**NCAT Report No. 97-1**

# PERFORMANCE OF STONE MATRIX ASPHALT (SMA) MIXTURES IN THE UNITED STATES

**by**

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## ABSTRACT

Stone Matrix Asphalt (SMA) mixtures have been used in the United States since 1991. The traffic rate has been high on many of these pavements resulting in a significant amount of traffic during a short period of time. In 1994 the Federal Highway Administration awarded a contract to the National Center for Asphalt Technology (NCAT) to determine the performance of SMA pavements. This report provides a summary of mix design and performance data obtained from 86 SMA projects. Data was collected on material and mixture properties, and performance was evaluated on the basis of several factors including rutting, cracking, raveling, and fat spots. The major conclusions from this study are: (1) Approximately 85 percent of the projects met the recommended Los Angeles abrasion requirement of 30, (2) SMA mixtures were produced approximately 90 percent of the time with 25-35 percent of the material passing the 4.75 mm sieve and 80 percent of the time with 7-11 percent of the material passing the 0.075 mm sieve, (4) Approximately 30 percent of the projects had average air voids during construction less than 3 percent, (5) Approximately 60 percent of the projects exceeded 6.0 percent asphalt content during production, (6) Over 90% of the SMA projects had rutting measurements less than 4 mm. Approximately 25% of the projects had no measurable rutting, (7) Construction of good longitudinal joints has taken some effort. Most projects had good joints and as contractors become more experienced with construction of SMA the quality of joints will improve, (8)

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Cracking (thermal and reflective) has not been a significant problem. SMA mixtures appear to be more resistant to cracking than dense mixtures, (9) There was no evidence of raveling on the SMA projects, (10) Fat spots appear to be the biggest performance problem. These are caused by segregation, draindown, high asphalt content, or improper type or amount of stabilizer, (11) Based on the findings in the study, SMA mixtures should continue to provide good performance in high volume traffic areas. The extra cost for construction should be more than offset by the increased performance.

# PERFORMANCE OF STONE MATRIX ASPHALT (SMA) MIXTURES IN THE UNITED STATES

## INTRODUCTION

Stone Matrix Asphalt (SMA) mixtures have been used in the United States since 1991. Now that the SMA mixtures have been exposed to a significant amount of traffic and several years of weathering some indications of performance can be determined. These mixtures have performed well in Europe for many years and it is expected that similar performance will be experienced in the U.S.

In 1994, the Federal Highway Administration funded the National Center for Asphalt Technology (NCAT) to evaluate the performance of the SMA pavements that had been constructed in the United States. The primary purpose of the study was to collect data on mix design, quality control, and performance of approximately 70 SMA pavements that had been identified. During the study, some additional SMA pavements that were constructed in 1994-1996 were included. This report provides a summary of the results obtained from the national study.

## TEST PLAN

The test plan involved inspecting a number of SMA sections in various states to determine performance. The performance characteristics to be evaluated included, but were not limited to rutting, cracking, quality of longitudinal joints, fat spots, uniformity, raveling, and any other observed performance characteristics. Data was also collected on material properties, mix design, and quality control. A number of photographs showing the surface texture, surface uniformity, and general overview of the projects were also taken at each site.

The inspection of pavements began in 1994 and was completed in 1996. After all the data was collected, the information was summarized so that overall conclusions, concerning performance of SMA pavements, could be made.

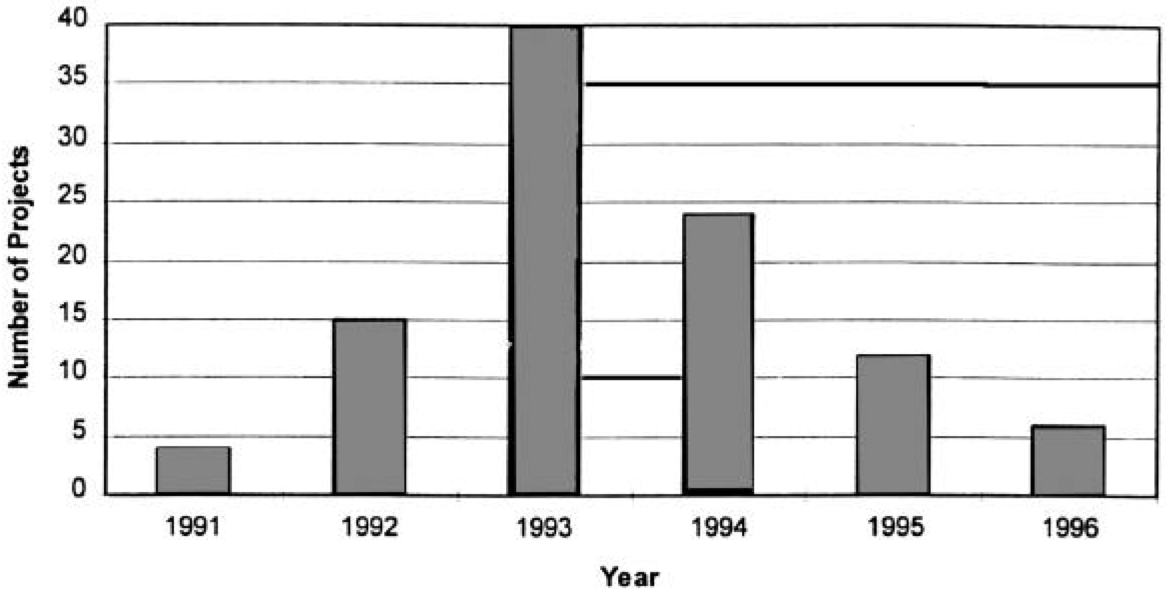
## OBSERVATIONS CONCERNING MIX DESIGN AND CONSTRUCTION

A number of SMA pavements were specifically identified to be included as part of this study. When visiting a state other SMA sections were inspected when in close proximity to one of the identified sections. Even though no sections were originally identified that were constructed in 1995 and 1996, several sections constructed during this time were inspected primarily to collect mix design and quality control information.

The data provided in this report was obtained from the following states: Alaska, Arkansas, California, Colorado, Georgia, Illinois, Indiana, Kansas, Maryland, Michigan, Missouri, Nebraska, New Jersey, North Carolina, Ohio, Texas, Virginia, Wisconsin, and Wyoming. Other states had constructed SMA mixtures but the biggest users of SMA are included in the states identified above.

Some states had built a number of relatively small test sections using various SMA mixtures. When appropriate, each test section was considered as a separate SMA pavement. So some of the SMA pavements tested may have included a few hundred tons of SMA while other SMA sections may have included as much as 50,000 to 100,000 tons or more.

A total of 140 SMA pavement sections were evaluated in this project. As shown in Figure 1, most of the SMA projects were built before 1994. Even though this plot shows that there is a significant drop in SMA projects inspected after 1994, this does not mean that the total amount of




Note: For four projects date of construction was not available

Figure 1. Plot for number of projects versus year

SMA constructed after 1994 had decreased. For this study, most of the projects inspected after 1994 were projects that were in close proximity to other SMA sections being evaluated. Most SMA sections constructed prior to 1994 were inspected whereas a much smaller percentage of the total projects constructed after 1994 were included. A summary of the data collected from these projects is provided in Table 1. Some of the data for various projects is not available.

All of the projects evaluated used a stabilizer (or special asphalt binder) to prevent draindown of the asphalt cement. In almost all cases, a fiber (cellulose or mineral) or a polymer was used as the stabilizer. Several states allowed the Contractor to choose whether to use a fiber or polymer while in other states the Department of Transportation (DOT) specified the type of stabilizer to be used. In one state, the contractor was required to use a fiber and polymer in all

Table 1. Summary of Data Collected on SMA Projects

| Project No. | Date of Construction | Initial In-Place Voids | L A Abrasion Loss, % | Design % Passing 4.75 mm Sieve | Design % Passing 0.075 mm Sieve | Production % Passing 4.75 mm Sieve | Production % Passing 0.075 mm Sieve | Design Voids, % | Design VMA, % | Design AC Content, % | Plant Voids, % | Plant VMA, % | Plant AC Content, % | Rutting, mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1991 | 6 | 19.6 | 28 | 10.8 | 26 | 10.5 | 3.1 | 16.4 | 6.5 | 3.6 | NA | 5.5 | 1.0 |
| 2 | 1991 | NA | 20/35 | 37 | 8.0 | 45/38 | 10.0 | 3.4 | 18.0 | 5.8 | 4.1/6.2/4.1 | NA | 5.5/5.6/5.7 | 7.6 |
| 3 | 1991 | NA | NA | 33.6 | 9.6 | NA | NA | 3.8 | 18.7 | 6.5 | NA | NA | NA | 0.8 |
| 4 | 1991 | NA | NA | 36 | 10.4 | 39 | 10.6 | NA | 18.2 | 6.5 | NA | NA | NA | 2.3 |
| 5 | 1992 | NA | 16 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.8 |
| 6 | 1992 | NA | NA | 28 | 9.4 | 28 | 8.3 | 3.1 | 18.2 | 6.3 | 1.8 | 17.4 | 6.6 | 2.4 |
| 7 | 1992 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 1.2 |
| 8 | 1992 | NA | NA | 28 | 9.7 | 26 | 9.7 | NA | 17.2 | 6.1 | NA | NA | NA | 3.0 |
| 9 | 1992 | NA | NA | 26 | 8.8 | 27/28 | 8.7/8.8 | NA | 18.8/18.7 | 6.8/6.6 | NA | NA | NA | 1.5 |
| 10 | 1992 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 14.0 |
| 11 | 1992 | 6.1 | 22 | 35 | 6.0 | 35 | 6.1 | 4.0 | 16.6 | 6.6 | 3.8 | 16.1 | 6.3 | 1.0 |
| 12 | 1992 | 7.8 | 25 | 28 | 9.9 | NA | NA | 4.0 | 18.0 | 6.1 | 6.4 | NA | NA | 1.3 |
| 13 | 1992 | NA | 25 | 28 | 9.9 | NA | NA | 4.0 | 18.0 | NA | NA | NA | NA | 2.5 |
| 14 | 1992 | NA | NA | 33.9 | 10.1 | NA | NA | 3.7 | 18.8 | 6.7 | NA | NA | NA | 1.9 |
| 15 | 1992 | NA | 24 | 31 | 4.0 | NA | NA | NA | NA | NA | NA | NA | NA | 3.8 |
| 16 | 1992 | NA | 24 | 31 | 4.0 | 28 | 4.0 | NA | NA | NA | NA | NA | NA | 3.8 |
| 17 | 1992 | NA | 16 | 29 | 9.0 | 28 | 8.0 | 3.0 | 18.2 | 5.9 | 5.4 | 19.7 | 6.0 | 7.9 |
| 18 | 1992 | NA | 16 | 29 | 9.0 | 30 | 8.1 | 3.0 | 17.7 | 6.5 | 3.9 | 18.7 | 6.3 | 6.0 |
| 19 | 1992 | NA | 13 | 29 | 9.0 | 30 | 8.8 | 3.0 | 19.3 | 6.5 | 3.9 | 18.5 | 6.3 | 6.4 |
| 20 | 1993 | 3.6 | 17 | 28 | 9.4 | 28 | 8.3 | 3.4 | 18.9 | 6.3 | NA | NA | NA | NA |
| 21 | 1993 | 4.2 | 18 | 25 | 9.0 | 26 | 9.1 | 3.8 | 19.2 | 6.3 | 2.2 | NA | 6.3 | 0.0 |
| 22 | 1993 | 5.2 | 20 | 25 | 9.0 | 26 | 9.1 | 3.2 | 17.6 | 6.0 | 2.0 | NA | 5.8 | 0.0 |
| 23 | 1993 | NA | NA | 28 | 9.9 | 27 | 9.8 | NA | 17.7 | 6.3 | NA | NA | NA | 3.3 |
| 24 | 1993 | NA | 21 | 30 | 9.8 | NA | NA | 3.2 | 14.3 | 5.8 | 1.7 | 13.3 | 5.6 | 0.7 |
| 25 | 1993 | 5.5 | NA | 32 | 8.0 | 33 | 7.2 | 4.0 | 15.1 | 7.0 | 3.9 | 14.3 | 7.1 | 0.0 |
| 26 | 1993 | 5.1 | NA | 32 | 8.0 | 30 | 7.2 | 3.5 | 15.0 | 6.0 | 3.6 | 15.2 | 6.1 | 0.0 |
| 27 | 1993 | 6.8 | 26 | 28 | 10.4 | NA | NA | 4.0 | 18.0 | 6.7 | 4.3 | NA | 6.0 | 11.1 |
| 28 | 1993 | 11.3 | 24 | 29 | 9.6 | 31 | 8.2 | 4.0 | 17.5 | 6.4 | 6.9 | NA | 5.6 | 4.1 |
| 29 | 1993 | 8.3 | 24 | 33 | 8.9 | 34 | 7.1 | 4.0 | 17.0 | 6.3 | 4.0 | 17.2 | 6.3 | 3.0 |

Table 1. Summary of Data Collected on SMA Projects (Continued)

| Project No. | Date of Construction | Initial In-Place Voids | L A Abrasion Loss, % | Design % Passing 4.75 mm Sieve | Design % Passing 0.075 mm Sieve | Production % Passing 4.75 mm Sieve | Production % Passing 0.075 mm Sieve | Design Voids, % | Design VMA, % | Design AC Content, % | Plant Voids, % | Plant VMA, % | Plant AC Content, % | Rutting, mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 1993 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 12.7 |
| 31 | 1993 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.0 |
| 32 | 1993 | 7.8 | 18 | 25 | 9.6 | 28 | 10.5 | NA | NA | NA | NA | NA | NA | 0.3 |
| 33 | 1993 | 6.5 | 18 | 25 | 9.6 | 28 | 11.2 | NA | NA | NA | NA | NA | NA | 1.0 |
| 34 | 1993 | 6.1 | 18 | 25 | 9.6 | 29 | 11.7 | NA | NA | NA | NA | NA | NA | 1.1 |
| 35 | 1993 | 7.6 | 18 | 25 | 9.6 | 27 | 11.3 | NA | NA | NA | NA | NA | NA | 0.8 |
| 36 | 1993 | 4.5 | 18 | 25 | 9.6 | 28 | 11.4 | NA | NA | NA | NA | NA | NA | 0.5 |
| 37 | 1993 | 6.1 | 18 | 25 | 9.6 | 30 | 11.6 | NA | NA | NA | NA | NA | NA | 1.5 |
| 38 | 1993 | 9.4 | 27 | 28 | 8.1 | 26 | 6.6 | 3.0 | 16.3 | 6.2 | 2.9 | 17.1 | 6.2 | 1.8 |
| 39 | 1993 | 5.5 | 27 | 28 | 8.1 | 28 | 7.8 | 3.0 | 15.9 | 6.0 | 2.0 | 16.0 | 6.0 | 1.3 |
| 40 | 1993 | 7.6 | 27 | 31 | 9.8 | 34 | 7.4 | 3.0 | 15.4 | 6.0 | 2.7 | 16.3 | 6.0 | 0.8 |
| 41 | 1993 | 6.4 | 27 | 31 | 9.8 | 35 | 5.0 | 3.0 | 15.7 | 6.0 | 2.6 | 16.9 | 6.0 | 0.5 |
| 42 | 1993 | 6.0 | 27 | 31 | 9.8 | 32 | 5.8 | 3.0 | 15.2 | 5.9 | 2.7 | 16.9 | 5.9 | 0.8 |
| 43 | 1993 | 7.4 | 27 | 31 | 9.8 | 31 | 9.9 | 3.0 | 16 | 6.1 | 3.2 | 17.5 | 6.1 | 0.5 |
| 44 | 1993 | 9.4 | 38 | 32 | 10.3 | NA | NA | 2.9 | 16.8 | 6.7 | NA | NA | NA | 2.3 |
| 45 | 1993 | 9.4 | 38 | 32 | 10.3 | NA | NA | 2.9 | 16 | 6.3 | NA | NA | NA | 2.5 |
| 46 | 1993 | 7.3 | 38 | 32 | 10.3 | NA | NA | 3.1 | 16.9 | 6.7 | NA | NA | NA | 2.5 |
| 47 | 1993 | 7.3 | 38 | 32 | 10.3 | NA | NA | 3.1 | 16.9 | 6.6 | NA | NA | NA | 2.3 |
| 48 | 1993 | 7.3 | 38 | 32 | 10.3 | NA | NA | 3.1 | 16.9 | 6.6 | NA | NA | NA | 2.3 |
| 49 | 1993 | 7.3 | 38 | 32 | 10.3 | NA | NA | 3.0 | 16 | 6.6 | NA | NA | NA | 2.3 |
| 50 | 1993 | 9.1 | 24 | 38 | 10.2 | NA | NA | 2.9 | 17.5 | 6.4 | NA | NA | NA | 0.3 |
| 51 | 1993 | 7.6 | 24 | 38 | 10.2 | 38 | 10.8 | 3.0 | 16.6 | 6.3 | NA | NA | NA | 0.5 |
| 52 | 1993 | 5.1 | 24 | 38 | 10.2 | 38 | 11.2 | 3.0 | 18.1 | 7.0 | NA | NA | NA | 0.3 |
| 53 | 1993 | 8.0 | 24 | 38 | 10.2 | 38 | 11.0 | 3.0 | 16.6 | 6.2 | NA | NA | NA | 1.3 |
| 54 | 1993 | 7.2 | 24 | 38 | 10.2 | 38 | 10.8 | 3.0 | 17.3 | 6.7 | NA | NA | NA | 0.5 |
| 55 | 1993 | 8.8 | 24 | 38 | 10.2 | 36 | 10.1 | 3.0 | 17.7 | 6.8 | NA | NA | NA | 0.5 |
| 56 | 1993 | NA | NA | 26.6 | 8.9 | 27.6 | 9.3 | NA | NA | 6.5 | NA | NA | 6.3 | 0.8 |
| 57 | 1993 | NA | NA | 27.4 | 9.3 | NA | NA | 3.8 | 19.4 | 6.8 | NA | NA | NA | NA |
| 58 | 1993 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 1.8 |
| 59 | 1993 | NA | 24 | 30 | 8.0 | 31 | 9.2 | NA | NA | 5.3 | NA | NA | NA | NA |

Table 1. Summary of Data Collected on SMA Projects (Continued)

| Project No. | Date of Construction | Initial In-Place Voids | L A Abrasion Loss, % | Design % Passing 4.75 mm Sieve | Design % Passing 0.075 mm Sieve | Production % Passing 4.75 mm Sieve | Production % Passing 0.075 mm Sieve | Design Voids, % | Design VMA, % | Design AC Content, % | Plant Voids, % | Plant VMA, % | Plant AC Content, % | Rutting, mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 1994 | 4.5 | 17 | 27 | 9.1 | 25.0 | 7.9 | 4.0 | 18.7 | 6.3 | 2.2 | 17.3 | 6.4 | 1.1 |
| 61 | 1994 | 5.3 | 17 | 26 | 9.0 | 29.0 | 7.9 | 3.6 | 19.4 | 6.0 | 2.9 | 17.7 | 6.0 | 0.2 |
| 62 | 1994 | 5.8 | 18 | 27 | 8.1 | 24.7 | 7.6 | 4.0 | 18.7 | 6.3 | 2.2 | 17.3 | 6.4 | 0.0 |
| 63 | 1994 | 4.4 | 18/21 | 30 | 9.7 | 29.2 | 9.3 | 5.4 | 19.8 | 6.0 | 3.0 | 18.0 | 6.1 | NA |
| 64 | 1994 | 4.4 | 18 | 24 | 9.0 | 24.7 | 8.6 | 4.3 | 19.4 | 6.3 | 3.4 | 19.0 | 6.4 | NA |
| 65 | 1994 | 5.0 | 17 | 28 | 9.1 | 29.0 | 8.3 | 3.8 | 18.4 | 6.0 | 3.6 | 17.9 | 6.0 | NA |
| 66 | 1994 | 4.9 | 18/21 | 24 | 9.0 | 23.7 | 8.7 | 4.0 | 19.5 | 6.3 | 3.8 | 18.9 | 6.2 | 0.0 |
| 67 | 1994 | 5.4 | 18 | 24 | 9.1 | 24.1 | 8.8 | 4.0 | 19.5 | 6.3 | 3.6 | NA | 6.1 | 0.0 |
| 68 | 1994 | 5.3 | 18 | 24 | 9.1 | 24.0 | 9.1 | 4.0 | 18.5 | 6.0 | 4.0 | 18.7 | 6.0 | 0.0 |
| 69 | 1994 | NA | 16 | 25 | 9.0 | 25.0 | 8.8 | 3.6 | 19.0 | 6.3 | 2.6 | NA | 6.3 | 0.0 |
| 70 | 1994 | NA | 16 | 25 | 9.0 | 26.0 | 9.1 | 3.8 | 18.2 | 6.0 | 3.6 | 18.2 | 6.1 | 0.0 |
| 71 | 1994 | 6.7 | 18/21 | 26 | 8.5 | 26.0 | 8.9 | 4.0 | 19.3 | 6.0 | 3.8 | 18.0 | 5.8 | 0.0 |
| 72 | 1994 | 4.5 | 20 | 26 | 9.9 | 26.0 | 9.0 | 3.2 | 18.5 | 6.3 | 2.3 | 17.8 | 6.3 | 0.0 |
| 73 | 1994 | NA | NA | 27 | 9.9 | 27/26 | 9.9/9.0 | NA | 17.6/16.6 | 6.3/5.7 | NA | NA | NA | 6.4 |
| 74 | 1994 | 2.6 | 26 | 34 | 10.7 | NA | NA | 3.0 | 13.1 | 5.8 | 2.6 | 13.1 | 5.2 | 1.4 |
| 75 | 1994 | 6.6 | 24 | 31 | 11.6 | 32.0 | 12.0 | 4.0 | 19.0 | 6.5 | 4.1 | NA | 6.5 | 0.4 |
| 76 | 1994 | 6.1 | NA | 24.3 | 9.9 | 24.3 | 10.4 | 4.5 | 17.4 | 5.6 | NA | NA | 6.2 | NA |
| 77 | 1994 | 5.0 | NA | 29.7 | 9.2 | 30.3 | 9.5 | 3.4 | 17.0 | 5.7 | NA | NA | 5.7 | 1.2 |
| 78 | 1994 | NA | 16 | 31 | 11.3 | NA | NA | NA | NA | NA | NA | NA | NA | 3.6 |
| 79 | 1994 | 3.1 | 19 | 25 | 7.8 | 35.0 | 10.0 | 4.4 | 15.7 | 5.5 | NA | NA | NA | 2.4 |
| 80 | 1994 | 3.1 | 19 | 25 | 7.8 | 35.0 | 10.0 | 4.4 | 15.7 | 5.5 | NA | NA | NA | 3.0 |
| 81 | 1994 | 3.1 | 19 | 25 | 7.8 | 35.0 | 10.0 | 4.4 | 15.7 | 5.5 | NA | NA | NA | 3.7 |
| 82 | 1994 | NA | 13 | 28 | 11.0 | NA | NA | 4.0 | 16.2 | 6.2 | NA | NA | NA | 0.7 |
| 83 | 1994 | NA | 13 | 28 | 11.0 | NA | NA | 4.0 | 16.2 | 6.2 | NA | NA | NA | 1.3 |
| 84 | 1995 | 4.9 | NA | 28 | 9.1 | 29.0 | 8.3 | 3.8 | 18.4 | 6.0 | 3.6 | 17.9 | 6.0 | 1.6 |
| 85 | 1995 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.0 |
| 86 | 1995 | 5.4 | 18 | 23 | 9.0 | 24.6 | 8.2 | 3.5 | 19.6 | 6.5 | 3.4 | 19.3 | 6.4 | 0.0 |
| 87 | 1995 | 5.3 | NA | 23 | 9.0 | 24.3 | 8.0 | 3.2 | 19.6 | 6.5 | 3.1 | 18.8 | 6.5 | 0.0 |
| 88 | 1995 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.0 |

Table 1. Summary of Data Collected on SMA Projects (Continued)

| Project No. | Date of Construction | Initial In-Place Voids | L A Abrasion Loss, % | Design % Passing 4.75 mm Sieve | Design % Passing 0.075 mm Sieve | Production % Passing 4.75 mm Sieve | Production % Passing 0.075 mm Sieve | Design Voids, % | Design VMA, % | Design AC Content, % | Plant Voids, % | Plant VMA, % | Plant AC Content, % | Rutting, mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 89 | 1995 | NA | NA | 34 | 10.3 | NA | NA | 4.0 | 15.8 | 5.8 | 3.5 | 15.1 | 5.6 | 2.8 |
| 90 | 1995 | 6.2 | NA | 32.6 | 10.2 | 35.1 | 10.4 | 3.9 | 20.1 | 6.4 | NA | NA | 6.6 | 0.3 |
| 91 | 1995 | NA | NA | 23.4 | 10.0 | NA | NA | 3.9 | 19.7 | 6.5 | NA | NA | NA | 0.5 |
| 92 | 1995 | 4.7 | NA | 22.4 | 9.9 | 23.3 | 10.2 | 3.7 | 17.4 | 6.0 | NA | NA | 6.0 | NA |
| 93 | 1995 | 4.9 | NA | 22.1 | 9.3 | 23.9 | 8.9 | 3.9 | 19.3 | 6.2 | NA | NA | 6.2 | NA |
| 94 | 1995 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 2.4 |
| 95 | 1995 | 8.25 | 29 | 29 | 7.7 | NA | NA | 6.2 | NA | 6.5 | NA | NA | NA | NA |
| 96 | 1996 | NA | NA | 23.3 | 9.7 | 26.1 | 10.2 | 4.5 | 19.9 | 6.3 | NA | NA | 6.3 | 0.0 |
| 97 | 1996 | 4.3 | NA | 26.8 | 9.8 | 28.6 | 9.8 | 4.2 | 20.1 | 6.4 | NA | NA | 6.2 | 0.0 |
| 98 | 1996 | 5.1 | NA | 22.4 | 8.0 | 23.5 | 8.0 | 4.0 | 19.1 | 6.0 | NA | NA | 6.1 | NA |
| 99 | 1996 | 5.4 | NA | 27.5 | 9.3 | 26.2 | 9.0 | 4.6 | 18.6 | 6.2 | NA | NA | 6.2 | 0.0 |
| 100 | 1996 | 4.6 | NA | 26.2 | 9.5 | 27.7 | 9.1 | 4.3 | 18.0 | 6.1 | NA | NA | 6.3 | NA |
| 101 | 1996 | NA | NA | 24.7 | 9.7 | 24 | 9.5 | 4.9 | 19.2 | 6.6 | NA | NA | 6.6 | NA |
| 102 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 3.0 |
| 103 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 1.6 |
| 104 | NA | NA | NA | 32 | 10.3 | NA | NA | 6.5 | 18.9 | 6.0 | 7.4 | NA | 6.0 | 3.6 |
| 105 | NA | NA | 37 | 29 | 8.3 | 57 | 3.0 | NA | NA | NA | NA | NA | NA | 2.3 |

Note: NA = Not Available

SMA work. The feeling in that state is that the fiber does the best job of preventing draindown while the polymer improves the asphalt cement properties at low and high temperatures.

It appears that SMA mixtures can be produced in drum mix or batch plants without any major problems. The bottleneck at the plant for production tonnage is typically the addition of mineral filler. For most dense graded projects the amount of mineral filler added to a HMA does not exceed one percent (typically lime). However, for SMA mixtures the amount of filler to be added is typically 4-5 percent.

Most of the SMA projects, using fiber, added the fibers in a loose condition. The fiber is typically blown, at the correct proportion, into the plant. In a few cases the fibers were added as pellets and fed into the mixture at the RAP feed.

Polymers were often preblended with the asphalt cement prior to blending into the SMA mixture. In many cases the polymer was added in small particles at the RAP feed. In this case, the aggregate, asphalt cement, and polymer were all mixed at the same time.

Mixtures evaluated were designed using 50-blow Marshall compaction. Some SMA mixtures are beginning to be designed using the Superpave gyratory compactor but this design method was not used for the SMA mixtures evaluated. Early SMA mixtures (1991-1993) were typically designed to have 3.5% air voids or less but more recently (1994-1996) mixtures have been designed closer to 4% air voids (Figure 2). Designing the mixtures at 3% air voids definitely results in a higher probability of fat spots and permanent deformation. For these reasons, many state DOTs are now requiring that the mixture be designed near 4.0 percent voids. Generally speaking, the design voids are somewhat lower for the northern states compared to the southern states. Approximately 25% of the projects to date were designed 2-3% air voids (primarily at 3.0

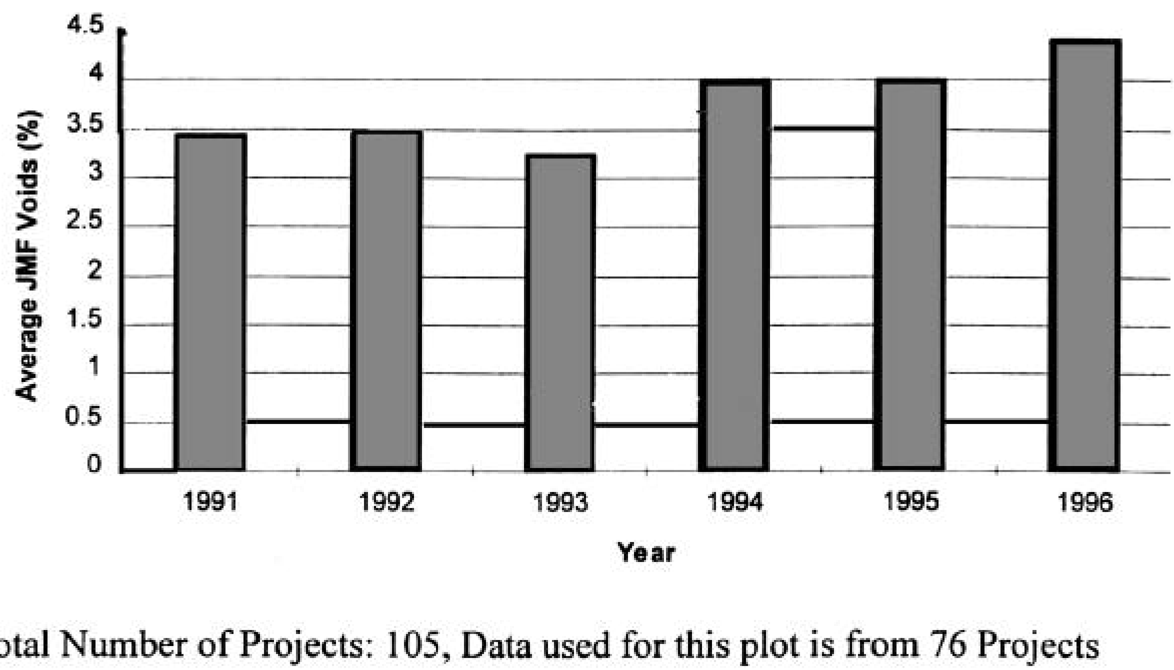
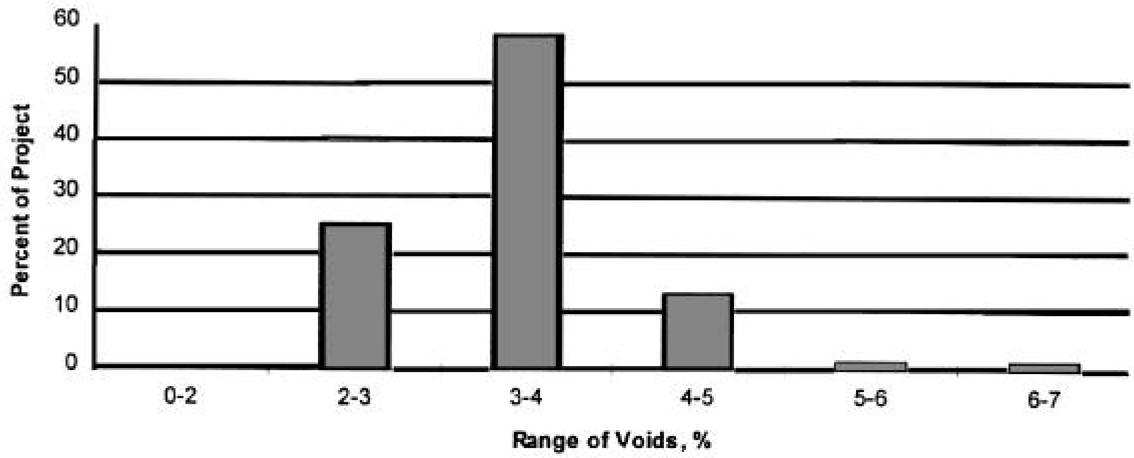



Figure 2. Trend for Design Air Voids for SMA Mixtures

percent) and close to 60% have been designed between 3 and 4 percent. About 15% have been designed above 4% voids (Figure 3). During construction approximately 32 percent of the average air voids were below 3 percent (Figure 4). This results in an increase of 7 percent from that shown in the design air voids. This clearly shows the need for proper field management to ensure that the air voids are within an acceptable range. Laboratory voids below 3 percent are considered to be too low for SMA.

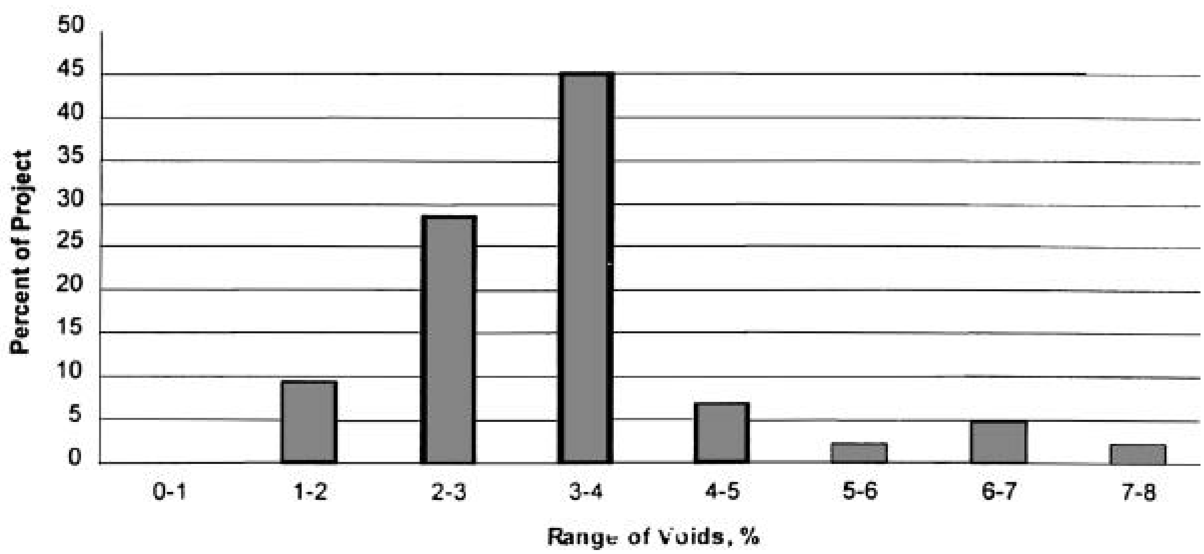
To date, SMA projects have been designed using all crushed aggregate. This requirement is probably one major reason that SMA mixtures tend to provide good performance. The L. A. abrasion of the aggregate, on the average, is lower that that used for dense mixtures. Eighty-five percent of the projects have had L. A. abrasion values below 30 (Figure 5).




Total Number of Projects: 105, Data used for this plot is from 75 Projects.

Average: 3.7%, Standard Deviation: 0.65%

Figure 3. Range of Design Air Voids Used for Design of SMA Mixture




Total Number of Projects: 105. Data used for this plot is from 42 Projects

Average: 3.5% Standard Deviation: 1.24%

Figure 4. Range of Laboratory Air Voids During Construction

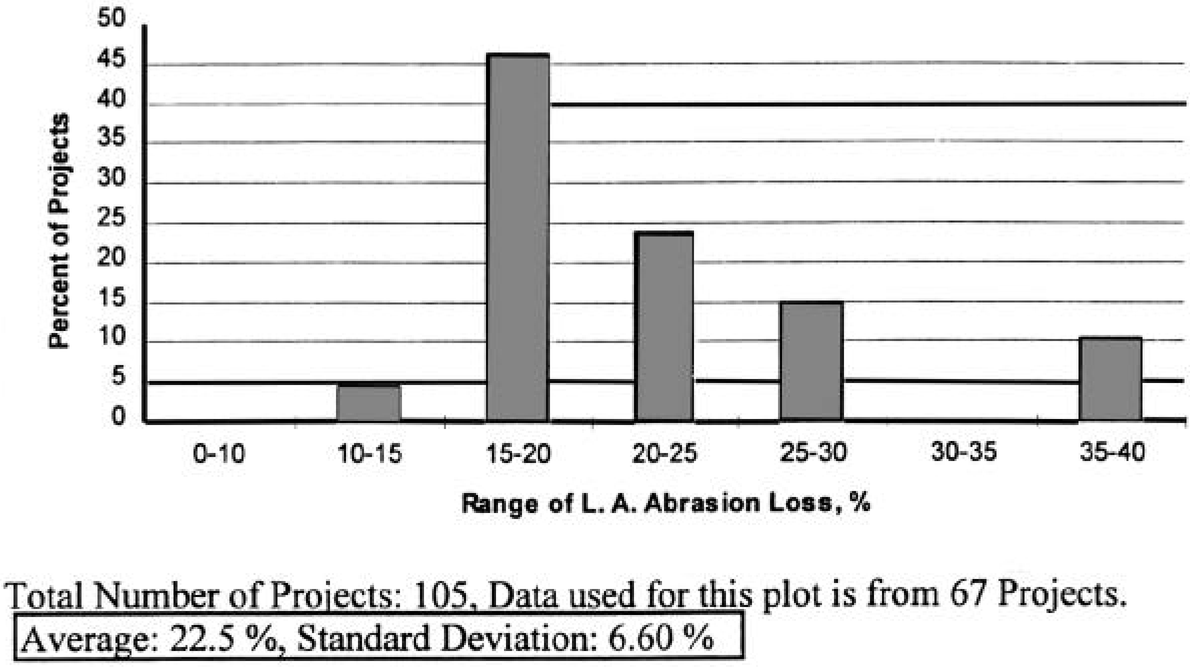
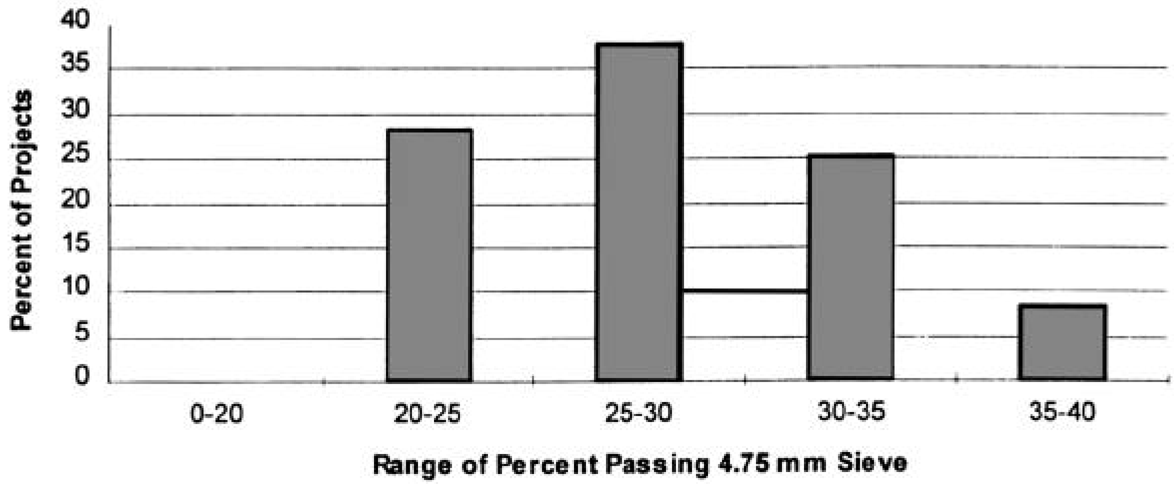



Figure 5. Distribution of L.A. abrasion values used for the SMA projects.

SMA mixtures have been designed approximately 90-95 percent of the time to have 20-35 percent of the material passing the 4.75 mm sieve and to have 7-11 percent passing the 0.075 mm sieve (Figure 6 and 7). During production, the measured gradation is similar to the mix design for the material passing 4.75 mm (Figure 8), but the percentage between 7 and 11 percent is less (80 percent) in the case of material passing the 0.075 mm sieve (Figure 9).

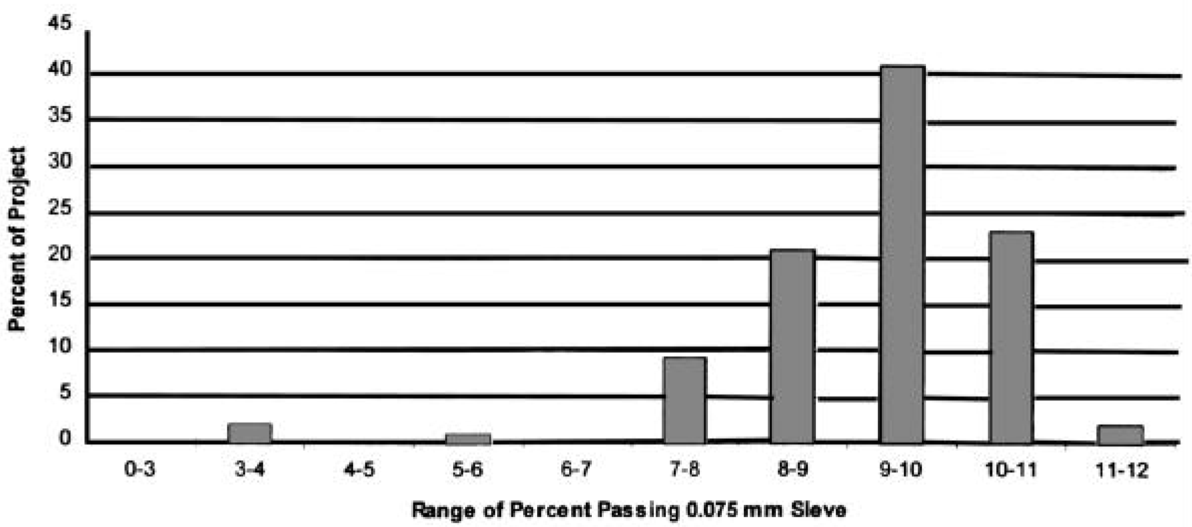
The SMA mixtures have tended to get coarser from year to year (Figure 10). The percent passing the 4.75 mm sieve has decreased from approximately 32 percent in 1991 down to approximately 26 percent for the projects constructed in 1996. Part of the reason for this trend was that the initial recommended requirements for the percentage passing the 4.75 mm was higher during the first couple of years and was reduced between 1993 and 1994 (*1*). The reduction was




Total Number of Projects: 105, Data used for this plot is from 95 Projects

Average: 28.8%, Standard Deviation: 4.12%

Figure 6. Distribution of percentage passing the 4.75 mm sieve during mix design.




Total Number of Projects: 105, Data used for this plot is from 95 Projects

Average: 9.3%, Standard Deviation: 1.19%

Figure 7. Distribution of percentage passing the 0.075 mm sieve during mix design.

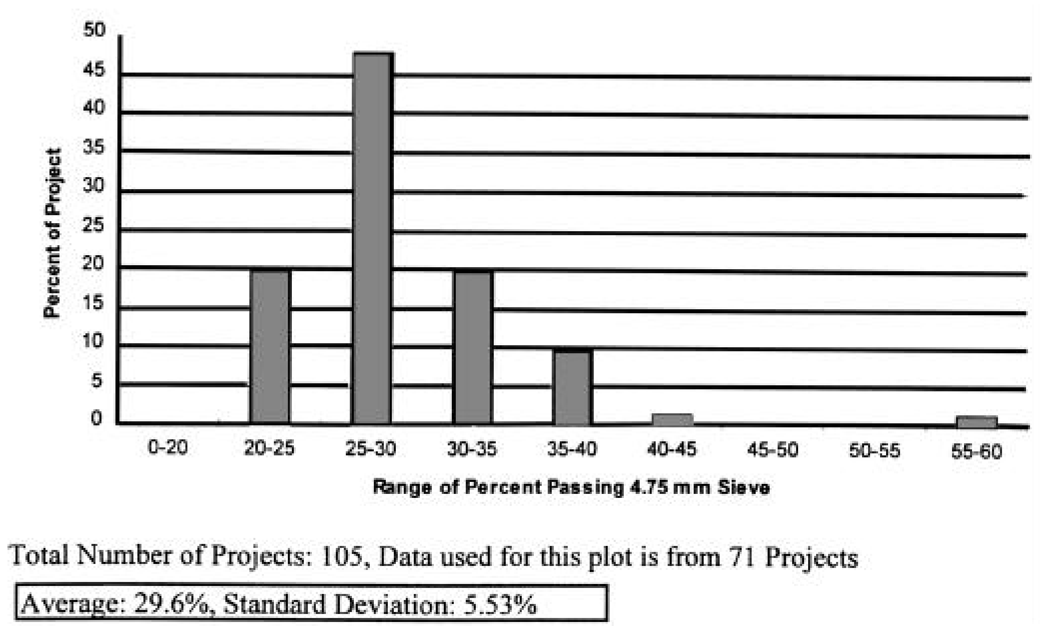



Figure 8. Distribution of percentage passing the 4.75 mm sieve during construction.

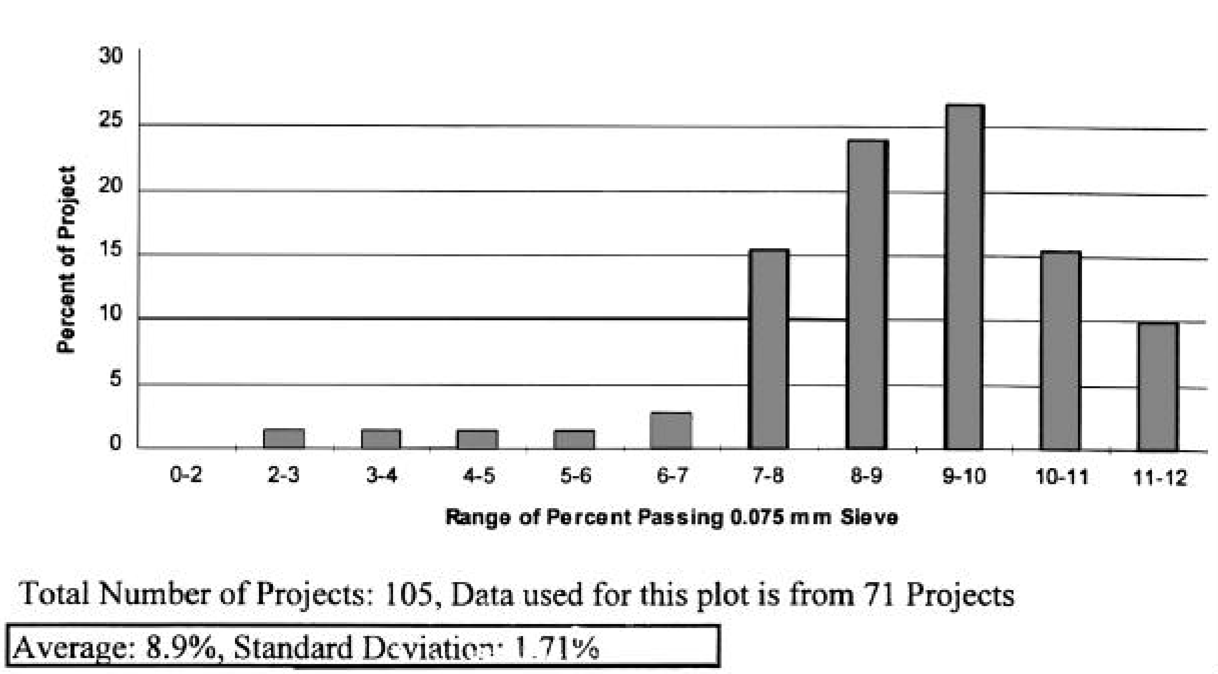
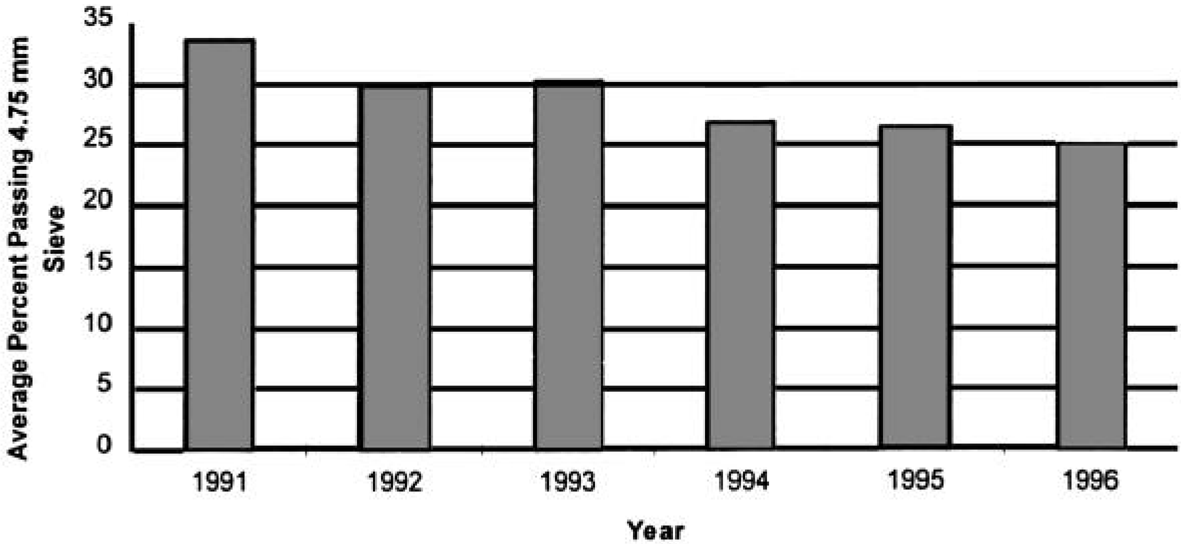
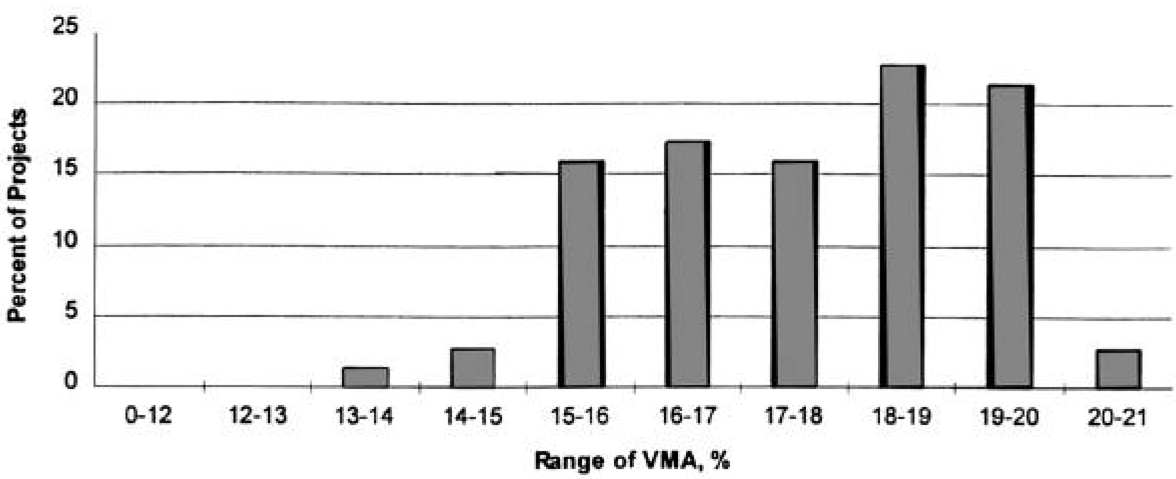



Figure 9. Distribution of percentage passing the 0.075 mm sieve during construction.




Total Number of Projects: 105, Data used for this plot is from 92 Projects

Figure 10. Trend for percent of aggregate passing the 4.75 mm sieve during mix design.




Total Number of Projects: 105, Data used for this plot is from 75 Projects

Average: 17.7%, Standard Deviation: 1.57%

Figure 11. Distribution of VMA during mix design.

made based on research that indicated for most SMA mixtures the percent of material passing the 4.75 mm sieve had to be less than 30 percent to ensure stone-on-stone contact and to meet minimum VMA requirements (*2*).

For over 90% of the SMA projects the VMA has ranged from 15-20 percent (Figure 11). The recommended minimum requirements for VMA shown in Reference *1* is 17 percent. It appears that about 53 percent of the projects would meet this recommended requirement. A trend in the VMA for the SMA mixtures during 1991-1996 is shown in Figure 12. The VMA values appear relatively high for the first two years then low for the third year. The numbers began to increase again after 1993.

Three factors have likely lead to this trend in VMA. Early projects attempted to use very hard aggregates which do not break down during laboratory compaction resulting in a higher VMA. In recent years, as more states have constructed SMA, the average abrasion loss being used has increased. The higher abrasion loss will result in lower VMA due to aggregate breakdown. The trend in air voids have shown that the air voids have increased with time. Since most SMA mixtures are designed on the rich side of the minimum VMA, a reduction in asphalt content (to increase air voids) has resulted in lower VMA. The third item that has affected VMA has been the decrease in percentage passing the 4.75 mm sieve. All of these items have worked to increase or decrease the VMA and likely have caused the trend shown in Figure 12.

Typically for SMA mixtures, the asphalt content should be at least 6.0 percent by weight. However, when a limit is established for minimum VMA, a minimum asphalt content does not need to be specified. For the projects investigated, the minimum recommended asphalt content of 6.0 percent was exceeded approximately 60 percent of the time (Figure 13). For production,

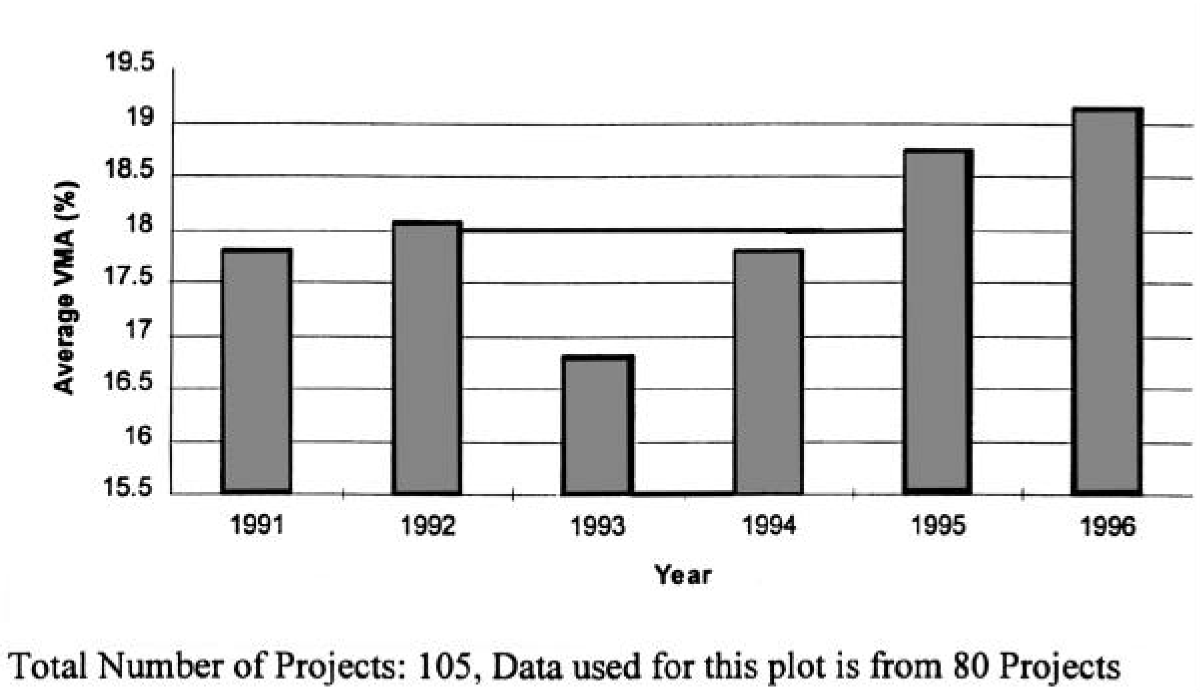



Figure 12. Trend for design VMA for SMA mixtures.

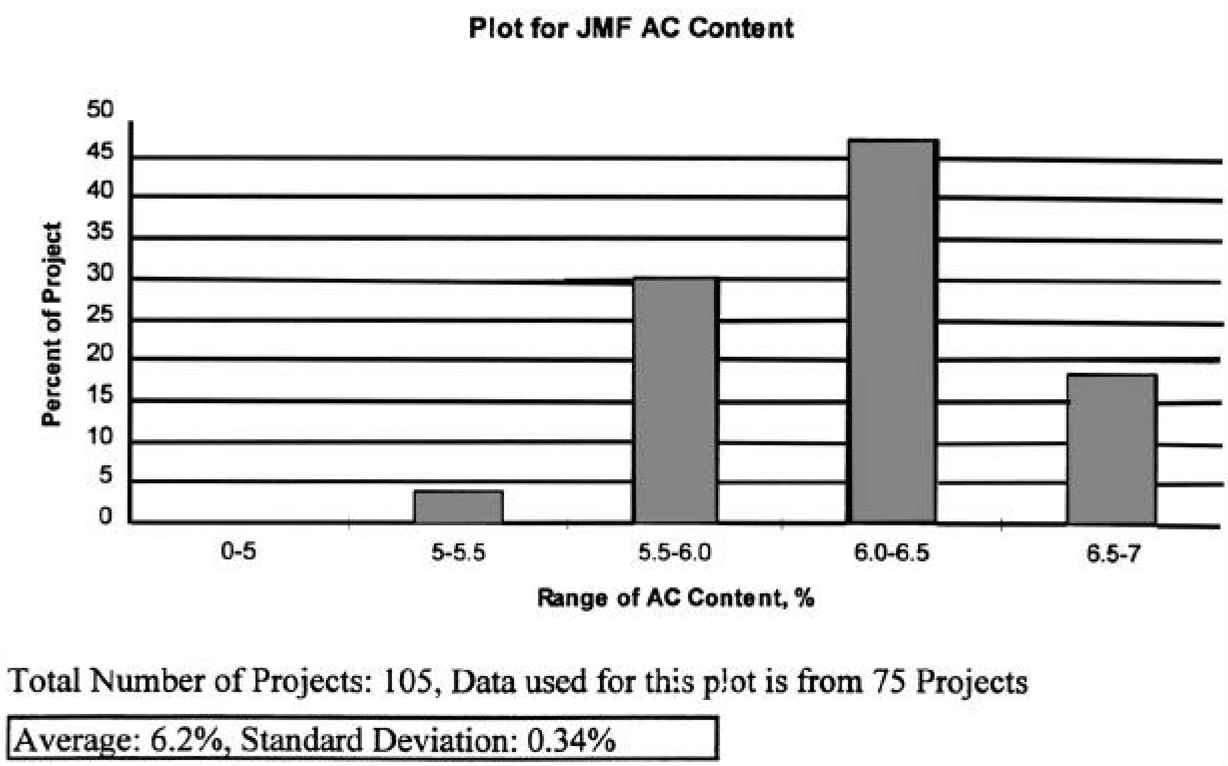
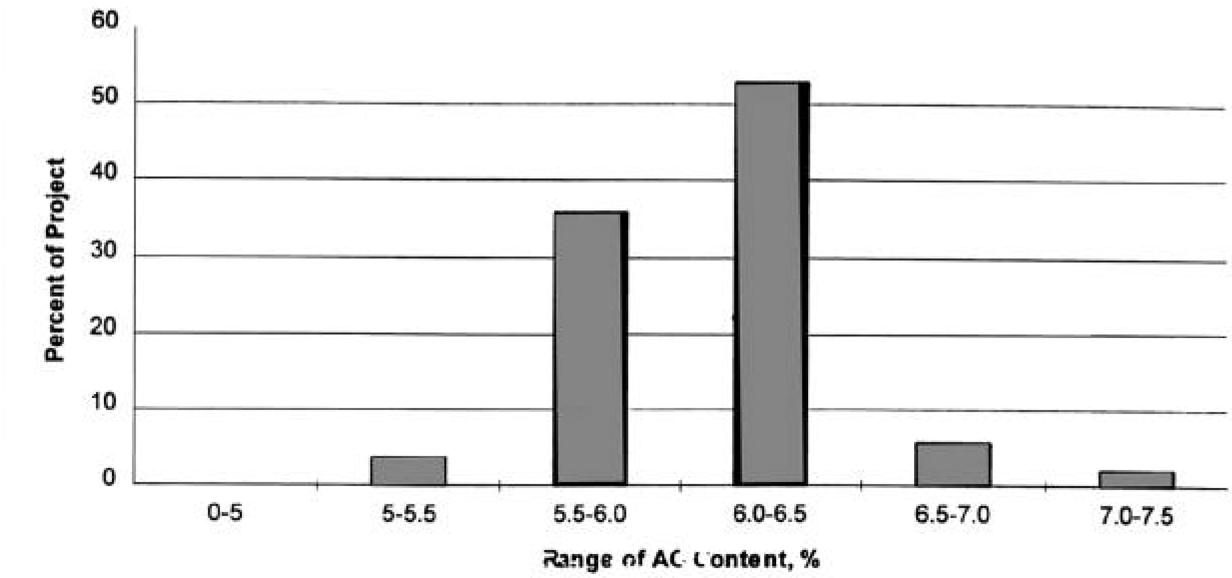



Figure 13. Range of mix design optimum asphalt content.




Total Number of Projects: 105, Data used for this plot is from 53 Projects

Average: 6.1%, Standard Deviation: 0.33%

Figure 14. Range of production asphalt content.

approximately 50 percent of the projects exceeded the 6.0 percent minimum recommended AC content (Figure 14).

Typically SMA mixtures should be compacted on the roadway to 5-7 percent air voids. However, there are a significant amount of projects that have been constructed with in-place air voids above 7 percent (approximately 25%) and below 5 percent (approximately 30%). A summary of this information is provided in Figure 15. SMA mixtures can be difficult to compact for contractors that have not had much experience with these types of mixtures. The mixes have a high coarse aggregate content, all crushed material, and relatively stiff binders. This combination makes the mixes more difficult to work but with experience they can be placed and properly

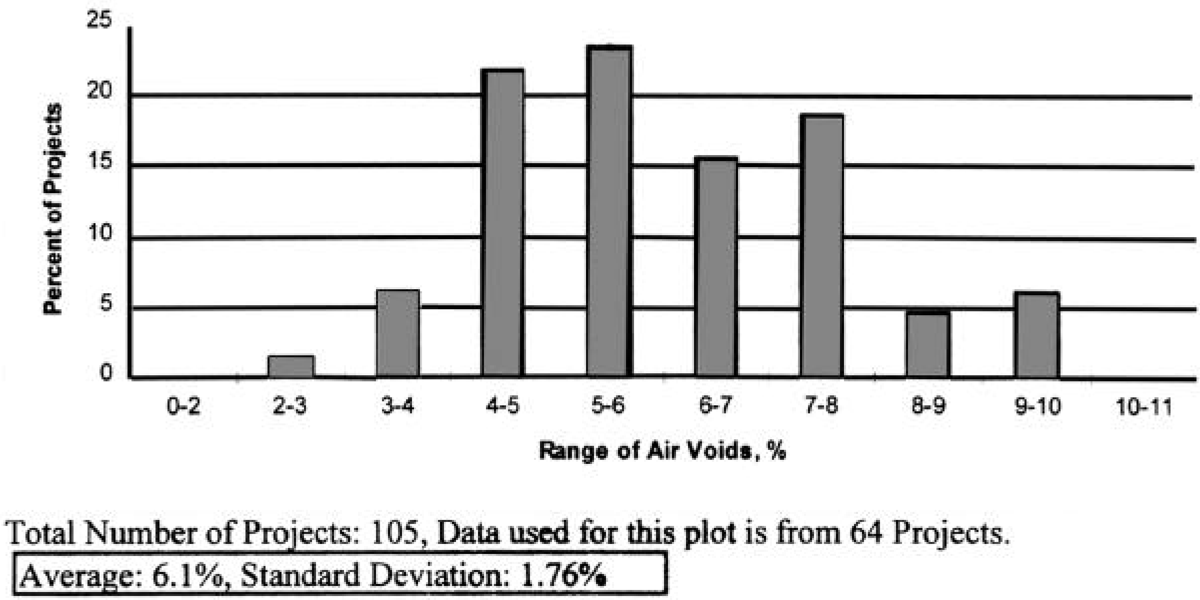



Figure 15. Distribution of initial in-place air voids.

compacted.

Segregation as observed in dense graded mixtures is not a problem with SMA mixtures. In construction of dense-graded mixtures there is a tendency for the coarse aggregate to separate from the fine aggregate resulting in excessive coarse aggregate particles in localized areas typically at the end of truck loads. However, with SMA mixtures reverse segregation occurs. Problems have not been observed with a large amount of coarse aggregate congregating together since the SMA mixture has high coarse aggregate content anyway. The problem that is observed is small localized sections not having sufficient coarse aggregate resulting in fat spots. This is a form of segregation. When some of the coarse aggregate is removed from an SMA mixture the asphalt content in the remaining finer mixture is higher and the VMA in the compacted finer mixture is lower. This results in low in-place voids leading to fat spots and possibly rutting.

**OBSERVED PERFORMANCE**

The various SMA mixtures were inspected to determine performance. Measurement of performance included evaluation of segregation (surface uniformity), quality of longitudinal joint, cracking, rutting, raveling, and fat spots. Obviously some of these performance parameters are related to some of the other parameters (e.g. rutting, fat spots, segregation).

The pavement surface was inspected to evaluate uniformity. In general the SMA mixtures had good uniformity. The coarse aggregate surface texture (Figure 16) appears to be good and tends to help keep surface water below the pavement-tire interface. There were no obvious signs of excessive coarse aggregate segregating from the mix. Some of the pavements inspected had some localized fat spots (Figure 17). These fat spots can vary from a few centimeters in diameter to a few hundred meters long in a few cases. In most cases, the small fat spots were no problem at all. In a few cases where those spots were large they had to be removed and replaced to ensure adequate pavement friction characteristics. Many of the SMAs that used modifiers had small spots about 50 mm in diameter where the modified binder built up on the screed of the paver and then came off at some point and was rolled into the pavement (Figure 18). These small spots do not cause any performance problems.

The fat spots can be caused by many things: insufficient fibers, high asphalt content, low coarse aggregate content, excessive temperature, and excessive moisture. Fibers are used in SMA mixtures to prevent draindown of the asphalt cement. If the fiber feed does not work properly, then the fiber content may be too low resulting in a potential for draindown. There is no good way to determine the amount of fibers in a mixture and sometimes feeding problems tend to result in lower fiber content. If the fibers get wet, they are very difficult, if not impossible, to properly

Figure 16. Close-up showing coarse aggregate surface texture.

Figure 17. Localized fat spot.

Figure 18. Small blemish caused by build up of mortar on screed.

feed. If the fibers quit feeding for a few seconds, a fat spot due to draindown will almost certainly occur. If polymers are being used as the stabilizer, failure to get the proper amount of polymer in the mixture can also cause draindown.

A high asphalt content can cause fat spots in SMA mixtures just as it does in dense mixtures. Compaction of mixes with high asphalt content tends to result in low voids. These mixtures with high asphalt content tend to flush during compaction resulting in fat spots.

The SMA mixture is sensitive to the percentage of material passing the 4.75 mm sieve. When the percentage passing the 4.75 mm sieve increases the VMA decreases significantly. So if the gradation becomes finer (more passing the 4.75 mm sieve) the VMA in the compacted mixture will decrease resulting in low voids and fat spots.

The temperature of the mixture affects the viscosity of the asphalt cement and high temperature can lead to draindown problems, especially when fibers are not used. The temperature must be controlled within an acceptable range or fat spots might occur.

Moisture in the mixture or in the existing surface being overlaid can cause fat spots. The moisture vaporizes at high temperatures during construction and will tend to remove the asphalt binder from the aggregate particles. When this happens, the excess asphalt binder tends to migrate to the surface under traffic resulting in a fat spot.

The quality of the longitudinal joints in the SMA mixture was closely observed for each site visited. A good longitudinal joint is more difficult to make in an SMA mixture than in a dense mix. Even with dense mixtures, care must be used to ensure construction of a good longitudinal joint. An SMA mixture has more coarse aggregate, all crushed aggregate, and a relatively stiff binder. This combination makes for difficulty in construction of good joints. Some of the SMA pavements had excellent joints, some had satisfactory but not great joints (Figure 19) and a few had unsatisfactory joints. Since many of these projects were the first ones built by some contractors, it is not unexpected to see some localized problems especially at joints. As Contractors and state DOTs get more experience with SMA, the quality of the work will continue to improve. At the time of inspection most joints were still tight with good texture.

Most of the SMA mixtures that have been placed have been overlays on high volume interstates. Many of these mixes were placed over old existing pavements that had joints or cracks. During the inspection there was very little cracking in the SMA mixtures. The small amount of cracking that was observed on a few projects appeared to be reflective cracks. These few cracks have remained tight and were not raveling (Figure 20). The high asphalt content in

Figure 19. Longitudinal joint that is acceptable but more open than desired.

these mixtures and the use of polymers will likely result in the SMA remaining intact adjacent to the crack. So at the time of inspection, there was no significant thermal cracking problem.

Rutting was measured on most of the SMA sections (Figure 21). A few pavements could not be measured for rutting due to the high rate of traffic. It was obvious that these few sections had no significant rutting since they were inspected from the shoulder but an exact measurement of rutting was not made on these sections. The rutting distribution is shown in Figure 22. It is clear from this figure that approximately 90% of the pavements evaluated had less than 4 mm average rutting. Approximately 70% of the pavements had less than 2 mm of rutting. Over 25% of the SMA pavements had no measurable rutting. There were six projects at the higher rutting rates (more than 6 mm) in which the rutting could be attributed to the SMA mixture. Although

Figure 20. Typical transverse crack in SMA mixture.

most of these SMA pavements are not very old, most have been exposed to a significant amount of traffic. So from a rutting point of view the SMA mixtures are providing excellent performance.

Typically, the performance of the SMA mixtures has been excellent in very high traffic areas (Figure 23). The surface uniformity of most projects has been very good.

Figure 21. Rut depth measurement.

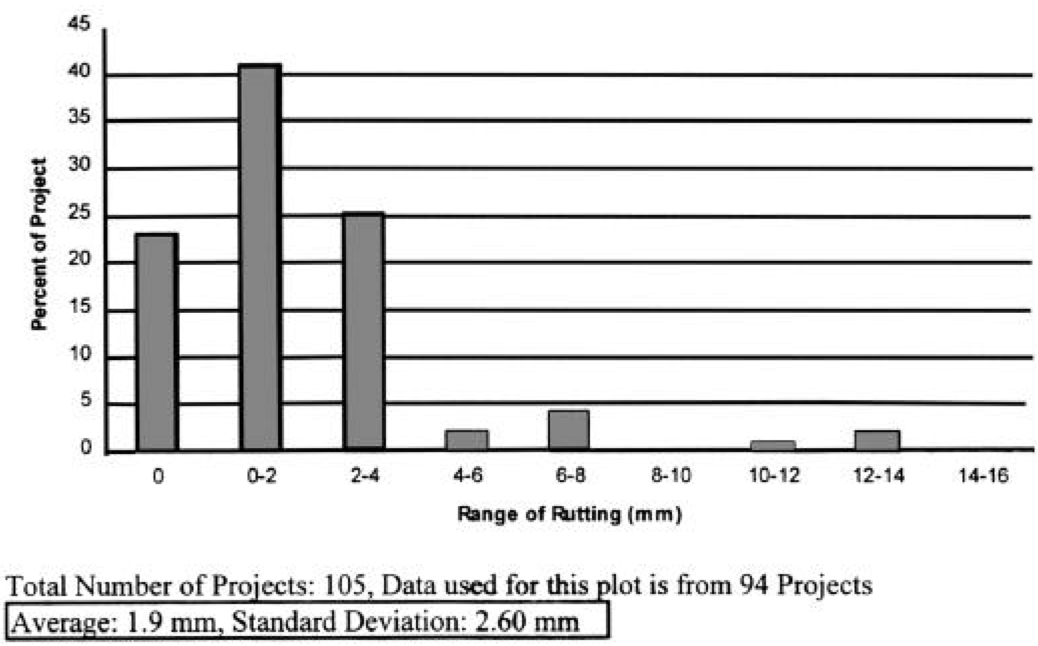



Figure 22. Distribution of rut measurements on SMA pavements.


Figure 23. Typical good performing SMA.

**CONCLUSIONS**

Over 100 of the SMA mixtures that were constructed in the United States since 1991 were inspected and evaluated as a part of this study. Even though the length of service of these pavements is five years or less, the amount of traffic has been high on many of these sections. This study provides a good indication of expected performance of SMA pavement in the U.S. Based on this study, the following conclusions are made:

- Approximately 85 percent of the projects used an aggregate meeting the recommended Los Angeles Abrasion requirement of 30 percent. No problem was observed in the SMA mixtures that could be contributed to L. A. abrasion.
- SMA mixtures were produced approximately 90 percent of the time with 20-35 percent of

the material passing the 4.75 mm sieve and 80 percent of the time with 7-11 percent of the material passing the 0.075 mm sieve.

- Approximately 32 percent of the projects had average laboratory air voids during construction less than 3 percent. Improved field management of SMA should result in a higher percentage of projects having between 3 and 4 percent laboratory air voids.
- Approximately 60 percent of the projects exceeded 6.0 percent asphalt content during production. The minimum recommended requirement of 6.0 percent asphalt content should not be met at the expense of low air voids.
- Over 90% of the SMA projects had rutting measurements less than 4 mm. Approximately 25% of the projects had no measurable rutting. The resistance to rutting appears to be excellent considering the high traffic volume on most of the SMA mixtures.
- Construction of good longitudinal joints has taken some effort. Most projects had good joints and as contractors become more experienced with construction of SMA the quality of joints will improve.
- Cracking (thermal and reflective) has not been a significant problem. SMA mixtures appear to be more resistant to cracking than dense mixtures. This is likely due to the relatively high asphalt content resulting in high film thickness.
- There was no evidence of raveling on the SMA projects.
- Fat spots appear to be the biggest performance problem. These are caused by segregation, draindown, high asphalt content, or improper type or amount of stabilizer.
- Based on findings in the study, SMA mixtures should continue to provide good performance in high volume traffic areas. The extra cost for construction should be more

than offset by the increased performance.

**REFERENCES**

1. National Asphalt Pavement Association. Guidelines for Materials, Production, and Placement of Stone Matrix Asphalt (SMA), IS 118, Lanham, Maryland, 1994.

2. Brown, E. R. and Rajib B. Mallick. Stone Matrix Asphalt Properties Related to Mixture Design. NCAT Report No. 94-2, National Center for Asphalt Technology, Auburn University, AL, 36849-5354, February 1994.