $H_2S$ (ppm) |
|---|---|
| Vicinity of Colloid Mill | negligible |
| Inside Opening of SEA Emulsion Storage Tank | 15 ppm |
| Pug Mill Platform | $<1.0$ |
| Over Truck Dump Body | $<1.0$ |
| Paver Hopper during Paving | negligible |

Quality Control and Post-Construction Evaluation:

The testing program consists of the following:

Traffic Analysis - - - - - - - - - - - - - - continuous analysis
Visual Evaluation - - - - - - - - - - - - - -6-month intervals for 3 years
Mays Meter (PSI) - - - - - - - - - - - - - - 6-month intervals for 3 years
Benkelman Beam Deflections - - - - - - - - -6-month intervals for 3 years
Dynaflect Deflections - - - - - - - - - - - -6-month intervals for 3 years

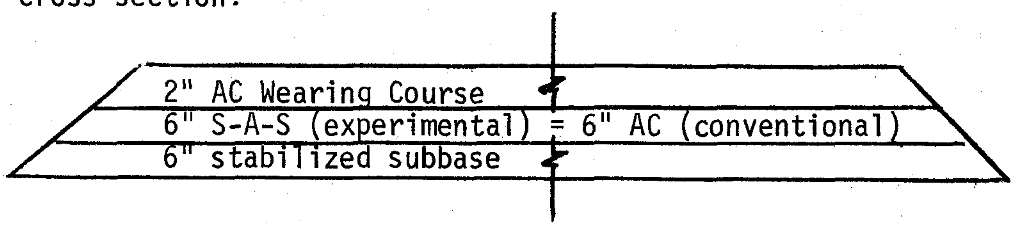
Cored Samples for density, marshall stability, hveem stability, resilient modulus, indirect tension - - -6-month intervals for 3 years

The post-construction evaluation as shown above is still in progress at this writing. This experimental work has thus far demonstrated that SULPHUR can be effectively used as a binder component to reduce asphalt demand.

## Sulphur, Louisiana

### General Information:

- Two lanes of Louisiana Highway 108 in Calcasieu Parish
- Constructed in January 1977
- Concept used: (S-A-S) quality aggregate substitute
- Roadway use: 6" base course replacing 6" AC base course
- Length of Experimental Section = 1375 feet
- Typical cross-section:




### Laboratory S-A-S Mix Design:

(1) Marshall Test (Modified)
Stability at 140$^{\circ}$F, pounds - - - - - - - - - - - 1200 min.
Flow Valve, 0.01 inch- - - - - - - - - - - - - - - 6 min.
Air Voids, percent in mixture- - - - - - - - - - 15 max.
Stability after immersion, pounds- - - - - - - - 60% of initial stability min.

(2) Workability, slump (inches)- - - - - - - - - - - - 1-1/2 - 6

### Mix Design (S-A-S):

81% - Sand (76%) + Mineral Filler (5%)
6% - Asphalt
13% - Sulphur

### Material Properties:

Asphalt Cement - AC-40 viscosity grade
viscosity @ 275$^{\circ}$F, SSF - - - - - 320
penetration @ 77$^{\circ}$F, 100 gm., 5 sec. - - - 62

Sulphur - supplied by Freeport Sulphur Company
purity - - - - - 99.830%
carbon content - - -.140%
ash - - - - - - - - - .004%
impurities - - - - -.026%
Mineral filler - limestone dust

Aggregate Specifications:

| U. S. Sieve No. | Sand Gradation % Passing |
|---|---|
| 4 | 100% |
| 8 | 95-100 |
| 16 | 80-95 |
| 30 | 65-85 |
| 50 | 30-60 |
| 100 | 10-25 |
| 200 | 5-15 |

specific gravity - - - - 2.65
loose unit wt. - - - - - 86.9 pcf
rodded unit wt. - - - - 97.4pcf
voids in mineral aggregates -- 41%

Special Design Considerations:

Problem - Sulphur seepage - with a 37-mile haul distance, the liquid sulphur has a tendency to seep downward.
Solution- Add mineral filler to mix design. Increasing the amount of minus No. 200 material controls the tendency of the liquid sulfur to seep.

Equipment Modifications:

(1) The plant - add a full circulating heated and insulated system (storage tank, pipes, etc.) for the molten sulphur. Note, the same weigh bucket was used for both sulphur and asphalt.

(2) The haul trucks - propane heated dump truck bodies were necessary to prevent cooling of the mixture below 245$^{o}$F. (5 dump truck bodies furnished by Shell Canada Limited.)

(3) The paver - A Barber-Greene Series 100 rubber tired finisher was modified by installing two double-acting hydraulic rams for balancing upward lift and downward pressure on the screed for the desired layer thickness. This was required because S-A-S mixtures are initially too soft to support the weight of a conventional screed assembly.

Construction Procedure:

sand dried and heated
↓
conveyed to hot bins
↓
add 4% mineral filler
↓
10-second dry mix
↓
add 6% asphalt
↓
30-second mix
↓
add 13% sulphur
↓
25-second mix
↓
haul 37 miles by heated dump trucks
↓
place in 2-inch lifts
↓
construct transverse joints as required
↓
apply 0.077 gal/sq. yd. of RC-250 tack coat to 1st and 2nd lifts and transverse joints of S-A-S base

Note: No compaction required

Average ambient Temperature = $43^{o}$F

Average pavement mix Temperature
at hot plant = $295^{o}$F
at paver = $290^{o}$F

| | | |
|---|---|---|
| Total Quantities = | sand - | 817 tons |
| | asphalt - | 60 tons |
| | sulphur - | 120 tons |
| | | 997 tons |

Quality Control:

| | |
|---|---|
| Marsh Briquettes - - - - - - - - - - - - - - - - | 4 for every 5 loads |
| Slump- - - - - - - - - - - - - - - - - - - - - - - | 1 min. for every 5 loads |
| Mix Gradation- - - - - - - - - - - - - - - - - - | 2 (1 each morning and evening) |
| Binder Content (Asphalt and Sulphur) - - - | 2 (1 each morning and evening) |
| Roadway Densities- - - - - - - - - - - - - - - | 5 per day |

Sulphur Emissions:

Instrumentation for measuring the sulphur gases provided by the U. S. Bureau of Mines, Boulder City, Nevada.

(1) - For continuous recording - a Hydrogen Sulfide Analyzer Model 850
(2) - For portable-type measurements - a Drager Multi-Gas Detector

Measurements during the project indicated little chance that concentrations of gases would be dangerous. Maximum readings obtained were as follows:

| Location | $H_2S$ (ppm) | $SO_2$ (ppm) |
|---|---|---|
| Sulphur Storage Tank | 0 | 0 |
| Asphalt Plant Hopper | 0.8 | 0 |
| Asphalt Plant Pug Mill | 2.0 | 0 |
| Asphalt Paver (Driver Level) | 3.0 | 0 |

Post-Construction Evaluation:

Evaluation of both the AC (control) base and the S-A-S (experimental) base strength is being accomplished by deflection analysis using the Dynaflect. Deflection values are then translated into a structural coefficient ($\bar{c}$), which is the index of strenth used in flexible pavement design. The following are the deflection-determined strength coefficients for the conventional black base and the S-A-S base at an adjusted pavement temperature of 60$^{o}$F:

| Age (days) | Structural Coefficient ($\bar{c}$) Black Base | S-A-S |
|---|---|---|
| 7 | 0.43 | -- |
| 40 | 0.41 | 0.44 |
| 70 | 0.38 | 0.47 |
| 100 | -- | 0.44 |

To date, the deflection analysis indicates that the S-A-S material is slightly better able to distribute induced loads and also slightly less susceptible to a change in strength with temperature than conventional asphaltic concrete.

## Kenedy County, Texas

General Information:

- o Two lanes (northbound) of U.S. 77 in Kenedy County
- o Constructed in April 1977
- o Concept used: (S-A-S) quality aggregate substitute
- o Roadway use: 10-inch, 7-inch and 4-inch S-A-S base course replacing 10-inch, 7-inch and 4-inch AC base course
- o Length of Experimental Section = 3000 feet
- o Traffic volume = 1973-3730 ADT; 1993-76,000 ADT w/20.8% Truck
- o Typical cross-section:

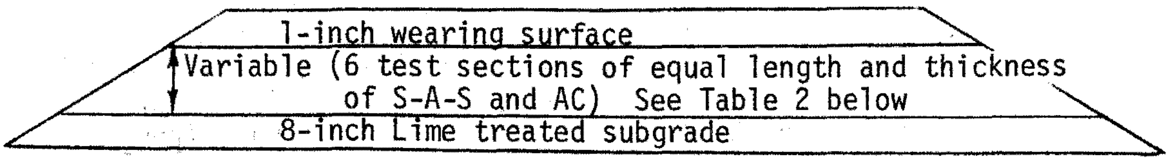



Table 2

| Section | Length | Material | Layer Thickness |
|---|---|---|---|
| 1 | 500' | S-A-S | 10" |
| 2 | 500' | S-A-S | 7" |
| 3 | 500' | S-A-S | 4" |
| 4 | 500' | Asphalt Concrete | 4" |
| 5 | 500' | Asphalt Concrete | 7" |
| 6 | 500' | Asphalt Concrete | 10" |

Laboratory S-A-S Mix Design:

(1) Marshall Test (Typical Test Value)
Stability at 140°F, pounds - - - - - 1200 (min) (2000)
Flow valve, 0.01 inch - - - - - - - - 6 (min)
Air Voids, percent in mixture - - - - 15 (max) (12)

(2) Workability, slump (inches) - - - - - 1-1/2 - 6

(3) Flexural strain at failure - - - - - 0.0035 in/in

Mix Design (S-A-S):

Sand - 80.8 weight percent of total mix
Asphalt - 6.2 weight percent of total mix
Sulphur - 13.0 weight percent of total mix

Material Properties:

Asphalt Cement - AC-20 viscosity grade
viscosity @ 275°F, stokes (min) - - - - - - - - - - 2.5
penetration @ 77°F, 100 g, 5 sec. (min) - - - - - 55
flash point, coc, F (min) - - - - - - - - - - - - - 450

Sulphur - supplied by Warren Petroleum & Texasgulf, Inc.

| | Warren Petroleum | Texasgulf, Inc. |
|---|---|---|
| purity | 99.95% | 99.97% |
| carbon content | .005% | .03% |
| ash | .003% | .003% |
| color | bright yellow | bright yellow |

Aggregate Specifications:

The mineral aggregate used in this project consisted of a 65-35% coarse to fine sand blend of the following two sands:

(1) a concrete type sand from Corpus Christi
(2) a field local sand

Individual sieve analyses of sands and the 65/35 blend and the project gradation specifications are as follows:

Percent Weight Passing

| Sieve Size | Concrete Sand | Field Sand | 65/35 Blend | Project Specifications |
|---|---|---|---|---|
| 3/8" | 100 | | 100 | 100 |
| No. 4 | 96 | | 97 | 90-100 |
| No. 8 | 91 | | 94 | 85-100 |
| No. 16 | 85 | | 90 | 80-95 |
| No. 30 | 65 | 100 | 77 | 65-85 |
| No. 50 | 21 | 70 | 39 | 30-60 |
| No. 100 | 2 | 38 | 14 | 10-25 |
| No. 200 | 1 | 10 | 4 | 5-15 |
| Plasticity Index | | | | 6 max |
| Liquid Index | | | | 25 max |

Equipment Modifications:

(1) The plant - add sulphur storage tank, sulphur pump, insulated pipes and fittings, valves and steam boiler to heat system.

(2) The haul trucks - propane heated dump truck bodies were necessary to keep the mix temperatures within the working temperature range ($250^{o}F$ - $300^{o}F$). (4 dump truck bodies loaned by Shell Canada Limited.)

(3) The paver - the hot S-A-S pavement mixtures are soft and plastic at the time of placement and cannot usually support the weight of the floating screed assembly on the conventional paver. The screed must therefore be fully supported for strike-off and consolidation.

The Barber-Greene Company has developed a modification kit for use with Barber-Greene Model Series 100 "Matmakers." For this project, a Barber-Greene "Matmaker" Model SB-170, Rubber-Tired Interstate Finisher equipped with automatic grade and slope controls and with the modification kit installed, was used. Other slight modifications were made on the hopper, auger chamber and screed for more efficient operation. Refer to page 31 of reference No. 2 for details.

Construction Procedure:

- sand dried and heated
- ↓ conveyed to pug-mixer
- ↓ 5-second min. dry mix
- ↓ add 6.2% asphalt
- ↓ 20-second min. mix
- ↓ add 13% sulphur
- ↓ 25-second min. mix
- ↓ haul 1 1/2 miles by heated dump truck
- ↓ place in 2-inch or 3-inch lifts depending on total thickness required. See figure below.
- ↓ construct transverse joints as required
- ↓ apply a heavy coat of emulsified asphalt Type EA-11M between lifts and to joint face

Note: No compaction required

The paving thickness layer sequence to construct the 10-inch, 7-inch and 4-inch S-A-S test sections were as follows:

| Total S-A-S thickness → | 10" | 7" | 4" |
|---|---|---|---|
| lift No. 4 | 2" | 2" | 2" |
| lift No. 3 | 2" | 2" | 2" |
| lift No. 2 | 3" | 3" | |
| lift No. 1 | 3" | | |

Ambient Temperature:(F°)
Average max = $81^{0}$ Average min = $59^{0}$ Average = $70^{0}$

Average pavement mix Temperature
at hot plant = $286^{0}$F
at paver = $281^{0}$F

Total Quantity of Sulphur = 238 tons

Quality Control:

The following schedule was used by the field laboratory personnel as a guide:

1. Check temperature of each truck load of mix and record
2. Make slump tests as required to monitor consistency of the mixture
3. Determine binder content of mixtures - asphalt and sulphur
4. Make set of 9 Marshall test specimens at least twice daily; three specimens to be tested in field at 24 hours, six specimens to be taken for post-construction evaluation by TTI.

5. Take 40 lbs. of mixture each 1/2 day of operation and place in containers for evaluation by TTI.
6. When plant is lined out, take one 200 lb. sample of mixture for study by TTI.

Sulphur Emissions:

The responsibility for collecting sulphur emissions data was shared by three agencies; TTI, The Bureau of Mines, and the Texas Air Control Board.

The instrumentation used was as follows: HOUSTON ATLAS Hydrogen Gas Analyzer; COLORTEC Hydrogen Sulfide Detector; Hi-VOL Air Sampler; DRAGER Multi-Gas Detector; INTERSCAN Hydrogen Sulfide Recorder or equivalent; SENTOX System; Bubbler-Gas/Particulate samplers.

Measurements confirmed that as long as the upper temperature limit of 300°F was not exceeded, concentrations of the gaseous pollutants remained below recommended allowable threshold limits. Measurements at various locations were as follows:

| Location | $H_2S$ (ppm) | $SO_2$ (ppm) | Sulphur Dust |
|---|---|---|---|
| Sulphur Storage Tank Area | .02 - 23 | 3 - 12 | -not measured- |
| Hot Mix Plant Area | Trace - 2.0 | Trace | |
| Paver Hopper | 2 - 5 | 0 - 0.5 | |
| Paver Operators Chair | Trace | 0 | |
| Directly Over Paved Surface | Trace - 1.3 | 0 | |

Post-Construction Evaluation:

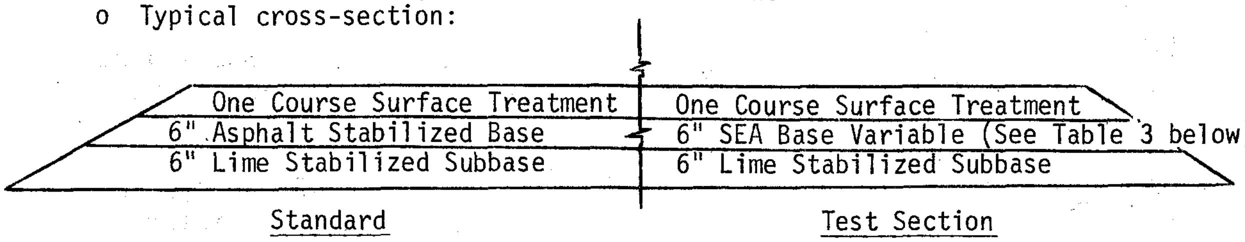
TTI is responsible for testing, evaluating and reporting the results of this experimental project over a 3-year period. The testing program consists of the following:

| | |
|---|---|
| Traffic Analysis - - - - - - - - - - - - - - | continuous analysis |
| Visual Evaluation- - - - - - - - - - - - - - | 6-month intervals for 3 years |
| Mays Meter (PSI) - - - - - - - - - - - - - - | 6-month intervals for 3 years |
| Benkelman Beam Deflections - - - - - - - - - | 6-month intervals for 3 years |
| Dynaflect Deflections- - - - - - - - - - - - | 6-month intervals for 3 years |
| Cored samples for density, marshall stability, hveem stability, resilient modulus, indirect tension- - - | 6-month intervals for 3 years |

## College Station, Texas

General Information:

- Two lanes of MH 153 in Brazos County
- Constructed in June 1978
- Concept used: (SEA) partial replacement for asphalt
- Roadway use: Base course
- Length of Experimental Section = 2700 feet
- Traffic volume = 8,100 VPD with 6.1% trucks
- Typical cross-section:




Six test sections were constructed with varying material and percent binder content as shown below:

Table 3

| Section | Length | Material | Thickness | SEA Binder Content |
|---|---|---|---|---|
| 1 | 450' | 40-60 SEA binder (Colloid Mix) Job mix aggregate | 6" | 5% |
| 2 | 450' | 40-60 SEA binder (Colloid Mix) 75:25 Gravel: Field Sand | 2"<br>4" | 6.8%<br>7.5% |
| 3 | 450' | 30-70 SEA binder (Colloid Mix) 75:25 Gravel: Field Sand | 2"<br>4" | 6.3%<br>7.0% |
| 4 | 450' | 30-70 SEA binder (direct substitution) 75:25 Gravel: Field Sand | 2"<br>4" | 6.3%<br>7.0% |
| 5 | 450' | 40-60 SEA binder (Colloid Mix) 50:50 Concrete Sand:Field Sand | 2"<br>4" | 7.9%<br>8.5% |
| 6 | 450' | 30-70 SEA binder (Colloid Mix) 50:50 Concrete Sand: Field Sand | 6" | 8.0% |

Laboratory SEA Studies:

Marshall and Hveem stabilities, percent air voids tests and other laboratory tests were run with a varying binder content, varying SEA ratio, and varying aggregate blend. The job mix formulas studies are as follows:

| Job Mix Formula | SAE Ratio | Binder Content | Aggregate Blend | Marshall Stability | Air Voids |
|---|---|---|---|---|---|
| 1 | 30/70 | 5.9% | 75-25 Gravel-Field Sand | 1400 | 10.3% |
| 2 | 30/70 | 7% | 75-25 Gravel-Field Sand | 1600 | 8.3% |
| 3 | 30/70 | 8% | 75-25 Gravel-Field Sand | 1800 | 4.5% |
| 4 | 40/60 | 6.2% | 75-25 Gravel-Field Sand | 2100 | 10.1% |
| 5 | 40/60 | 7% | 75-25 Gravel-Field Sand | 1900 | 7.7% |
| 6 | 40/60 | 8% | 75-25 Gravel-Field Sand | 2200 | 5.7% |
| 7 | 50/50 | 6% | 75-25 Gravel-Field Sand | 1100 | 13.5% |
| 8 | 50/50 | 7.5% | 75-25 Gravel-Field Sand | -- | 12.8% |
| 9 | 50/50 | 8% | 75-25 Gravel-Field Sand | 1400 | 12.2% |
| 10 | 50/50 | 10% | 75-25 Gravel-Field Sand | 2700 | 5.6% |
| 11 | 30/70 | 6% | 50-50 Conc. Sand-Field Sand | 650 | 12.8% |
| 12 | 30/70 | 7.5% | 50-50 Conc.Sand-Field Sand | 800 | 9.2% |
| 13 | 30/70 | 8.5% | 50-50 Conc. Sand-Field Sand | 800 | 7.6% |
| 14 | 40/60 | 6% | 50-50 Conc. Sand-Field Sand | 1025 | 12.7% |
| 15 | 40/60 | 7.5% | 50-50 Conc. Sand-Field Sand | 1100 | 9.8% |
| 16 | 40/60 | 8.5% | 50-50 Conc. Sand-Field Sand | 1100 | 7.1% |
| 17 | 50/50 | 6% | 50-50 Conc. Sand-Field Sand | 250 | 15.8% |
| 18 | 50/50 | 7% | 50-50 Conc. Sand-Field Sand | 600<br>900 | 14.5% |
| 19 | 50/50 | 8% | 50-50 Conc. Sand-Field Sand | 200<br>900 | 12.2% |
| 20 | 50/50 | 8.5% | 50-50 Conc. Sand-Field Sand | 950 | 6.1% |
| 21 | 50/50 | 9.5% | 50-50 Conc. Sand-Field Sand | 8400 | 9.0% |

Mix Design (SEA):

A 40/60 and 30/70 sulphur-asphalt ratio was used for the emulsion binder. See Table 3 above for the binder content and type of material for the 6 test sections. Binder content for the standard mix was 5% asphalt.

Material Properties:

Asphalt cement - EXXON AC-20 viscosity grade

penetration @ 77°F, 100 g, 5 sec. - - - - - - - - 55 min.
specific gravity 60°F - - - - - - - - - - - - - - - 1.04
specific gravity 77°F - - - - - - - - - - - - - - - 0.96
wt/gal, lbs @ 275°F - - - - - - - - - - - - - - - - 8.01

Sulphur - supplied by Texas gulf, Inc.
commercial grade - - - - - - - - - - - - - 99.97% purity

SAE Binder (40/60 - sulphur/asphalt)
specific gravity 60°F- - - - - - - - - - - 1.28
specific gravity 77°F - - - - - - - - - - 1.18
wt/gal, lbs @ 275°F- - - - - - - - - - - - 9.83
(30/70 sulphur/asphalt)
specific gravity 60°F- - - - - - - - - - - 1.21
specific gravity 77°F- - - - - - - - - - - 1.12
wt/gal, lbs. @ 275°F - - - - - - - - - - - 9.30

Note: Silicone in the amount of 1 ppm was added to the hot asphalt prior to preparing the SEA emulsion. There is some evidence that silicone makes the SEA emulsion more stable and the SEA pavement mixes easier to work.

Aggregate Specifications:

Four aggregate types were used as follows:

(1) Bank Run Gravel (2) Field Sand (3) Concrete Sand (4) Pea Gravel

Three aggregate blends were used as follows:

(1) 75:25 Bank Run Gravel: Field Sand
(2) 50:50 Field Sand: Concrete Sand
(3) 55:30:15 Bank Run Gravel: Pea Gravel: Field Sand

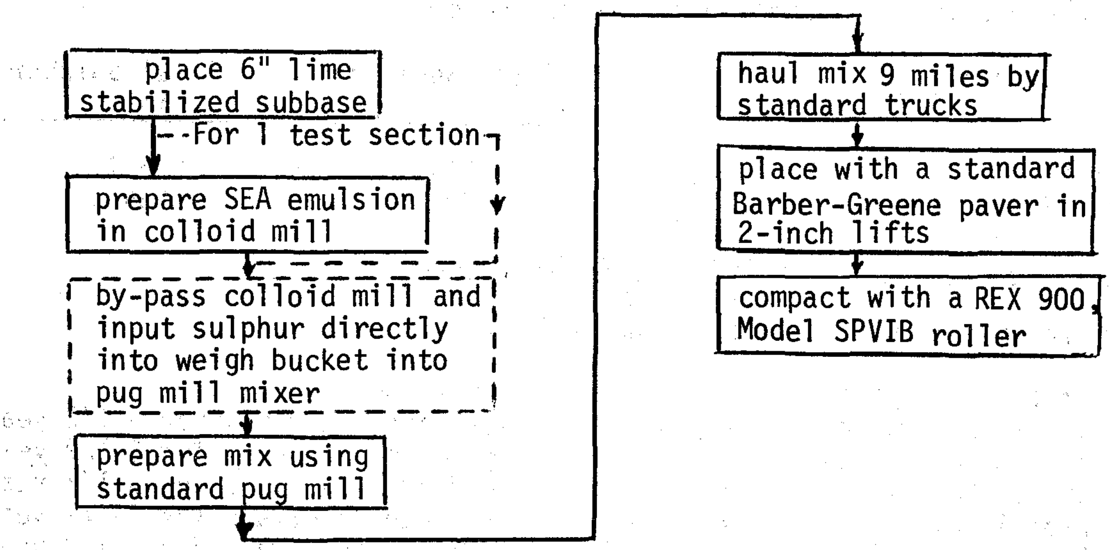
Individual sieve analyses of the aggregate blends are as follows:

| | Percent Passing | | |
|---|---|---|---|
| Sieve Size | 75:25 Bank-run Gravel: Field Sand | 50:50 Concrete Sand: Field Sand | 55:30:15 Bank-run Gravel: Pea Gravel: Field Sand |
| 1 1/2" | 100 | | 100 |
| 3/4" | 91 | | 93 |
| 3/8" | 81 | | 83 |
| No. 4 | 75 | 100 | 70 |
| No. 8 | 71 | 96 | 50 |
| No. 16 | 63 | 91 | 43 |
| No. 30 | 53 | 81 | 36 |
| No. 50 | 30 | 55 | 20 |
| No. 100 | 10 | 17 | 6 |
| No. 200 | 2 | 3 | 2 |

Equipment Modifications:

(1) The plant - a colloid mill supplied by Texasgulf, Inc., was added to emulsify the liquid asphalt and sulphur prior to introduction into the mixer. Since one test section called for direct substitution of the sulphur into the pugmill, provisions for bypassing the sulphur around the colloid mill and directing it to the weigh bucket were made. Heat traced insulated lines and heated and insulated storage for the liquid sulphur were also required.

Construction Procedure:




Ambient Temperature

Average max = 94°F  Average min = 74°F  Average = 84°F

Average Pavement Mix Temperature

at hot plant = 255°F

at paver = 225°F

Total Molten Sulphur Utilized = 74 Tons

Sulphur Emissions:

Instrumentation for measuring sulphur emissions consisted of the following:

(1) DRAGER multi-gas detector with tubes
(2) COLORTEK, hydrogen sulphide detector cards
(3) ROTOROD gas sampler, Model 721

Measured emissions at some of the critical construction areas are as follows:

| Location | $H_2S$(ppm) | $SO_2$(ppm) |
|---|---|---|
| Sulphur Storage Tank Area | 4.5 | - |
| Hot Mix Plant Area | Trace - 1.0 | 0 - 10 |
| Vicinity of Paver | 0 - Trace | 0 - Trace |

Particulate Sulphur Measurements were as follows:

| Location | Total Sediment mg | Total Sulphur mg |
|---|---|---|
| Test Site | 120.07 | 0.654 |
| Hot Mix Plant | 1008.47 | 0.595 |

Quality Control and Post-Construction Evaluation:

The testing program consists of the following:

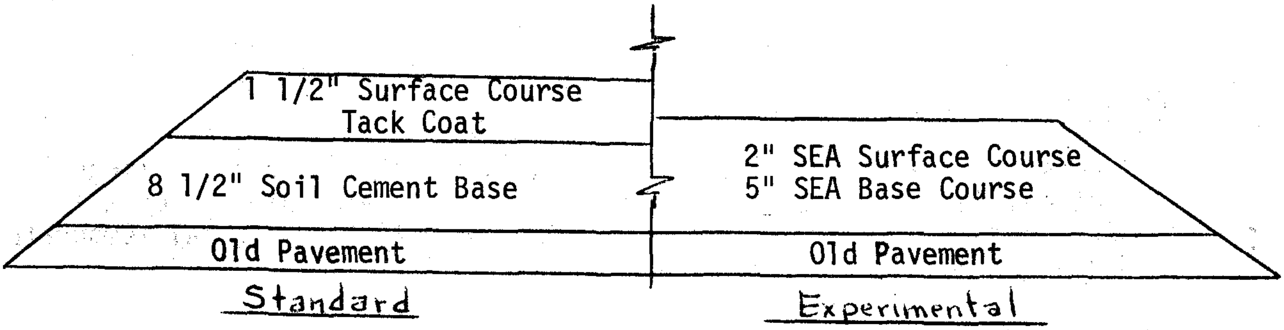
| | |
|---|---|
| Traffic Analysis- - - - - - - - - - - | -continuous |
| Visual Evaluation - - - - - - - - - - | -6-month intervals for 3-1/2 years |
| Mays Meter (PSI)- - - - - - - - - - - | -6-month intervals for 3-1/2 years |
| *Duomorph- - - - - - - - - - - - - - - | -6-month intervals for 3-1/2 years |
| Profilometer- - - - - - - - - - - - - | -6-month intervals for 3-1/2 years |
| Dynaflect Deflections - - - - - - - - | -6-month intervals for 3-1/2 years |
| Cored Samples for density, marshall and hveem stability, resilient modulus, indirect tension | - 6-month intervals for 3-1/2 years |
| Interim and Final Reports - - - - - - | -6-month intervals for 3-1/2 years |

*(measures very small bending strains and is used to determine the material's stiffness)

## Darrow, Louisiana

General Information:

- o Two lanes of Louisiana Highway 22 in Ascension Parish
- o Constructed in November 1978
- o Concept used: (SEA) partial replacement for asphalt
- o Roadway use: 5" Base course + 2" Surface course
- o Length of Experimental Section = 1 mile
- o Traffic volume - 1500 ADT/lane
- o Typical cross-section:




The experimental section consisted of the following:

| Material | Aggregate | % SEA Binder |
|---|---|---|
| SEA Surface Course (1-2" lift) | Gravel/Sand Blend | 5.4% |
| SEA Base Course (2-2 1/2" lifts) | Blends of Local Sand/ Concrete Sand as follows: 75/25 65/35 50/50 | 9.0% |

Mix Design (SEA):

A 40/60 sulphur-asphalt ratio was used for the emulsion binder.

Material Properties:

Asphalt Cement - AC 30 viscosity grade
penetration @ 77$^{o}$F, 100 gm., 5 sec. - - - - - 63
Sulphur - supplied by Gulf Freeport Chemical Company

Equipment Modifications:

(1) The plant - a colloid mill developed by Gulf Oil Canada Limited and called the Sulphur-Asphalt Mixing Module (SAM) was added to emulsify the liquid asphalt and sulphur prior to introduction into the mixer.

Later in the project, the concept of direct substitution of the sulphur into the pugmill was utilized;therefore provisions for directing the sulphur and asphalt to the weigh bucket were made.

Construction Procedure:

A construction procedure similar to that described for the College Station, Texas project was utilized. Typical temperatures for the SEA hot mix upon arrival at the project were 285$^{o}$F. Typical temperatures during compaction were 235$^{o}$F.

Sulphur Emissions:

Their analysis of the earlier project in Sulphur, Louisiana indicated that gas emissions were well below the recommended Maximum Allowable Concentration. Therefore, no sulphur gas emissions were made.

Quality Control:

The quality control and frequency of tests described for the Sulphur, Louisiana project were utilized here.

Post-Construction Evaluation:

Evaluation will be accomplished by deflection analysis using the Dynaflect as described for the Sulphur, Louisiana project.

In addition, samples of material prepared both by direct substitution of the sulphur into the pugmill and by utilizing the colloid mill have been made available to the FHWA Office of Research. They will evaluate the samples using a scanning electron microscope to determine material composition. This should provide a good comparison of the sulphur-asphalt blending techniques.

## San Antonio, Texas

A 600-foot research roadway section was recently constructed utilizing a new binder, "Sulphlex," for the hot mix material. This test section is within the Southwest Research Institute complex in San Antonio, Texas, and will become a part of their road system and should therefore experience a small amount of car and truck traffic.

"Sulphlex" is a plasticized sulphur cement consisting of approximately 75% sulphur and 25% chemical plasticizers. "Sulphlex" is used as the binder in a hot mix material and is intended as a total replacement for asphalt.

The Southwest Research Institute has research this concept of utilizing "Sulphlex" as the binder in lieu of asphalt and reports that:

(1) it appears from the results thus far that the chemical reaction is quite stable and reversion of "Sulphlex" to crystalline elemental sulfur is unlekely. However, this aspect will receive continual evaluation until long term data has been obtained.

(2) hot mix properties such as marshall stability, etc. equal or exceed present requirements.

The preparation of the "Sulphlex" binder for this experimental section was accomplished at the Southwest Research Institute by mechanical mixing. Molten sulphur was delivered and pumped into a pair of heated 4-foot diameter tanks. The required chemicals were then added and mixed with a mechanical mixer. The prepared "Sulphlex" binder was then transported by trucks to the plant for mixing with the aggregate.

The significance of this experimental section was to illustrate that construction of a hot mix made with "Sulphlex" is performed with conventional equipment. Conventional equipment was used at the plant to prepare the hot mix, a conventional Barber-Greene paver was used for the spreading and a conventional steel roller was used for compaction. No modifications were required for any of this equipment.

Typical temperatures for the "Sulphlex" hot mix were as follows:
at plant - 240°F
at roadway - 170°F

The "Sulphlex" hot mix was placed in 1 1/2 inch lifts on a 4 inch crushed limestone base. Several sections of rigid, flexible and intermediate "Sulphlex" hot mix were laid including two control sections; one AC control and one PCC control. The following table summarizes the test sections constructed:

| | Total Thickness | Binder Content | Length of Test Section (Feet) |
|---|---|---|---|
| Control AC | 3" | 6% (AC-10) | 100 |
| Control PCC | 8" | 5.5 sack mix | 40 |
| Rigid | 3"<br>8" | 8%<br>6% | 100<br>40 |
| Flexible | 3"<br>3" | 6%<br>8% | 100<br>100 |
| Intermediate | 3"<br>8" | 6%<br>8% | 100<br>40 |

It is important to recognize that "Sulphlex" is not intended to replace asphalt in-total in roadway construction but will be offered as an asphalt alternate so as to enhance conservation measures for the asphalt petroleum product.

Once the plasticizing chemicals are optimized and the preparation of this new binder is "scaled-up," an experimental test section on a medium-density highway should be constructed so as to evaluate its performance.

## CONCLUSIONS

A quick overview of the field trials in Region 6 is summarized below. The order in which they are listed follows the order of actual construction.

| Location | Date Constructed | Roadway Use | Concept | Mix Design | Experimental Section |
|---|---|---|---|---|---|
| Lufkin, Texas (U.S. 69) | September 1975 | 5" 7" Base Course | SEA | 30/70 weight % of sulphur/ asphalt binder | 2 lanes 3650 ft. |
| Sulphur, La. (Hwy.108) | January 1977 | 6" Base Course | S-A-S | 81%-sand 6%-asphalt 13%-sulphur | 2 lanes 1375 ft. |
| Kenedy County, Texas (U.S. 77) | April 1977 | 10" 7" 4" Base Course | S-A-S | 80.8%-sand 6.2%-asphalt 13.0%-sulphur | 2 lanes 3000 ft. |
| College Station, Texas (MH 153) | June 1978 | 6" Base Course | SEA | 40/60 30/70 } weight % of sulphur/ asphalt binder | 2 lanes 2700 ft. |
| Darrow, La. | November 1978 | 5" Base Course 2" Surface Course | SEA | 40/60 50/50 } weight % of sulphur/ asphalt binder | 2 lanes 5280 ft. |
| San Antonio, Texas Southwest Research Institute | December 1978 | 8" 3" Surface Course | "Sulphlex" binder | 0% asphalt 75% sulphur 25% plasticizers | 2 lanes 480 ft. |

Where are we now?

(1) The experience gained from the test sections constructed in Texas, Louisiana and other parts of the U.S. and Canada suggests that sulphur may be the answer to two very critical concerns facing the highway industry:
  a. construction of energy - alleviate through partial replacement of asphalt with sulphur
  b. conservation of high quality natural aggregate - alleviate through replacement of high quality aggregate with sulphur and marginal or low quality aggregate.

(2) The material characterization procedure, mix design methodology, construction equipment and quality control procedures have been tested and modified as necessary since the first Texas trial in 1975.

(3) The low emissions measured at the trial sections indicate that toxic emissions will not be a problem. Further research is underway.

(4) We are presently in a position where we need to develop and refine the necessary technology for our future use.

(5) The question of long range performance needs to be evaluated.

State agencies are encouraged to construct trial sections on an experimental or research effort so as to obtain construction experience, determine and evaluate their benefits of utilizing sulphur in pavements and obtain short range and long range performance evaluations. It is only through actual construction evaluations that we will be able to fully evaluate the overall potential benefits of this new SEA and S-A-S construction material.

The recent development of "Sulphlex" which replaces the asphalt in total as the binder in hot mix, climaxes the research of utilizing sulphur as a highway construction material. It is important to recognize that "Sulphlex" is not intended to replace asphalt in-total in highway construction but will be offered as an asphalt alternate so as to enhance conservation measures for the asphalt petroleum product. Further research work by the Southwest Research Institute in San Antonio, Texas should optimize the plasticizer composition and scale-up the preparation of this new binder AND at that time actual highway construction evaluations will also be promoted.

List of Recommendations for Improved Practice

(1) It is recommended that for best workability and strength, processing of SEA binders should be accomplished in the temperature range of 265$^{o}$F to 285$^{o}$F. To minimize hydrogen sulfide formation, temperatures should not exceed 300$^{o}$F.

(2) The "slump" test is an excellent indicator of the workability of the S-A-S mix and therefore should be included in the design and quality control specifications.

(3) To assure that a smooth S-A-S mix mat is layed, extra care should be taken not to feed "cold" material (less than 240$^{o}$F) or too stiff a material (less than 1-1/2 inch slump) to the paver augers.

(4) So as to avoid tearing of the S-A-S mixture during pavement, extra care should be taken that an excess of No. 50 to No. 100 mesh sand is not contained in the mixture.

(5) It is recommended that goggles be required in areas such as the hot mix plant and in the vicinity of the paver. This should eliminate the irritating of the inner surfaces of the eyelids by sulphur dust.

(6) Modify conventional asphaltic concrete batch plant so that the plant has the capability to produce either conventional asphalt concrete or S-A-S mixes.

## REFERENCES


(1) Research Report, "Sulphur/Asphalt Mixture Design and Construction Details - Lufkin Field Trials" by Bob M. Gallaway and Donald Saylack, Texas Transportation Institute, January 1976

(2) Construction Report, "Sand-Asphalt-Sulphur Pavement Field Trial, Highway U. S. 77, Kenedy County, Texas" by V. Izatt, B. Gallaway, and D. Saylack, Texas Transportation Institute, April 1977

(3) Research Report, "Sand-Asphalt-Sulphur Hot Mix" by D. E. Carey, Louisiana DOTD, June 1977

(4) Construction Report, "Sulphur-Asphalt-Sand Paving Project; Highway La 108, Sulphur, Louisiana" by J. O. Izatt, The Sulphur Institute, July 1977

(5) Information and Project Status Letters from Bob M. Gallaway, Texas Transportation Institute

(6) Construction Report, "Sulphur Extended Asphalt Field Trials - MH 153, Brazos County, Texas" by J. O. Izatt, Texas Transportation Institute, September 1978

(7) Information from Don Carey, Louisiana DOTD

(8) Information from John Dale and Allen Ludwig, Southwest Research Institute, San Antonio, Texas