Pothole Signing?

Asphalt Concrete Anti-Stripping Techniques

Study SD99-10
Executive Summary

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ACKNOWLEDGEMENTS

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**TECHNICAL REPORT STANDARD TITLE PAGE**

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15. Supplementary Notes

A Final Report is published separately as SD99-10-F.

16. Abstract

In 1999 the South Dakota Department of Transportation initiated a research project to assess asphalt concrete anti-stripping techniques. The overall objective of the research was to evaluate the effectiveness of anti-stripping additives in reducing the moisture damage of HMA mixtures. The research evaluated the best method of adding lime to HMA mixtures to minimize personnel exposure and environmental impacts, determined the effectiveness of other anti-stripping additives, and developed guidelines for future use of anti-stripping additives in South Dakota.

The research constructed six test sections at two locations in the eastern and western parts of the state, respectively. The test sections included none (control), lime, UP5000, and liquid anti-strip additives. The mixtures were sampled during construction and two years after construction. The moisture sensitivity of the various mixtures was evaluated in the laboratory using resilient modulus, tensile strength, resistance to permanent deformation, and resistance to thermal cracking. The analysis of the laboratory data indicated that the addition of lime has the best potential of reducing the moisture sensitivity of South Dakota's asphalt concrete mixtures. On the other hand, the two years in-service did not show any significant variations in the performance of the various treatments. Based on the data generated from this research, it has been recommended that lime on wet aggregate should be used to minimize moisture damage of asphalt concrete mixtures in South Dakota.

17. Keywords

asphalt concrete, stripping, moisture damage, lime, liquid anti-strip, UP5000, test sections.

19. Distribution Statement

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# GLOSSARY OF TERMS

<table>
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<tr>
<th>Abbreviation</th>
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<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
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<td>AC</td>
<td>Asphalt concrete</td>
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<td>APA</td>
<td>Asphalt pavement analyzer</td>
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<td>American Society of Testing and Materials</td>
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<td>FMLC</td>
<td>Field mixed-lab compacted</td>
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<td>Falling weight deflectometer</td>
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<td>HMA</td>
<td>Hot mixed asphalt</td>
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<td>Mr</td>
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<td>NDOT</td>
<td>Nevada Department of Transportation</td>
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<td>OSHA</td>
<td>Occupational Safety and Health Administration</td>
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<td>PG</td>
<td>Performance grade</td>
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<td>RSCH</td>
<td>Repeated shear constant height</td>
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<td>SDDOT</td>
<td>South Dakota Department of Transportation</td>
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<tr>
<td>SSD</td>
<td>Saturated surface dry</td>
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<td>SST</td>
<td>Simple shear test</td>
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<td>TS</td>
<td>Tensile strength</td>
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<td>TSRST</td>
<td>Thermal stress restrained specimen test</td>
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<td>UP5000</td>
<td>Ultrapave 5000</td>
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EXECUTIVE SUMMARY

In the late 1970s and early 1980s a significant number of pavements in the United States began to experience distress associated with moisture sensitivity of hot mixed asphalt (HMA) materials. Premature rutting, raveling and wear were observed on many pavements. The causes of this sudden increase in pavement distress due to water sensitivity have not been conclusively identified. Practitioners and researchers suggest that changes in asphalt binders, decreases in asphalt binder content to satisfy rutting associated with increases in traffic (traffic volume, traffic weight and tire pressure), changes in aggregate quality, more widespread use of selected design features (open graded friction courses, chip seals and fabric inter-layers) and poor quality control were primarily responsible for increased water sensitivity problems.

In 1999 the South Dakota Department of Transportation (SDDOT) initiated a research project to assess asphalt concrete (AC) anti-stripping techniques. The overall objective of the research was to evaluate the effectiveness of anti-stripping additives in reducing the moisture damage of HMA mixtures. The research evaluated the best method of adding lime to HMA mixtures to minimize personnel exposure and environmental impacts, determined the effectiveness of other anti-stripping additives, and developed guidelines for future use of anti-stripping additives in South Dakota. The project started on July 1, 1999 and was completed on February 28, 2003. A total of thirteen tasks were completed during the project duration.

Review of Literature

An extensive literature review was conducted under this research. The review covered the various areas of current practices, testing and evaluation methods, field construction methods, research and development activities, etc… A report was produced summarizing all aspects of the literature review. The following represent the most significant findings of the literature review.

- Moisture damage of HMA mixtures usually is associated with loss of adhesion or loss of cohesion. However, moisture damage is a function of many factors including materials characteristics, environmental factors, and construction practices.

- Methods of treatment to reduce moisture damage (particularly stripping) include use of good aggregates, pavement surface sealants, pretreatment of aggregates, and use of additives.

- Numerous studies have been conducted at state highway agencies and universities to evaluate pavement distresses due to moisture and to evaluate the effectiveness of chemical additives and lime. Studies show that pretreatment of aggregates with lime is the most effective method.

- Several laboratory tests have been used to assess the moisture sensitivity of HMA mixtures. However, no single test has proven to be exclusive under all combinations of materials, traffic, and environmental conditions. The AASHTO T-283 seems to be the most commonly used by state highway agencies to assess the moisture sensitivity
of HMA mixtures at the mix design stage and during construction.

- The majority of state highway agencies recognize that their pavements are affected by moisture damage leading to premature rutting, cracking, and raveling failures. Most of the surveyed agencies require the use of lime to improve the resistance of HMA mixtures to moisture damage. Also control of in-place air voids to between 5 and 8% and a minimum placement temperature specification are used to protect HMA mixtures from excessive moisture damage.

- The most common remedies for moisture damaged HMA pavements are listed based on their degree of effectiveness as follows: removal, recycle, mill and fill, overlay, and chip seal.

- There are several methods of adding lime to the HMA that are currently being practiced by various agencies. The most common method is to add dry lime to wet aggregates that are 2-3 percent above saturated surface dry (SSD) condition. The treated aggregates can then be used directly into the HMA mix or stockpiled for marination purposes with the direct use technique being the most commonly used in the field. In order to achieve uniform distribution of the lime on the aggregate and to reduce the generation of dust during the process of adding the lime to the wet aggregate, a continuous pugmill has been commonly used.

**Evaluation of Existing Sections**

The research evaluated the performance of three in-service sections near Brookings, South Dakota (SD): two sections with lime and one section with liquid anti-strip. The evaluation program included conditions surveys and laboratory evaluation of field cores. The analyses of the data generated from this evaluation indicated that lime is more effective than the liquid anti-strip especially under multiple freeze-thaw cycling which represents actual field conditions.

**Construction of Field Sections**

The work plan called for the construction of two field projects to evaluate the field performance of various anti-strip additives. Each project included the following six test sections:

- Section 1: Control no additive
- Section 2: Lime on wet aggregates (4% above SSD)
- Section 3: Lime on wet aggregates (4% above SSD)
- Section 4: Lime on aggregate at in-situ moisture content
- Section 5: Ultrapave additive (UP5000) on aggregate at in-situ moisture content
- Section 6: Liquid anti-strip additive blended into the binder

**SD314 Test Sections**

The test sections on SD314 in Yankton, SD were constructed on August 28-31, 2000. The aggregates used on this project were a blend of quartzite and gravel and consisted of four
stockpiles: rock, gravel, sp. rock, and manufactured sand. The rock and gravel came from the Koralevitz Pit while the add rock and manufactured sand came from the Spencer Quarry. The same gradation was used for all six sections. The asphalt binder was a PG64-22 un-modified supplied by Jebro.

The contractor for the SD314 project was Hodgman & Sons. The constructed HMA layer consisted of 1.25" bottom lift and 1.5" top lift. The existing pavement below the new HMA layer consisted of an old 3.5" HMA layer over 6"-9" portland cement concrete pavement. The conditions of the pavement at the time of construction showed transverse cracks at 30'-40' spacing and some rutted areas were milled. The construction activities went very smooth except some wet weather prevailed which increased the moisture content of the stockpiled materials. In-place moisture content testing showed the aggregates to be at a moisture content of 4.5%. This level of moisture is well above the SSD condition of the aggregate which made the distinction between sections 2, 3 (4% above SSD) and 4 (in-place moisture content) very unlikely. In other words the in-place moisture content of the aggregate qualified for sections 2 and 3 without any additional water. However, the moisture content of the aggregate was higher than what was planned for section 4.

**US 14 Test Sections**
The test sections on US14 in Wall, SD, were constructed on October 2-10, 2000. The aggregates used on this project were a blend of limestone and gravel and consisted of five stockpiles: 3/4" rock, crusher fines, dry fines, Lien rock, and washed sand. The sources of aggregates were from O'Connell Pit, Opperman Sand and Gravel, and Pete Lien and Sons Rapid City Quarry. The same gradation was used for all six sections. The asphalt binder was a PG64-28 supplied by Koch.

The contractor for the US 14 project was Border States Paving Inc. The constructed HMA layer consisted of 1.5" bottom lift and 1.5" top lift. The existing pavement below the new HMA layer consisted of an old 5.0" HMA layer over 6" crushed aggregate base. The conditions of the pavement at the time of construction showed transverse cracks at 30'-40' spacing. Similar to the case of SD 314 test sections, wet weather prevailed during construction which made the distinction between sections 2 and 3 and section 4 very difficult. The top lift of the liquid anti-strip section (section 6) was placed during rainy weather. At one time, the construction of this section was stopped due to problems with curing of the tack coat. In addition the last 1,000 feet of the lime on wet aggregate section (section 2) was placed under heavy rain.

**Evaluation of Test Sections**
Two types of samples were obtained during the construction of the test sections on both projects: loose mixtures and compacted mixtures. The loose mixtures were sampled from the top lift at one location from each section. The compacted mixtures were sampled in the form of 6" cores and 7"x12" slabs at two locations from each section. In total, 24 cores, 16 slabs, and 5-five gallons buckets of loose mix were sampled from each section of both projects. The samples were shipped to the researchers laboratory for testing and evaluation.

The following laboratory tests were conducted on field cores and slabs and loose mix samples
that were obtained from the two projects.

Resilient modulus of the HMA mixtures
Tensile strength of the HMA mixtures
Resistance of HMA mixtures to rutting using the Superpave simple shear test (SST) device
Resistance of the HMA mixtures to rutting in the Asphalt Pavement Analyzer (APA)
Resistance of the HMA mixtures to low temperature cracking using the thermal stress restrained specimen test (TSRST)

A comparison of the moisture sensitivity properties of the mix design materials with the moisture sensitivity of the mixtures sampled during construction indicated that the laboratory moisture sensitivity test conducted at the mix design stage can reliably predict the moisture sensitivity of field produced mixtures as long as the testing conditions are kept similar. Therefore, it is recommended that the SDDOT adopts a narrow range of saturation of 70-80% for all moisture sensitivity testing during mix design and on field sampled materials. The 70-80% represents the saturation range recommended by the latest AASHTO T-283 method.

Based on the analysis of the laboratory data generated on the construction samples, the following findings were made.

- The construction of the test sections on SD314 generated highly variable in place air voids within each section and among the various sections. This variation in air voids made it impossible to use the properties of the field cores to compare the performance of the various mixtures. Therefore, the properties of the field cores were only used to compare the mixtures resistance to moisture damage performance within individual sections and not across sections.

- The construction of the test sections on US14 was less variable than the SD314 sections. Even though the in place air voids varied among the various sections, the in place air voids within individual sections were less variable. Some comparisons among sections were possible.

- The field mixed-lab compacted (FMLC) samples were compacted to a narrow range of air voids and were ideal to compare the performance of the various mixtures.

- The resilient modulus and tensile properties of the FMLC samples measured at both the unconditioned and conditioned stages indicated that the lime treated mixtures on both projects (SD314 and US14) have better moisture resistance than the control, UP5000, and liquid anti-stripe mixtures. The superior performance of the lime treated mixtures was shown through higher retained strength after the moisture conditioning process.

- In general, the control, the UP5000, and the liquid anti-stripe mixtures generated unconditioned strength properties which are similar to the lime treated mixtures. However, when these mixtures were moisture conditioned, their strength fell significantly below the conditioned properties of the lime treated mixtures.
• Unfortunately, the wet weather conditions during the construction of both projects made it impossible to differentiate between the lime on wet aggregate and the lime on in-situ aggregate mixtures.

• The Superpave repeated shear constant height (RSCH) test indicated that all mixtures have similar rutting resistance at the unconditioned stage. Future testing of field cores under the RSCH will identify the impact of long term field moisture conditioning on the rutting resistance of the various mixtures.

• The APA testing of the various mixtures under both the dry and under water conditions indicated that all mixtures have similar resistance to rutting. It is believed that the APA testing may have been compromised due to the following two reasons: a) the APA is an empirical test which may not be sensitive enough to pick up changes in HMA mixtures as those resulting from the addition of lime, UP5000, or liquid anti-strip, and b) the under water testing may not be severe enough to show the true impact of moisture conditioning on the various mixtures. Therefore, it is recommended that future cores be tested in the APA under the dry condition to assess the long term impact of field moisture conditioning.

• The fracture temperatures of the various mixtures measured with the TSRST showed that all mixtures would resist low temperature cracking at temperatures colder than the low temperature grade of the asphalt binders of -22°C for SD314 and -28°C for US14. This indicates that the low temperature cracking resistance of the various mixtures is entirely controlled by the binder and it is not significantly impacted by the various treatments. This observation is very encouraging since it implies that the potential improvement in the moisture sensitivity of the mixtures would not be achieved on the expense of their resistance to low temperature cracking.

Performance of Test Sections

The objective of this task was to assess the performance of the field test sections on the two projects. The initial monitoring plan included the following assessments:

- Condition surveys: cracking, raveling, and bleeding
- Rut depth measurements
- Roughness measurements
- Falling weight deflectometer (FWD) testing
- Laboratory evaluation of cores

Peter Sebaaly (PI) and Dan Johnston (Manager) conducted field surveys of the test sections of SD314 on July 23, 2001 and September 17, 2002, and of US14 on July 26, 2001 and September 18, 2002. The field surveys included visual observations, rut depth measurements, and digital pictures.
Cracking, Raveling, and Bleeding

Sections on SD314
All the test sections of SD314 showed reflective transverse cracking spaced at 25-30 feet. The control section on SD314 showed low severity raveling while the others did not show any raveling. All the sections of SD314 are experiencing chocolate rocks pop-outs which is a characteristic of the source of aggregate used in the HMA mix and not related to the type of anti-stripping additives used.

Sections on US14
All the test sections of US14 showed reflective transverse cracking spaced at 25-30 feet. On some parts of section 4 (lime on aggregate at in-situ moisture content) the shoulder was milled and repaved as part of the test section construction activity. The second year field survey indicated that the presence of the reflective transverse cracking is greatly reduced in the parts of the section where the shoulder was milled as compared to the un-milled parts.

Rut Depth Measurements
The string line method was used to assess the surface rutting of the test sections during the two condition survey visits. None of the test sections on both projects (i.e. SD314 and US14) showed any noticeable rutting in both wheel-paths.

Roughness Measurements
Based on the observations of the two field survey visits and the absence of surface rutting, it was decided that roughness measurements are not necessary.

Falling Weight Deflectometer Measurements
Based on the observations of the two field survey visits and the absence of surface rutting and structural cracking, it was decided that FWD measurements are not necessary.

Laboratory Evaluation of Cores
In the absence of any surface conditions to indicate different performance of the various anti-stripping additives, it was decided that additional laboratory evaluation of field cores may lead to some insightful observations. A common air void content among all sections was identified to be around the 5% level. The measured properties of the two years old cores included the following:

Unconditioned and Conditioned resilient modulus (Mr)
Unconditioned and Conditioned tensile strength (TS)
Resistance to rutting using the SST device
Resistance to rutting using the APA

The Mr and TS properties indicated that all of the sections, except the control, have similar unconditioned properties. But the conditioned properties showed a significant drop for the
control, UP5000, and liquid anti-strip as compared with the lime treated sections. The SST data showed the lime on wet aggregate mixtures performed the best. This time again the APA showed that it is not sensitive enough to assess changes in anti-stripping additives of HMA mixtures.

Comparing the properties of the cores sampled during construction with the cores sampled after two years in service indicated that the SD314 mixtures exhibit higher mechanical properties than the US14 sections but they are more sensitive to aging and moisture damage which could negatively impact their long term performance.

**Improved Testing**

Based on the field and laboratory observations, it was decided to compare the performance of the various mixtures under a laboratory-based multiple freeze-thaw conditioning process. The multiple freeze-thaw is used to accelerate the moisture damage process on the various mixtures. The mechanical properties of the mixtures in terms of Mr and TS were evaluated at various freeze-thaw cycles. The Mr property was evaluated after freeze-thaw cycles of: 0, 1, 3, 6, 9, 15, and 18, and the TS property was evaluated after freeze-thaw cycles of: 0, 1, and 18. Each freeze-thaw cycle consists of freezing the saturated (75%) sample at –18 °C for 16 hours and then thawing the frozen sample at 60 °C for 24 hours.

The Mr data show that lime-treated mixtures significantly out-performed the control and mixtures with other anti-stripping agents at both locations. On the SD314 mixtures, the control, UP5000, and liquid anti-strip mixtures disintegrated after the 9th cycle while the lime-treated mixtures held a good level of Mr for the entire 18 cycles. On the US14 sections, the control, UP5000, and liquid anti-strip mixtures disintegrated after the 3rd cycle while the lime-treated mixtures held a good level of Mr for the entire 18 cycles.

In the case of the tensile strength properties, the UP 5000 and liquid anti-strip mixtures provided a dry tensile strength higher than the control and lime-treated mixtures (148 psi vs. 122psi for SD314). After one freeze-thaw cycle, the control, UP 5000, and liquid anti-strip mixtures maintained a tensile strength significantly lower than the lime-treated mixtures while after 18 cycles, the control, UP 5000, and liquid anti-strip mixtures completely disintegrated.

**Evaluating Moisture Sensitivity at the Mix Design Stage**

This research recommends the use of the AASHTO T283 process to evaluate the moisture sensitivity of HMA mixtures during the mix design process with the following exceptions:

- Evaluate moisture sensitivity at exactly the optimum binder content.
- Specify a minimum dry tensile strength.
- Specify a minimum retained tensile strength ratio of 80%.
Specification Changes

The laboratory evaluations of field mixtures and field cores at the unconditioned and conditioned stages (both single and multiple freeze-thaw cycles) indicated that the addition of lime to wet aggregates would provide the best resistance to moisture damage of typical South Dakota HMA mixtures. The following represents recommendations for the application of lime to HMA mixtures which minimize workers exposure and environmental hazards.

*Lime should be added to pre-moistened aggregates with moisture content between 1 and 2 percent above the saturated surface dry moisture content of the aggregate. This amount of moisture normally translates into a total moisture content between 3-4%. The exact amount of moisture required should be as approved by the SDDOT. The moisture should be added by way of spray bars at the entry end of the pugmill mixer and prior to the addition of lime. After the addition of lime to the moistened aggregate, the aggregate should be mixed using an enclosed twin-shaft pugmill with a minimum effective mixing length of 4.5 ft. Directly introduce the completed mixture into the hot plant.*

Findings and Conclusions

This research project evaluated the effectiveness of three different anti-stripping additives: Lime, UP5000, and a liquid additive. The evaluation conducted an extensive laboratory program and field performance studies. HMA mixtures were evaluated in the laboratory to measure their resistance to rutting and cracking. Two field projects were constructed with six test sections each and evaluated the performance of the various anti-stripping additives under actual traffic and environmental conditions. Based on the analyses of the laboratory data and the field performance of the various test sections, the following findings and conclusion were made.

- The construction of the test sections on SD314 generated highly variable in place air voids within each section and among the various sections. This variation in air voids made it impossible to use the properties of the field cores to compare the performance of the various mixtures. Therefore, the properties of the field cores should only be used to compare the mixtures resistance to moisture damage performance within individual sections and not across sections.

- The construction of the test sections on US14 was less variable than the SD314 sections. Even though the in place air voids varied among the various sections, the in place air voids within individual sections were less variable. Some comparisons among sections were possible.

- The FMLC samples were compacted to a narrow range of air voids and were ideal to compare the performance of the various mixtures. The resilient modulus and tensile strength properties of the FMLC samples measured at both the unconditioned and conditioned stages indicated that the lime treated mixtures on both projects (SD314 and US14) have better moisture resistance than the control, UP5000, and liquid anti-strip mixtures. The superior performance of the lime treated mixtures was shown through higher retained strength after the moisture conditioning process.
• In general, the control, the UP5000, and the liquid anti-strip mixtures generated unconditioned strength properties which are similar to the lime treated mixtures. However, when these mixtures were moisture conditioned, their strength fell significantly below the conditioned properties of the lime treated mixtures.

• The Superpave repeated shear constant height (RSCH) test indicated that all mixtures have similar rutting resistance at the unconditioned stage. Future testing of field cores under the RSCH will identify the impact of long term field moisture conditioning on the rutting resistance of the various mixtures.

• The APA testing of the various mixtures under both the dry and under water conditions indicated that all mixtures have similar resistance to rutting. It is believed that the APA testing may have been compromised due to the following two reasons: a) the APA is an empirical test which may not be sensitive enough to pick up changes in HMA mixtures as those resulting from the addition of lime, UP5000, or liquid anti-strip, and b) the under water testing may not be severe enough to show the true impact of moisture conditioning on the various mixtures. Therefore, it is recommended that future cores be tested in the APA under the dry condition to assess the impact of long term field moisture conditioning.

• The fracture temperatures of the various mixtures measured with the TSRST showed that all mixtures would resist low temperature cracking at temperatures colder than the low temperature grade of the asphalt binders of -22°C for SD314 and -28°C for US14. This indicates that the low temperature cracking resistance of the various mixtures is entirely controlled by the binder and it is not significantly impacted by the various treatments. This observation is very encouraging since it implies that the potential improvement in the moisture sensitivity of the mixtures would not be achieved on the expense of their resistance to low temperature cracking.

• The multiple freeze-thaw experiment showed that the lime-treated mixtures performed significantly better than the control, the UP5000, and the liquid anti-strip mixtures at both locations. In addition multiple freeze-thaw testing represents the most reliable and effective method for evaluating the resistance of HMA mixtures to moisture damage.

• The laboratory evaluation of the two year old cores indicated: a) the unconditioned Mr and TS properties of the SD314 sections have increased by a factor ranging between 25 and 50%, b) the conditioned Mr and TS properties of the SD314 sections remained constant, c) the unconditioned and conditioned Mr and TS properties of the US14 sections remained constant, and d) the resistance of the SD314 sections to rutting as measured by the SST have deteriorated while the resistance of the US 14 sections to rutting have remained the same.

• The 2001 and 2002 conditions surveys of the test sections on SD314 and US14 indicated that the all test sections are performing similarly. There is no evidence of rutting, fatigue cracking, and raveling on any of the sections. After two years of service, the only observed distress has been in the form of reflective transverse cracking which is caused by the
underlying concrete pavements.

- The laboratory evaluation of the two-year old cores from both projects (SD314 and US14) indicated that the lime treated mixtures are exhibiting superior moisture conditioned properties than the control, the UP5000 and the liquid anti-strip mixtures. The permanent deformation testing of the cores in the SST device showed that the lime treated mixtures offer the best resistance to rutting.

- In addition to the data generated in this research, the effectiveness of lime in improving the moisture resistance of HMA mixtures and prolonging the pavement life has been verified through a recent study conducted for the Nevada DOT (27). The Nevada study compared the long term performance of field projects constructed with and without lime under similar materials, traffic, and environmental conditions. The evaluation program used laboratory testing, pavement performance data, and pavement design concepts to assess the impact of lime treatment on the actual performance life of flexible pavements under Nevada’s northern and southern regions. The study concluded that lime treatment extends the performance life of HMA pavements by an average of 3 years. This represents an average increase of 38% in the expected pavement life. The percent increase in pavement life of 38% compares very favorably with the percent increase in the cost of HMA mixtures due to lime treatment of 12% with marination and 6% without marination.

Implementation Recommendations

This research effort showed that lime is more effective than both the UP5000 and the liquid anti-strip additive in reducing the impact of moisture damage on HMA mixtures. Based on the laboratory evaluation of mix designs, field mixtures, and field cores, the following implementation recommendations can be made.

- The extensive laboratory evaluations of the field mixtures and cores sampled from the two projects indicated that the UP5000 and the liquid anti-strip additives used on the two projects do not offer effective resistance to moisture damage of SDDOT’s HMA mixtures. It is recommended that their usage and the usage of any other new anti-stripping product should be evaluated using the multiple freeze-thaw process with 6-cycles prior to acceptance for field applications.

- This research recommends the use of the AASHTO T283 process, including the freeze-thaw cycle, 70-80% saturation, and 7±0.5% air voids, to evaluate the moisture sensitivity of HMA mixtures during the mix design process with the following exceptions:

  - Evaluate moisture sensitivity at exactly the optimum binder content.
  - Specify a minimum dry tensile strength.
  - Specify a minimum retained tensile strength ratio of 80%.

- This research showed that the addition of lime to wet aggregates would provide the best resistance to moisture damage of typical South Dakota HMA mixtures. The following
represents a recommendation for the application of lime to HMA mixtures which minimizes workers exposure and environmental hazards.

*Lime should be added to pre-moistened aggregates with moisture content between 1 and 2 percent above the saturated surface dry moisture content of the aggregate. This amount of moisture normally translates into a total moisture content between 3-4%. The exact amount of moisture required should be as approved by the SDDOT.* The moisture should be added by way of spray bars at the entry end of the pugmill mixer and prior to the addition of lime. *After the addition of lime to the moistened aggregate, the aggregate should be mixed using an enclosed twin-shaft pugmill with a minimum effective mixing length of 4.5 ft.* Directly introduce the completed mixture into the hot plant.

- The field surveys of the test sections indicated that the two year period is not long enough to assess the differences in field performance of the various anti-strip additives. The following extended performance monitoring program is recommended:
  - Conditions surveys of the test sections should be continued on an annual basis.
  - Field cores should be obtained after 5 and 8 years of service or as seems necessary by the conditions surveys.
  - Field cores should be evaluated through a laboratory program similar to the one used on the two years old cores.