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# EVALUATION OF LABORATORY PROPERTIES OF SMA MIXTURES

**Research Report**

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# ABSTRACT

Stone Matrix Asphalt (SMA) has been proven to resist permanent deformation in Europe and has shown promise in the United States as a stable and durable surface mixture. SMA mixtures were developed in Europe and have been used successfully for the past twenty years to provide resistance to rutting under heavy loads and wear from studded tires. The SMA also shows potential for improved long term performance and durability. The success in Europe has encouraged the U.S. to adopt the use of SMA mixtures particularly on high volume roads such as Interstates and urban intersections. However, this new methodology has to be evaluated using U.S. materials and construction methods to insure satisfactory performance in the U.S. This NCAT report is an effort to compare, through laboratory tests developed for dense graded mixtures, the properties of SMA mixtures to that of dense graded mixtures. It evaluates the laboratory test properties of SMA mixtures, which will assist in characterizing and understanding performance. Primary emphasis in the laboratory was to evaluate SMA properties for various aggregate types, aggregate gradations, fiber types and contents, and asphalt contents. This report also discusses SMA projects constructed in 1991 and 1992 and provides information on materials used as well as mixture properties.

# INTRODUCTION

## BACKGROUND

A twenty-one member group representing AASHTO, NAPA, FHWA, TRIS, Asphalt Institute, and SHRP participated in a two week tour of six European nations, in mid September 1990 (1). The nations visited were Sweden, Germany, France, Italy, Denmark and United Kingdom.

The study tour members evaluated and reviewed state-of-the-art pavement construction methods and asphalt mixture types that were prevalent in these countries. In the opinion of the European Asphalt Study Tour (EAST) members, the special purpose mixture with the greatest promise for improving performance of mixtures in the U.S., was Stone Matrix Asphalt (SMA) (1). A smaller group representing FHWA, AASHTO, and NCAT visited Sweden and Germany in Spring 1991 to look specifically at SMA materials, construction, and performance.

In Europe, SMA mixtures have been used in the upper layer for the past twenty years to reduce the amount of rutting under heavy traffic (1, 2, 3). The gradation of the aggregate and optimum asphalt content (AC) are considerably different from that used for dense graded mixtures (2). Coarse stone-to-stone contact is prevalent in SMA mixtures but does not occur in HMA (4). Dense graded mixtures also have aggregate to aggregate contact but most of this takes place within the fine aggregate particles which do not offer the same shear resistance as the coarse aggregate. Inspection of a core removed from an existing dense graded mixture shows that the coarse aggregate is floating in the fine aggregate matrix. The traffic loads for SMA are carried by the coarser aggregate particles instead of the fine aggregate asphalt mortar (5, 6). The European experience (7) and established performance records show SMA to be more cost effective than dense graded HMA for high volume roads. However, there exists a number of factors that would influence the SMA performance in the U.S. (8). Factors such as changes in asphalt cement source and grade, types of aggregate, environmental conditions, production and construction methods need to be evaluated in the U.S. Evaluation of these factors would help to determine the long term performance of SMA and provide information to make changes as needed to suit U.S. conditions.

There is an SMA Technical Working Group that is attempting to solve many of the problems that may be encountered with the materials, design, construction, or performance of SMA. Information may be obtained from this group by contacting the FHWA, Office of Technology, Washington, D.C.

## OBJECTIVE

One objective of this study was to review the SMA projects constructed during 1991 and 1992 in the U.S. The other objective was to evaluate the potential of existing laboratory tests to predict the performance of SMA mixes. This study used two different types of aggregates and three types of fibers. Their effect was determined by varying the following parameters:

i. Fiber content.

ii. Fine aggregate content.

iii. Filler content.

iv. Asphalt content.

## SCOPE

The laboratory study was conducted using granite and local silicious gravel aggregates. Three different types of stabilizers (two cellulose and one mineral fiber) were used, with varying filler content and fine aggregate content. One of the cellulose materials was produced in the U.S. and the other was produced in Europe. The mineral fiber was also produced in Europe. Gradation changes were made to determine the effect of gradation on mixture properties. Also, the asphalt content was varied from the job mix formula to determine the sensitivity of each of the SMA mixtures to asphalt content.

For evaluation of test properties of the SMA mixtures the following tests were performed on the laboratory samples:

1. Marshall stability and flow ( 140°F).
2. Gyratory properties, including Gyratory Elasto Plastic Index (GEPI), Gyratory Shear Index (GSI) and shear stress required to produce a one degree gyration angle.
3. Resilient modulus at temperatures of 40°, 77° and 104°F. The stress level applied was 15 percent of the indirect tensile strength. One load cycle consisted of 0.1 second of applied load and 0.9 second with no load.
4. Indirect tensile strength at 77°F.
5. Creep:
    (a) Static confined ( 140°F) test at 20 psi confining pressure and 120 psi vertical pressure. The loading time was one hour, and recovery time was 15 minutes.
    (b) Dynamic confined (140°F) test at 20 psi confining pressure and 120 psi vertical pressure. These numbers were selected to represent typical values expected in the in-place pavement. Each load cycle consisted of 0.1 second of applied load and 0.9 second with no load as in the resilient modulus test.

# SMA REVIEW

REVIEW

Stone Matrix Asphalt (SMA) is a hot mix asphalt, developed in Germany during the mid-1960’s (1, 3). In Europe, it is primarily known as "Splittmastixasphalt," revealing its German origin (Splitt-crushed stone chips and mastic-the thick asphalt cement and filler). SMA has been referred to over the years as Split Mastic, Grit Mastic, or Stone Filled Asphalt (1, 3). SMA is now in regular use for surface courses in Germany, Austria, Belgium, Holland and the Scandinavian countries (7). Japan has also started to use SMA paving mixtures, as well, with good success (9). A general definition of SMA developed by the SMA Technical Working Group is “A gap graded aggregate-asphalt hot mix that maximizes the asphalt cement content and coarse aggregate fraction. This provides a stable stone-on-stone skeleton that is held together by a rich mixture of asphalt cement, filler, and stabilizing additive.”

The original purpose of SMA was to provide a mixture that offered maximum resistance to studded tire wear (1, 3). SMA has also been shown to provide high resistance to plastic deformation under heavy traffic loads with high tire pressures as well as good low temperature properties (3). A study conducted by the Ministry of Transportation (MTO), Ontario, Canada, on SMA pavement “slabs” trafficked with a wheel tracking machine gave less rut depths in comparison to that occurring in a dense friction course (7). The Georgia DOT has also performed a significant amount of wheel tracking tests on SMA mixtures with positive results. Also, the SMA has a rough surface texture as illustrated in Figure 1 (3) which provides good friction properties after the surface film of asphalt cement is removed by traffic. Other essential features that enhance the feasibility of SMA in contrast to conventional HMA are increased durability, improved aging properties and reduced traffic noise (7).

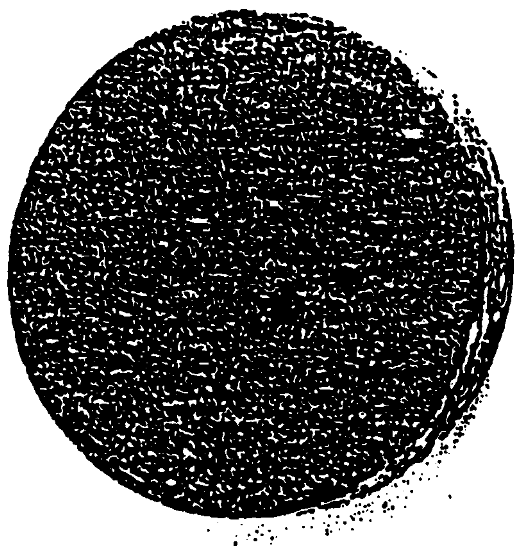
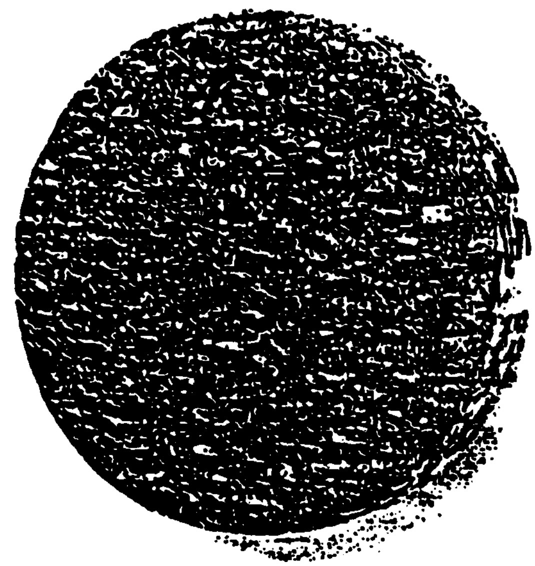
| Smooth surface of conventional dense graded mix. | Typical rough surface of a 7/16" (11 mm) SMA. |
|---|---|
|  |  |

Figure 1. comparison of SMA and conventional dense graded mix surfaces (Ref. 3).

SMA is a hot mix with a relatively large proportion of stones and substantial quantity of mastic, i.e., asphalt cement and filler (7). The main concept, of having a gap gradation of 100 percent crushed aggregates, is to increase the pavement's stability through interlocking and stone-to-stone contact (7). The stone-to-stone contact is demonstrated in Figure 2 showing close stone-on-stone contact for an SMA gradation and less contact for a dense graded paving mixture. Notice how the coarse aggregate floats in the fine aggregate matrix for the dense graded mixture.

## SMA MIXTURES IN EUROPE

### Aggregates

In Europe, the aggregates are divided into more size fractions during the construction process than in the United States (11). This same procedure of increased numbers of stockpiles is used for dense graded mixtures as well as for SMA mixtures. For example, the sizes of coarse aggregate typically available are: 2 to 5 mm, 5 to 8 mm, 8 to 11 mm, 11 to 16 mm, 16 to 22 mm, and 22 to 32 mm. The fine aggregate generally passes the 2 mm sieve. Having more stockpiles available allows for closer control of the aggregate gradation than in the U.S. but all sizes are not used for most work.

The maximum aggregate size for the European SMA mixes can vary from 1/4 inch to as large as 1 inch, but most SMA mixes tend to use relatively small coarse aggregate particles. In Europe, the size of the largest particles are typically 3/16", 5/16" or 7/16" as illustrated in Figure 3 (3). The percent passing each sieve size is illustrated in Figure 3, and the sieve sizes raised to the 0.45 power are given in Figure 4.

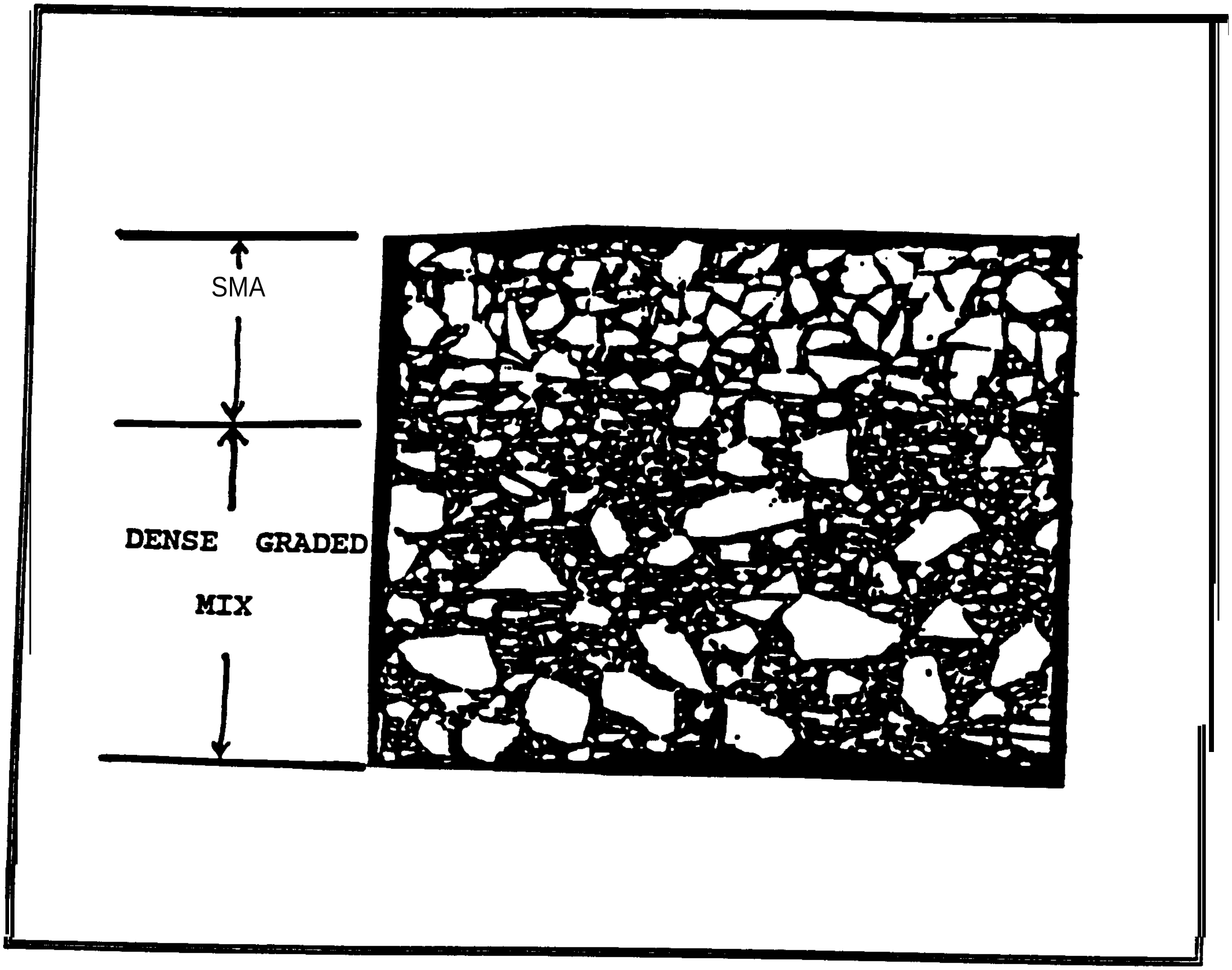



**Figure 2. Pavement** section with a Stone Matrix Asphalt (SMA) **surface course over a conventional paving mix (Ref. 7).**

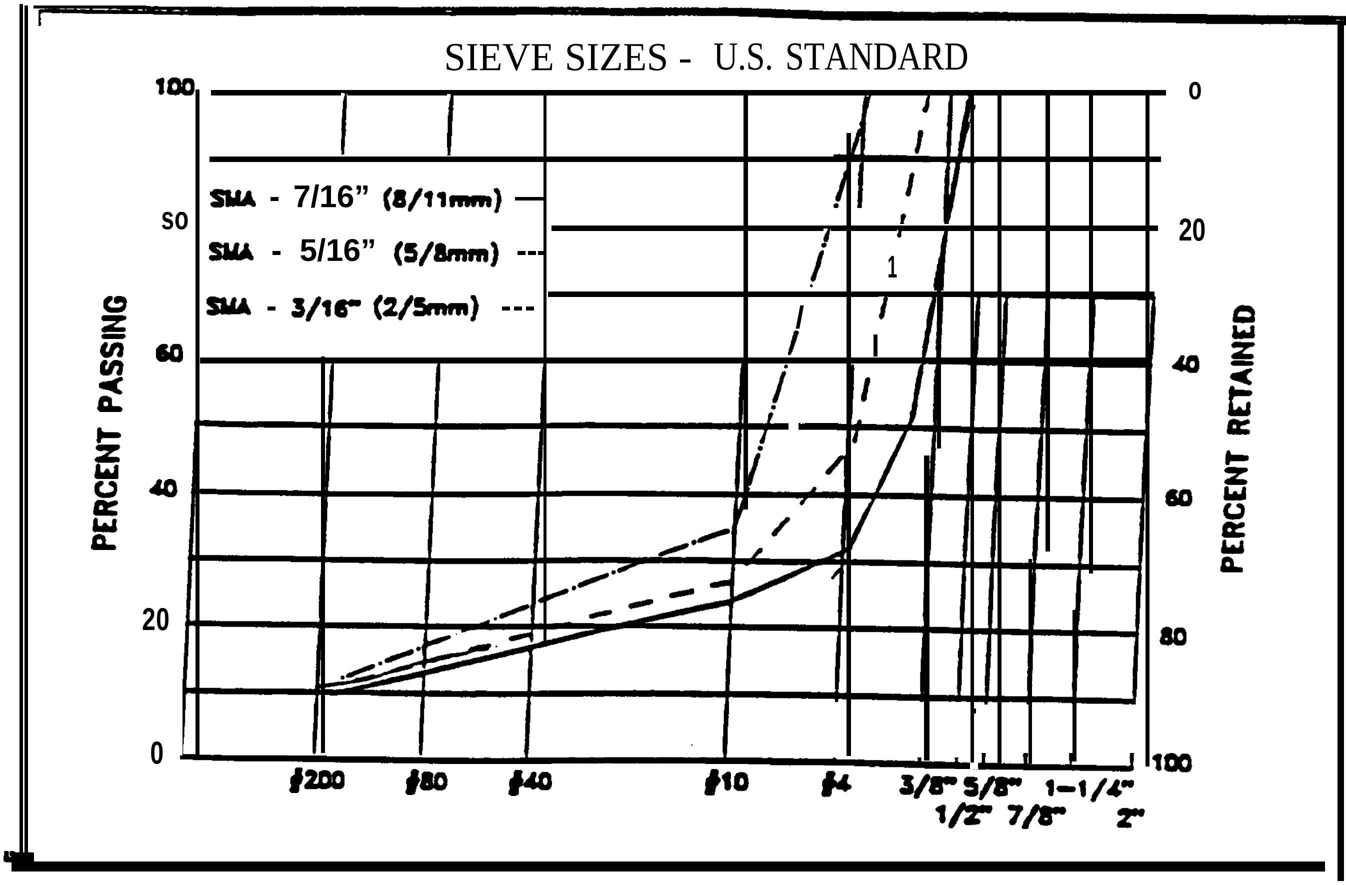



Figure 3. Typical Gradation for SMA mixes in Europe (Ref. 3).

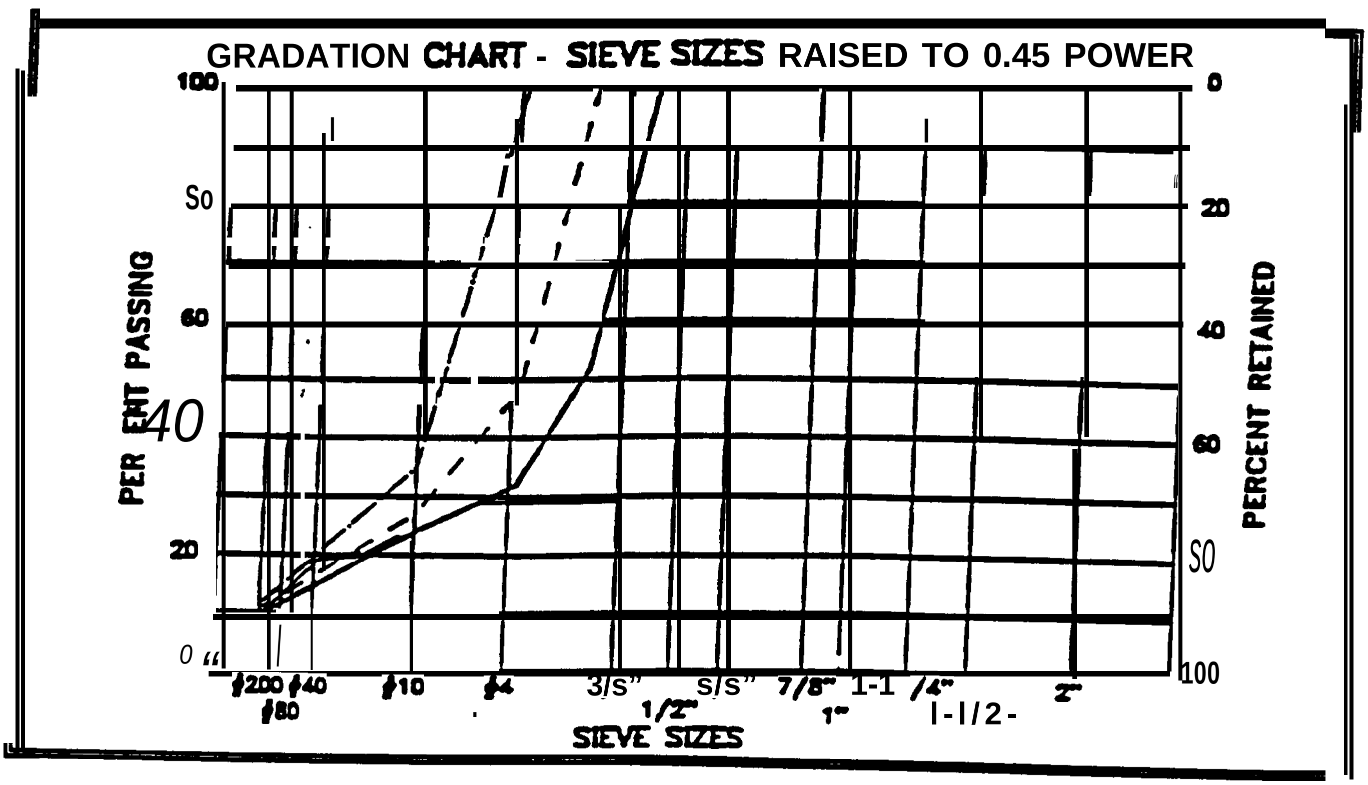
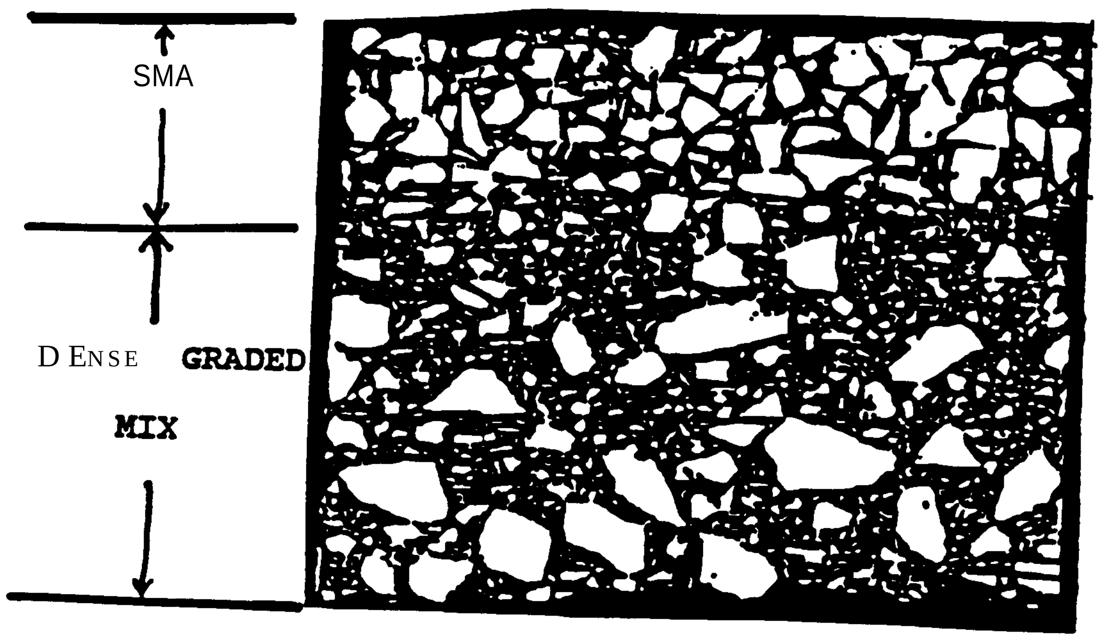



Figure 4. Gradation Chart-sieve sizes raised to 0.45 power (Ref. 3).

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## Mineral Filler

In general, 8-12 percent of the total amount of aggregate in the mix passes the No. 200 sieve (7). This large amount of filler plays an important role in the properties of SMA mix particularly in terms of air voids, voids in the mineral aggregate and optimum asphalt content (3, 7). Since the amount of material passing the No. 200 sieve is relatively large, the SMA handles and performs very differently from other HMA mixtures (7). A primary difference between SMA and open graded mixtures is the low air voids (approximately 3 percent) in the SMA mixtures, whereas open graded friction courses may have more than 20 percent air voids.

## Asphalt Content

In Europe, the optimum AC content for SMA mixtures is above 6.0 percent and in some specifications is required to be above 6.5 percent. The voids are filled with mastic, which contains fines, asphalt cement and special stabilizers or fibers. For SMA mixtures which contain organic or mineral fibers the range of optimum AC contents is normally slightly higher than that required when polymers are used as the stabilizer. Typically, the mixtures with organic fibers have slightly higher optimum AC contents than those with mineral fibers. The high AC contents and mastic provide a mixture that has excellent durability.

## Mix Design

In Europe, the Marshall method of mix design is used to verify satisfactory voids in SMA mixtures (1, 2). Laboratory specimens are prepared by using fifty blows of the Marshall hammer per side (2). The optimum AC content for SMA mixes is selected to produce approximately 3 percent voids (1, 2). In Europe, Marshall stability and flow values are generally measured for information but not used for acceptance (11).

### Fiber Stabilizer

Fibers, as a stabilizing agent, are usually added to reduce the draindown of the binder material during mixing, hauling and placing operations (1, 2). Loose organic fibers, such as cellulose, are typically added at the rate of 0.3 percent by weight of mixture. Mineral fibers are often added at a rate of 0.4 percent by weight of mixture.

In the laboratory, special care is taken to assure that the fibers, either organic or mineral, are uniformly combined with the dry aggregates before the asphalt cement is added (1). Mixing continues until all the coarse and fine aggregate, mineral filler and fibers are coated with asphalt cement.

### Polymer Stabilizer

Polymer stabilizers have also been used in a more limited basis in SMA mixtures (2). In some cases, the polymers are preblended with the asphalt cement and added to the mix during the mixing process. In other cases, the polymers are added to the aggregate in the plant before the asphalt cement is injected (2). One purpose of the polymer stabilizer is to minimize the asphalt cement draindown during the hauling, mixing, and placing operation (2). The other purpose is to increase the stiffness of the AC at high, in service temperature and/or to improve the low temperature properties of the binder material (2). Polymers are typically added to the mix at a rate of 3.0 to 8.0 percent, by weight of asphalt cement.

### Production and Laydown of SMA Mixes in Europe

The total production of HMA in European countries is lower than that in the United States. For example, in West Germany, an average of 40 million tons of HMA is produced annually (11), compared to about 500 million tons of mix (13) in the United States. Resurfacing work, for a one lane, three mile section of Autobahn, requiring 15,000 tons of mix is a job of considerable size in Europe (11). Most of the German plants (batch plants) use up to six different aggregate sizes in SMA production (11). In Europe, aggregates that pass through the screen deck are stored in up to six hot bins, whereas in the U.S. most plants have four hot bins. Hence, the European plants have better aggregate control and flexibility in meeting aggregate gradation requirements.

For batch plants in Europe, fibers are added to the dry mixing cycle in the pugmill. Mixing time is slightly increased, to ensure thorough distribution of the fibers. An additional 5-10 seconds mix time after introduction of the fibers is usually sufficient (3) in batch plants. The temperature of the SMA mix is generally between 300 to 330°F upon discharge from the mixing plant and should be at least, but usually more than, 275°F upon delivery to the laydown equipment.

In Europe, typically, steel wheel rollers, each having a minimum weight of 10 tons are utilized immediately behind the paver. The compaction should take place between 265°F and 300”F.

## SMA PROJECTS IN THE U.S.

By 1993 SMA projects had been constructed in at least 12 states in the U.S. At least 5-6 additional states had planned to build SMA sections in 1993. A list of those states, placing SMA in 1992 is shown in Table 1. States planning to construct projects in 1993 are shown in Table 2. (Information in Tables 1 and 2 furnished by John Bukowski, FHWA) This is not a complete list of SMA pavements constructed but is a list of those that are on file at FHWA.

All the mix designs for SMA construction have been performed using the 50 blow Marshall hammer. Even though these mixtures are used on heavy duty roads, 75 blow compaction should not be used since it will tend to break down the aggregate more and will not result in a significant increase in density over that provided with 50 blows. SMA mixes have been more easily compacted on the roadway to the desired density than the effort required for conventional HMA mixes (10).

The air void content has been typically around 3.0 percent in laborato<sub></sub>ry compacted samples for the SMA mixes and approximately 5-6 percent initially in-place.

Batch and drum plants have been successfully used in SMA production with no major problems existing with either type plant. Addition of the fiber initially had been in the form of pellets through the RAP feeder, halfway down the drum in a drum mix plant. Recently a more common method of addition of loose fibers has been to blow them directly into the drum mix plant. Loose fibers have been added directly to the pugmill in a batch plant (10).

Thickness of most of the SMA mixtures produced in the U.S. has been 1 1/2 inches. Compaction has been by static steel wheel rollers however, vibratory rollers have been successfully used, and rubber tire rollers have been tried without success. Vibratory rollers worked well on some projects, but these rollers in some cases may have a tendency to produce bleeding and to breakdown aggregate (10). If a vibratory roller is used it must be watched closely to insure that these problems do not occur. Rubber tire rollers have proven to be inappropriate for use on SMA mixtures due to a problem with AC sticking to the rubber tires.

It is too early to draw conclusions on the performance of SMA mixtures in the U.S. but so far initial results have been good. No significant distresses had occurred on the SMA projects constructed in 1991 and 1992 at the time this report was prepared. These initial SMA projects should provide data needed to evaluate performance of SMA mixtures under U.S. conditions, but a centralized effort to collect this performance data needs to be implemented. The SMA Technical Working Group is serving as this centralized effort.

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# Table 1. Stone Matrix Asphalt 1992 Completed Projects

| | Alaska (Seward Hwy) | Maryland (US-15) | Maryland (1-70) | Ohio (us-33) | Wisconsin (143) | Texas (1-36/ SH171) | California (1-40) | Michigan (1-94) | Missour<sup></sup> (1-70) | Georgia (1-7s) | | Virginia (us-29) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Surface 1.5" thick 3-1000 ft sections | Surface & Leveling 2.5" thick 2 miles | Surface 1.75" thick 7 miles | Surface 1.5" thick 4 miles | Surface 1.5" thick 6-400 ft sections | Surface 1.25" thick 6 miles | Surface 1.5" thick 2-1000 ft sections | Surface 1.5" thick 7 miles | Surface 1.75" thick 3 miles | Surface & Binder 1 mile | | Surface 1.5" thick 4 lanes |
| Gradation | (JMF) | (JMF) | (JMF) | (JMF) | (JMF) | (JMF) | (JMF) | (JMF) | (JMF) | Surface | Binder | (JMF) |
| 3/4" | 100% | 100% | 100% | 100% | 100% | 100% | 99% | 100% | 100% | 100% | 100% | 100% |
| 1/2" | 86 | 84 | 81 | 97 | 100 | 91 | 86 | 100 | 98 | 100 | 72 | 89 |
| 3/8 | 71 | 68 | 61 | 77 | 98 | 69 | 75 | 70 | 70 | 79 | 48 | 65 |
| # 4 | 34 | 28 | 28 | 36 | 36 | 28 | 29 | 28 | 34 | 39 | 27 | 26 |
| # 8 | 22 | 15 | 15 | 18 | 21 | (#lo) 15 | 24 | 20 | 18 | 24 | 20 | 18 |
| # 16 | | 13 | 12 | 14 | 17 | | 19 | 17 | 15 | | | 16 |
| # 30 | 14 | 12 | 11 | 12 | 14 | (#40) 13 | 15 | 15 | 14 | | | 15 |
| # 50 | | 12 | 11 | 10 | 13 | | 13 | 13 | 13 | 15 | 14 | 13 |
| # 100 | 12 | 11 | 10 | 8 | 12 | (#80) 13 | 11 | 11 | 13 | | | 11 |
| # 200 | 9 | 9 | 9 | 6 | 11 | 10 | 9 | 10 | 10 | 8 | 8 | 9 |

| | Alaska (Seward Hwy) | Maryland (US-15) | Maryland (1-70) | Ohio (US-33) | Wisconsin (I-43) | Texas (I-36/ SH171) | California (140) | Michigan (I-94) | Missouri (1-70) | Georgia (I-75) | | Virginia (US-29) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AC by wt of mix (actual) | 6.5% 5.9% | 6.5/6 .3/6.0 | 6.3/5.9% | 6.6% | 7.0% 6.2% | 6.4% | 5.6/5.4% | 6.4/6.7% | 6.6% | 5.9 | 5.8 | 6.3/5.8% |
| Additive | Cellulose Fibers /Polyolefin | Cellulose Pellets/ Elastomer/ Polyolefin | Domestic Produced Cellulose/ Polyolefin | Cellulose Pellets | Elastomer/ Polyolefin/ Domestic Produced Cellulose/ Mineral Fibers | Cellulose Pellets | Polyolefin | Domestic Produced Cellulose/ Polyolefin | Cellulose Fibers/ Mineral Fibers | Domestic Produced Cellulose/ Elastomer | | Cellulose Pellets/ Polyolefin |
| Air Voids | 3% | 2-4% | 2-4% | 3-5% | 3% | 4% | 3% | 3% | 3.8% | 3.8% | 3.4% | 3.5% |
| VMA | 17 | 18 | 18 | 16.5 | 16-18 | 18 | | 17 | 18 | 17 | 16 | 18 |
| Plant | Batch | Drum | Drum | Drum | Drum | Drum | Drum | Drum | Batch | Drum | | Batch |
| Quality | 4,000 tons | 10,000 tons | 25,000 tons | 16,000 tons | 2,000 tons | 8,000 tons | 1,000 tons | 12,000 tons | 4,000 tons | 1,000 tons | | 2,000 tons |

Information furnished by John Bukowski, FHWA

# Table 2. Stone Matrix Asphalt 1993 Planned Projects

| STATE | LOCATION | SIZE | DESCRIPTION | STABILIZER | DOT CONTACT |
|---|---|---|---|---|---|
| Alaska | Anchorage | 20,000 Tons | 1.5" Surface<br>Batch Plant | Cellulose/<br>Polyolefin | Tom Moses |
| Arizona | 1-40 | 10,000 Tons | 1.S" Surface<br>Drum Plant | Cellulose/<br>Polymer | George Way |
| California | Rt 152<br>Santa Clara | 1,000 Tons | 2" Surface | Cellulose | Jack VanKirk |
| Georgia | I-95<br>Savannah | 62,000 Tons | 1.5" Surface<br>2.5" Binder<br>Overlay on PCC | Cellulose<br>& Modified<br>Asphalt | Don Watson |
| Illinois | 1-80<br>I-57<br>I-55<br>us 24<br>US 36<br>Rt 121<br>Rt 1<br>Lament Rd | 12,000 Tons<br>5,000 Tons<br>4,000 Tons<br>8,000 Tons<br>16,000 Tons<br>3,000 Tons<br>5,000 Tons<br>11,000 Tons | 1.5" Surface | Cellulose<br>Polymer<br>Mineral Fiber<br>Mineral Fiber<br>Cellulose<br>Polymer<br>Polymer<br>Cellulose | Enc Harm |
| Kansas | us 54 | 1,000 Tons | 1.5" Surface | Fiber | Rodney Maag |
| Maryland | I-95 (Toll Road)<br>I-83<br>1-195<br>I-695<br>1-70 | 55,000 Tons<br>14,000 Tons<br>1,000 Tons<br>34,000 Tons<br>17,000 Tons | 1.5" Surface<br>Drum Plant | Cellulose/<br>Polymer | Larry Michael |
| Michigan | 1-96/1-94<br>us 131 | 40,000 Tons | 1.5" Surface<br>Drum Plant | Cellulose/<br>Polyolefin | Dan Vreibel |
| Missouri | 1-70 | 30,000 Tons | 1.75" Surface | Cellulose | G. Manchester |
| Nebraska | Hwy 75 | 27,000 Tons | 1.5" Surface | Polymer | Laird Weishahn |
| North Carolina | us 264 | 2,000 Tons | 1.5" Surface | Cell. /Polymer | Jim Trogden |
| Ohio | US-23 (Sandusky)<br>I-75 (Findlay) | 60,000 Tons<br>20,000 Tons | 1.5" Surface | Cellulose | Roger Green |
| Texas | us-79<br>us-323<br>US-60/83 | 5,000 Tons<br>7,000 Tons<br>1,000 Tons | 1.5" Surface | Cell. Pellets | Paul Krugler |
| Virginia | 1-66 | 10,000 Tons | 1.5" Surface | Cell. Pellets | Bob Horan |
| Wisconsin | US-51<br>us-63<br>us-45<br>I-43 | 5,000 Tons<br>5,000 Tons<br>5,000 Tons<br>15,000 Tons | 1.5 Surface | Polymers/<br>Mineral &<br>Cellulose Fibers | Steve Shoeber |

# TEST PLAN

Many SMA projects have been constructed and many more will be constructed within the next few years. It is essential that data be developed to provide guidance in mix design and construction to the users of SMA. The test plan for this study was developed to provide guidance to those individuals involved in mix design and quality control of SMA mixtures.

This section describes the materials used, mix design procedures, the various changes in material content and testing methodology for this SMA study. Two aggregate types, one asphalt cement and three types of fibers were used in this study.

## AGGREGATES

**The two types** of aggregate selected for use were granite and silicious gravel. The granite from Buford, Georgia had an LA abrasion of 35 percent (based on present FHWA guidelines this is a marginal SMA aggregate) and soundness loss of 0.4 percent. Tests (ASTM C127) conducted in the laboratory gave the following results for the coarse granite aggregate:

Apparent specific gravity = 2.674

Bulk specific gravity = 2.632

Absorption (%) = 0.61

Tests (ASTM C128) conducted on the fine granite aggregate gave the following results:

Apparent specific gravity = 2.664

Bulk specific gravity = 2.621

Absorption (%) = 0.60

The gravel from Montgomery, AL had an LA Abrasion of 46.5 percent (based on present FHWA guidelines this aggregate should no be used for SMA. The guidelines at the time this report was written were LA Abrasion less than 30 and only crushed stone aggregates) and sulfate soundness loss of 0.4 percent. The results for the aggregate specific gravity and absorption properties tested in the laboratory are summarized below. The tests were conducted in accordance with ASTM C127 for coarse aggregate and ASTM C128 for the fine aggregate. The coarse aggregate results were:

Apparent specific gravity = 2.643

Bulk specific gravity = 2.599

Absorption (%) = 0.65

The following results were obtained for the fine aggregate:

Apparent specific gravity = 2.655

Bulk specific gravity = 2.611

Absorption (%) = 0.64

These two aggregates were selected for this study since they were locally available, they are common aggregates available in many states, and in some states it will be necessary to use aggregates with LA Abrasion over 30. Even though these aggregates were used for this study, it is recommended at this time that SMA's be built with crushed stone aggregate having LA Abrasion of 30 or below.

## ASPHALT CEMENT

The material source for the asphalt cement (AC-20) was Chevron U.S.A., Inc., Mobile, Alabama. Table 3 gives the various test properties for the asphalt cement as supplied by the supplier. The AC meets all the requirements for an AC-20.

**Table 3. Test Properties for Asphalt Cement.**

| Test conducted | Results | Specifications |
|---|---|---|
| 1. Viscosity @ 140”F, Poise | 2083 | 2000 $\pm$ 400 |
| 2. Viscosity @ 275”F, cst | 423 | 210 min |
| 3. COC Flash, “F | 600 | 450 min |
| 4. Penetration @ 77°F | 83 | 40 min |
| 5. Thin Film Oven Test | | |
| i. Weight Loss, % | 0.01 | |
| ii. Viscosity @ 140”F, P | 6258 | 10,000 max |
| iii. Ductility @ 77°F, cm | 150+ | 20 min |
| iv. Viscosity ratio | 3.00 | |
| 6. Specific gravity @ 77°F | 1.0208 | |
| 7. Lbs / Gallon @ 77°F | 8.5018 | |

## FIBERS

Three different types of fibers were used in this study. Two were cellulose fibers from different producers, and one was mineral fiber. The additives were:

1) Additive 1 (U.S. Cellulose)

2) Additive 2 (European Cellulose)

3) Additive 3 (European Mineral fiber)

## SELECTING THE OPTIMUM ASPHALT CONTENT AND SAMPLE PREPARATION

The optimum AC content for the SMA mixtures was selected to produce 3.5 percent air voids. A total of 18 samples per mix type evaluated in this study were prepared at optimum asphalt content using the Corps of Engineers Gyratory Machine set at 75 revolutions. This compaction effort was selected because it gave the same density as that obtained with 50-blows with the Marshall hammer. The dense graded mix samples were compacted at 300 revolutions of the GTM which is typical of that used for these mixtures. The machine set-up was as follows for both mix types:

i) Vertical pressure = 120 psi

ii) Angle of gyration = 1 degree.

The Gyratory Machine was used for compaction so that engineering properties of the mixture could be determined. It is recommended (at this time) that all mix designs for projects be performed with 50 blows of the Marshall hammer. To minimize any differences between the two methods the Gyratory was set to provide the same density as that provided with 50 blows with the hammer. Also previous studies have shown that the Gyratory Machine orients the particles very similar to that obtained in the field.

Eighteen samples for each mixture type studied were prepared for testing. The 3 samples, of the 18 samples i pared, which had VTM farthest from the target value of 3.5 percent were discarded. Also the average VTM of all samples for a particular mixture had to be between 2.5 and 4.5 or the samples were discarded and additional samples made. At the beginning of this study it was noted that there was a significant variability in voids between samples for the SMA mixtures (more than expected for dense graded HMA) and this is the reason that the outliers were discarded. For every change in the fiber content, filler content, percent passing the No. 4 sieve or percent passing the No. 200 sieve it was essential to develop a new optimum AC content to give VTM equal to 3.5 percent. The study was not set up to look at the sensitivity of the mix to changes in proportions but was set up to help establish the optimum proportions. Samples prepared using the optimum asphalt content selected during mix design did not always provide air voids equal to 3.5 percent. That explains why the air voids in the samples prepared for testing were not exactly 3.5 percent.

## SUMMARY OF MIXTURES EVALUATED

The samples evaluated in this study were produced using granite and gravel aggregates. Two cellulose fibers and one mineral fiber were used with each type of aggregate as illustrated in Figure 5.

For each additive-aggregate combination, the mixture modifications made are presented in Figure 6. The fiber content used for all mixtures was 0.3 percent by weight of mixture. The amount recommended for mineral fiber is 0.4 percent but 0.3 percent was used in this study to provide a direct comparison with cellulose, Variations in fiber content were from 0.0 to 0.5 percent as indicated in Figure 6. The aggregate gradation selected as the JMF for all mixtures is stated in Table 4 and was the same for both aggregate types. The gradation was varied by adjusting the

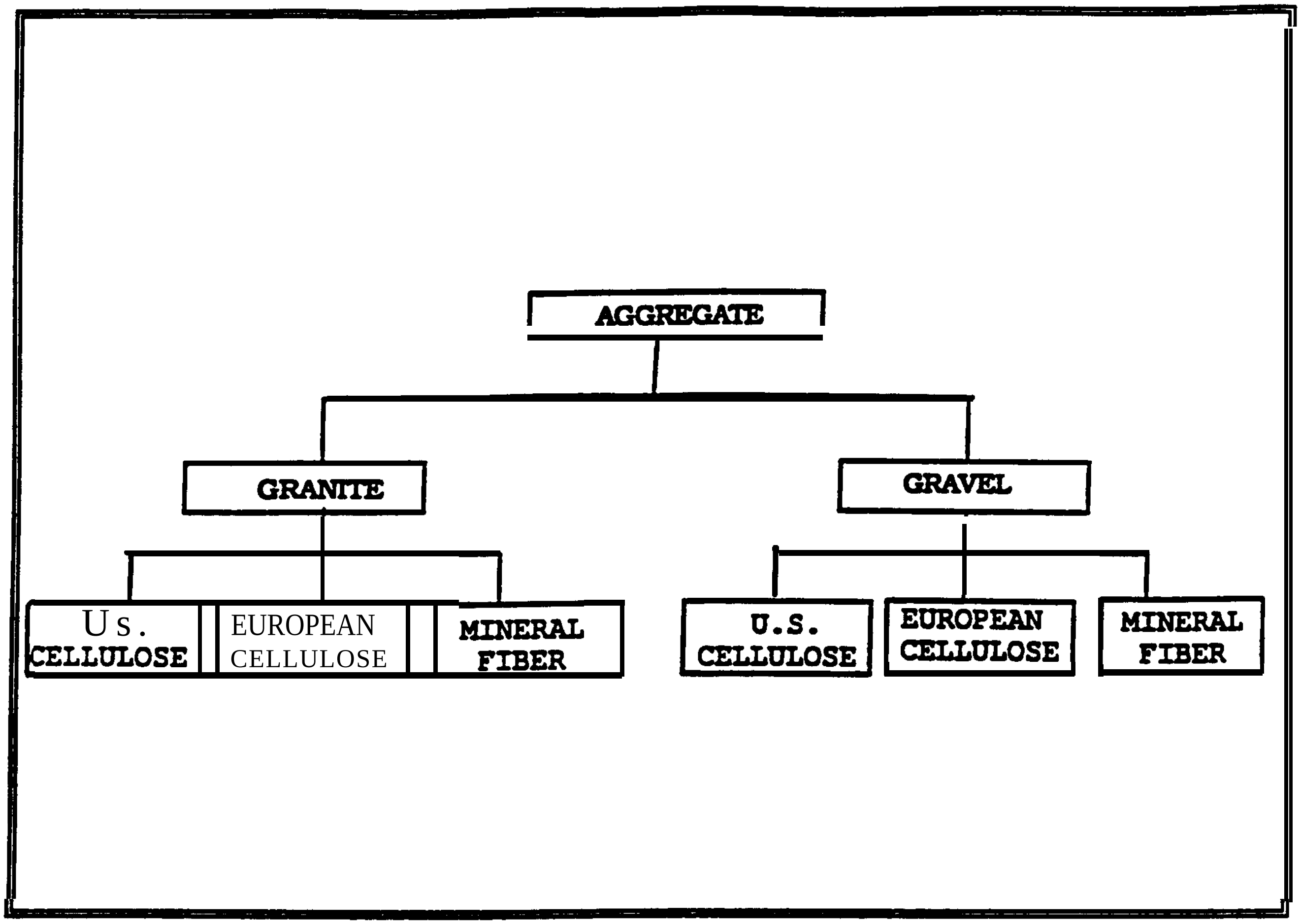


**Figure 5. Different fiber-aggregate combinations**

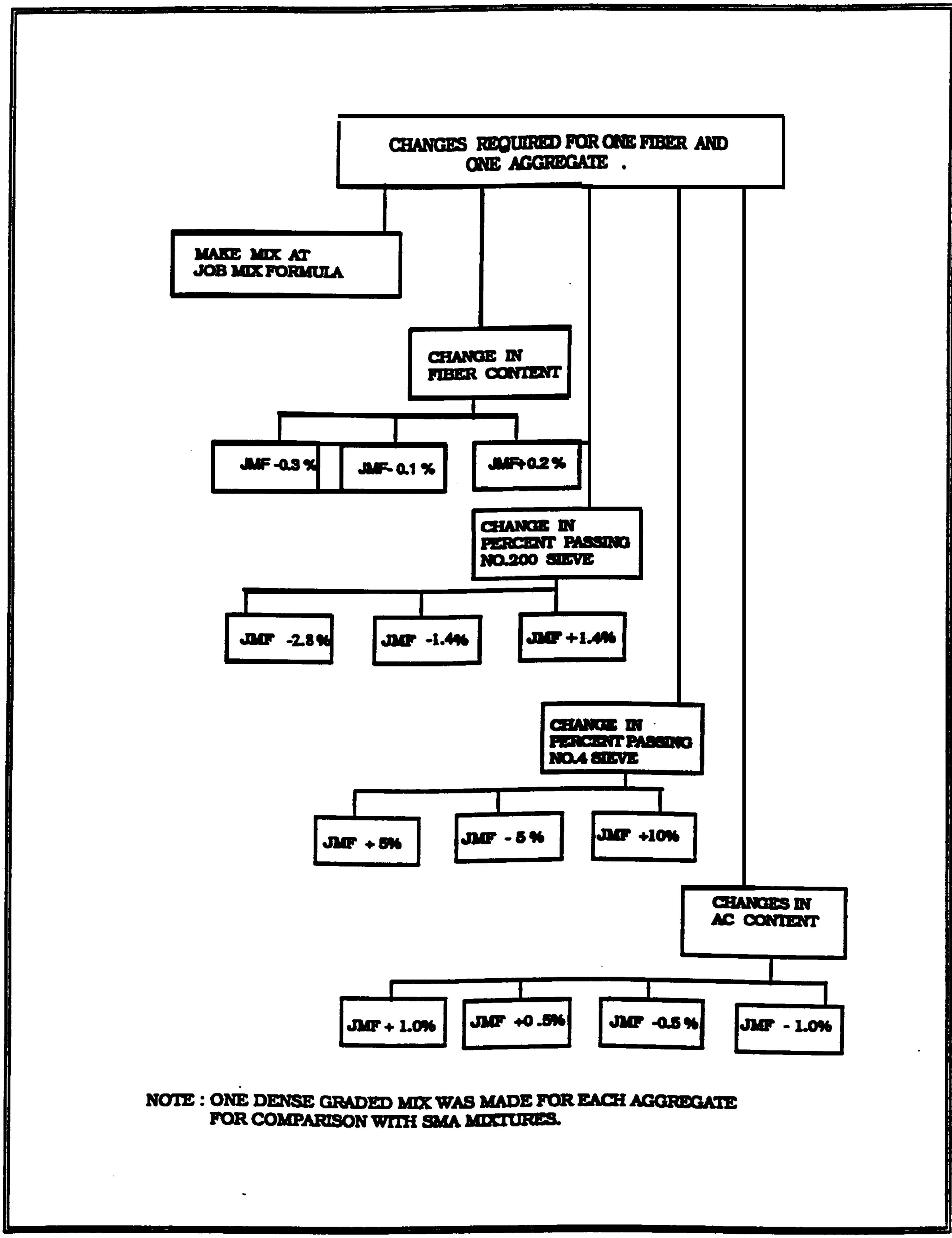


**Figure** 6. **Flowchart for the various material combinations.**