



Stripping of Hot-Mix Asphalt Pavements under Chip Seals

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Minnesota Department of Transportation

April 2013

Research Project
Final Report 2013-08



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Technical Report Documentation Page

1. Report No. MN/RC 2013-08	2.	3. Recipients Accession No.	
4. Title and Subtitle Stripping of Hot-Mix Asphalt Pavements under Chip Seals		5. Report Date April 2013	
		6.	
7. Author(s) Thomas J. Wood and Melissa K. Cole		8. Performing Organization Report No.	
9. Performing Organization Name and Address Office of Materials and Road Research Minnesota Department of Transportation 395 John Ireland Boulevard, MS 330 St. Paul, MN 55155		10. Project/Task/Work Unit No.	
		11. Contract (C) or Grant (G) No. (C) LAB904	
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Research Services 395 John Ireland Boulevard, MS 330 St. Paul, MN 55155		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes http://www.lrrb.org/pdf/201308.pdf			
16. Abstract (Limit: 250 words) The higher costs of hot-mix asphalt pavement are causing more agencies to choose pavement preservation techniques to maintain their pavements. Some agencies have experienced stripping of the asphalt surface under chip seals, this distress appears to occur mostly in urban areas on curb and gutter streets. The main objective of the study was to determine what causes the stripping and to develop test methods to determine if the street will strip prior to placement of the chip seal. Both field and lab methods were used. Research focused on determining air voids, permeability, and density of the samples. Once these were determined, correlations were developed to determine the conclusions.			
17. Document Analysis/Descriptors Chip seals, Stripping (Pavements), Air voids, Density, Pavements, Permeability, Preservation		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 60	22. Price

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Final Report

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April 2013

Published by:

Minnesota Department of Transportation
Research Services
395 John Ireland Boulevard, MS 330
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Acknowledgements

Many thanks are given to the Local Road Research Board for funding the project.

Thanks also to the Technical Advisory Panel (TAP), MnDOT bituminous office, and cities of Brooklyn Center, Eden Prairie, and Woodbury, and numerous other cities for all their help with this project. Without it the project could not have been completed.

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Executive Summary

Stripping of hot-mix asphalt (HMA) under chip seals on urban streets has been an issue for years. This project studied the issue to determine what causes the stripping and how to deal with the stripping. Low density or high air voids appear to be the main cause of the stripping. Lab testing validated the theory that HMA mixes not prone to stripping will strip if not properly compacted. Better construction methods are recommended.

Chapter 1. Introduction

Objectives of Research and Methodology

This report represents task 6 – Draft Final Report of Local Road Research Board (LRRB) project number 904, Minnesota State Planning and Research project number MPR 10-(042) study entitled, “Stripping of Hot-Mix Asphalt Pavements under Chip Seals”.

The objectives of this research project were to determine why some streets suffer from stripping of the hot-mix asphalt (HMA) pavement after placement of asphalt chip seal. Using this data we will recommend how to determine if streets will suffer from stripping prior to chip sealing. Also recommendations will be made on how to improve performance of streets starting with paving of the asphalt pavement.

The research efforts were made up of the following tasks:

- Task 1 Survey Cities and Counties to determine the extent of the stripping under chip seals.
- Task 2 Develop and modify existing test methods to determine if the HMA in place on streets is prone to stripping.
- Task 3 Core and test the cores from City streets.
- Task 4 Review past and present construction methods of cities for asphalt paving streets.
- Task 5 Analyzed the test results from cores.
- Task 6 Draft final report
- Task 7 Final Report
- Task 8 Implementation Plan

Background: Stripping Under Chip Seal Distress

For more than twenty years, Cities have experienced pavement deterioration of the upper 0.5 to 1.0 inch of HMA pavements under chip seals. The distress causing this is stripping of the asphalt layer directly beneath the chip seal (Figures 1 and 2). This distress starts as a small blister and becomes enlarged to the size of a small pothole; at which time the chip seal delaminates off of the asphalt pavement.

With the high cost of asphalt, the use of pavement preservation treatments has grown rapidly as agencies preserve their roadway system. Most of the incidents of this distress have been located on urban curb and gutter streets. If the distress is localized small patch will restore the street. However, as the area of deterioration expands a thin mill and overlay may be required to restore the street. This distress may lead to an expensive maintenance problem.



Figure 1: Stripping of asphalt pavement under chip seal.



Figure 2: Asphalt deterioration under chip seal.

Chapter 2. Research Methodology

Task 1

In this task surveys were sent to Cities and Counties using the Survey Monkey™ tool to determine the extent of the stripping under chip seals in Minnesota. See Appendix A for a copy of the Interim Report for Task 1 submitted in November 2010. This report includes all the questions asked and results of the survey. Sixty-six responses were received.

More than 60 percent of the respondents stated their agency was experiencing stripping under chip seal. Based on these findings and interviews with select cities the next step was to determine the cause of the stripping problems. One observation made was that streets suffering from stripping issues had density variability. Areas close to the stripped areas had high air voids. When coring, complete cores in the areas with low density and high air voids were not able to be obtained as they fell apart. Based on preliminary field sampling the following hypothesis was developed: **Low density may cause asphalt paving mixes to stripping to strip because of this low density and high air voids.**

Task 2

This task looked at stripping test methods and selected tests to determine if stripping can be determined. To test the laboratory methods selected, a level 3 super pave mix that has been proven to not be prone to stripping was selected. The HMA samples were compacted at three (3) levels of air voids (density), 7, 10, and 14 percent air voids. Based on these tests the higher the air voids or lower density the HMA suffered more stripping tendencies. This finding supports the hypothesis that low density and air voids may cause stripping.

Task 3

In Task 3 we cored and tested the cores from city streets experiencing stripping. A group of streets were selected to be sampled for lab testing to validate findings from Task 2 and determine what causes stripping of the chip seals on streets.

Efforts were made to develop field test requirements that could be performed to determine if the street is a good candidate for a chip seal, i.e. will not strip 2-4 years after placement. The Nuclear Density Tester (NDT) and NCAT Field Permeameter were used on streets without a chip seal. Lab testing on the cores taken from both streets with and without a chip seal included the following; air voids (ASTM T269, T166 & T209) and lab permeability (ASTM PS 129-1).

The data from the city's streets correlates with the finding in Task 2. As air voids increased and density decreased the chance of stripping also increased. The best method to check for variability in density in the pavement is NDT. A second hypothesis that was brought forward was the one could fog seal the street with light application of asphalt emulsion and that it would stop water infiltration into the mat but would allow water vapors to escape similar to TYVEK® house wrap does for homes.

Using cores from a two (2) year old fog seal and the lab permeability (ASTM PS 129-1) test method it was demonstrated that fog seal did not allow water in liquid state to infiltrate the HMA but allowed water in a vapor state to escape. (See Appendix C).



Figure 3: Nuclear density tester.

Task 4

In Task 4 current methods used by cities to construct their streets was reviewed. These methods were compared to MnDOT's standard specifications for paving. During discussion with agency personnel one fact that relates to density became apparent. Most cities were using ordinary compaction to obtain density. Ordinary compaction, when executed properly should yield good density of the pavement. However, one issue with ordinary compaction is that contractor and agency personnel must ensure that all areas of the pavement receive proper number of rolling passes at proper temperature of asphalt mixture. When streets have variable widths and curves are present it is more difficult to ensure the rolling pattern is consistent throughout asphalt pavement placement. MnDOT recommends using specified density methods. With specified density the agency will take cores randomly from pavement to verify that proper density has been achieved (see Appendix D).

Task 5

Analysis of the data collected in Task 3 was discussed and presented in Task 5. Using the different methods outline above, it was shown that all the test methods correlated. The data showed that streets had high variability in density from 7 to 12 percent air voids in areas close stripped areas. In the areas with severe stripping cores were not able to be retained for testing. This was due to the cores breaking into many pieces after pulling the core from the pavement. Nuclear density testing showed great amount of variability in the mix weight per cubic foot from

areas of not stripping to areas suffering from stripping. One street had weight from 145 lbs. per cubic foot in areas of the street with no issues to a low of 117.3 lbs. per cubic foot in areas suffering from stripping. For field evaluation of streets the nuclear density tester is the fastest and easiest to use of method tested. After discuss with experts from around the country it is recommend to not chip seal a street if the variability in density varies more than 6 lbs. per cubic foot as measured with nuclear density tester. (See appendix E)

Task 6 and 7

Task 6 and 7 was developing the draft final report and a final report of the findings from Tasks 1-5.

Task 8

Task 8 will develop a draft implementation outline for the Research Implementation Committee (RIC) to use. Three (3) main recommendations for the outline are:

1. Present finding of study at many conferences.
2. Include data about variability of density into bituminous training classes offered by MnDOT to help insure better constructions methods are followed.
3. Develop a handout to inform agencies about the stripping under chip seal issues and recommendation on preventing this distress.

Chapter 3. Conclusions and Recommendations

Conclusions

The stripping of the HMA pavement after application of chip seal is caused by areas of high air voids or low density. The lack of proper compaction allows water to permeate into the HMA and cause pavement to strip. This also occurs in HMA that are not prone to stripping. A cause for lack of uniform density is the use of the ordinary compaction method. For ordinary compaction to work, inspections must ensure all areas of the pavement receive proper compaction efforts at the correct temperature for the mat.

Recommendations

It is recommended that agencies use specified density methods to ensure proper uniform compaction of the HMA paving. An observation by a city's personnel was when the city switched to specified density the same Contractor brought two 20- to 25-ton steel rollers and a 20- to 25-ton pneumatic roller instead of one 6- to 8-ton steel roller they used in the past when ordinary compaction was specified. The cost of the HMA was the same per ton. Areas that need more research into are what effects recycled asphalt (RAP) now used in wear course have on stripping.

There are currently three options for existing streets with low density and high air voids variability. These options are as follows:

1. Do nothing and allow the street to fail prematurely.
2. Chip seal earlier in pavement life to try to keep pavement structure as dry as possible to limit moisture damage. From the surveys in Task 1, it appears that chip sealing the pavement within the first 1-4 years of life helped to limit the stripping issues.
3. Fog seal pavement with a CSS-1h diluted to one part water and one part emulsion.

Appendix A: Task 1 Report

**Minnesota Local Road Research Board (LRRB)
Investigation No. 010-042**

Stripping of Hot Mix Asphalt Pavements under Chip Seals

Interim Report

Submitted to the LRRB technical advisory panel in fulfillment of:
Task 1 on November 9, 2010

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Introduction: In recent years, Mn/DOT has received reports of stripping, or deterioration, of the upper ½ to 1 inch of hot mixed asphalt (HMA) pavements under chip seal surface treatments. This distress (Figure 4) usually starts out as a small blister and develops to small potholes, at which point the chip seal delaminates from the pavement. These distresses can become an expensive maintenance problem. These distresses could also impede the deployment of cost saving preventive maintenance (PM) treatments if the treatments are viewed as the cause of the distresses.



Figure 1. Early stage of HMA deterioration under a chip seal (251 Reid).

This report represents task 1 of the Minnesota Local Road Research Board (LRRB) project number 2010-042, entitled, “Stripping of Hot Mixed Asphalt Pavements under Chip Seals”. The overall goal of this research project is to determine the underlying cause of the stripping distresses, identifying which pavements are at greatest risk and implement risk mitigation strategies that include improved specifications and practices. The main purpose of this task report was to identify the extent of the problem among local government entities.

Minnesota cities and counties were asked to complete an online survey, using the Survey Monkey™ tool, describing their experience with the stripping under chip seal distress. Appendix A is a draft of the survey that was used to populate Survey Monkey™. The survey opened for response in early September and received 66 responses.

Findings and Observations: The survey responses show that the problem of stripping of the HMA under a chip seal happens in over 60% of the agencies that responded. The first chip seals were applied when the streets were between four (4) and eight (8) years of age. The distress seems to appear between two (2) to four (4) years after chip seal application. Note that 60 percent of respondents reported that they did not have un-chip sealed roadways the same age as the chip sealed roadways. The ninth question asked for comments. Appendix A lists all the comments received. Below are a few selected comments.

“As a rule of thumb, we will seal coat a street twice over a 15 to 20 year period prior to mill and overlay. Stripping more common after second seal coat.”

“We have one road we sealed when it was only a year old and the stripping has not occurred on that road yet.”

“So far this has only shown up in our first recycled asphalt wear courses installed from 1996 to 1998. We have heard that there was a problem with the Mn/DOT formula that hopefully has been corrected.”

“We think this is occurring in pavements put down in the early 1990’s where they first started to use RAP in the mix.”

Recommendations for next task: Based on the information from the survey, the research should to study the types of HMA mixes used to determine if some types, or blends, of HMA and recycled asphalt pavement (RAP) are more prone to stripping. Density may also be a contributing factor.

Appendix A: Survey Results

Question 1: asked the name of the Agency fill out survey.

Question 2: **Does your city use chip sealing as a Preventive Maintenance treatment?** 60 responded Yes, and 6 responded No.

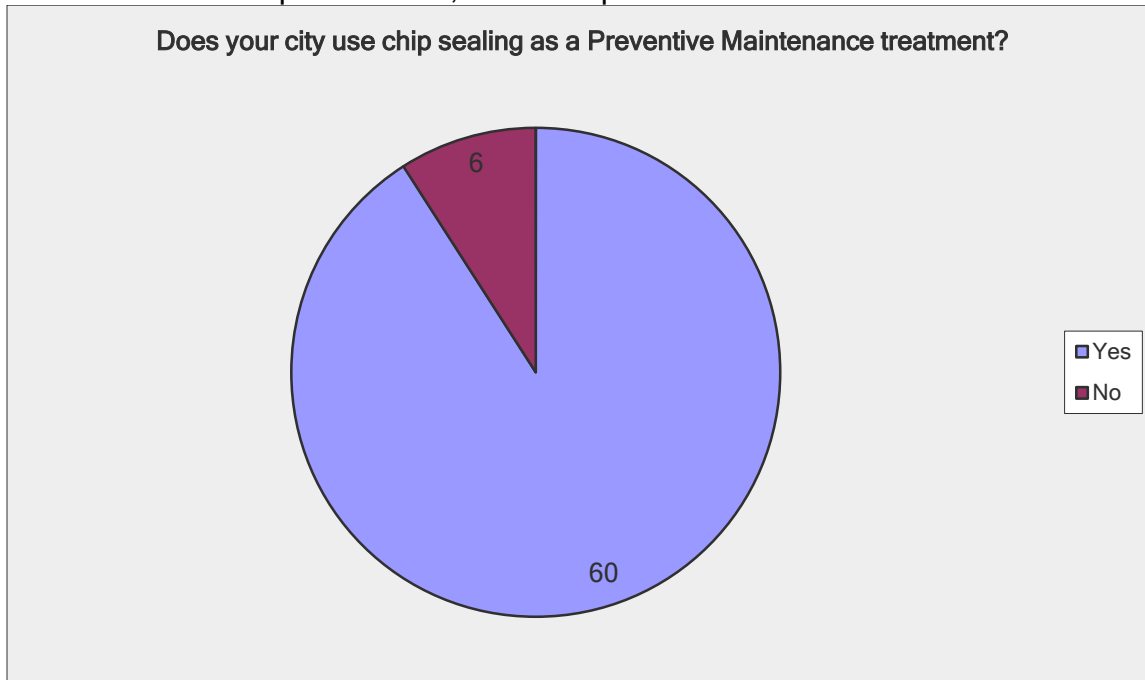
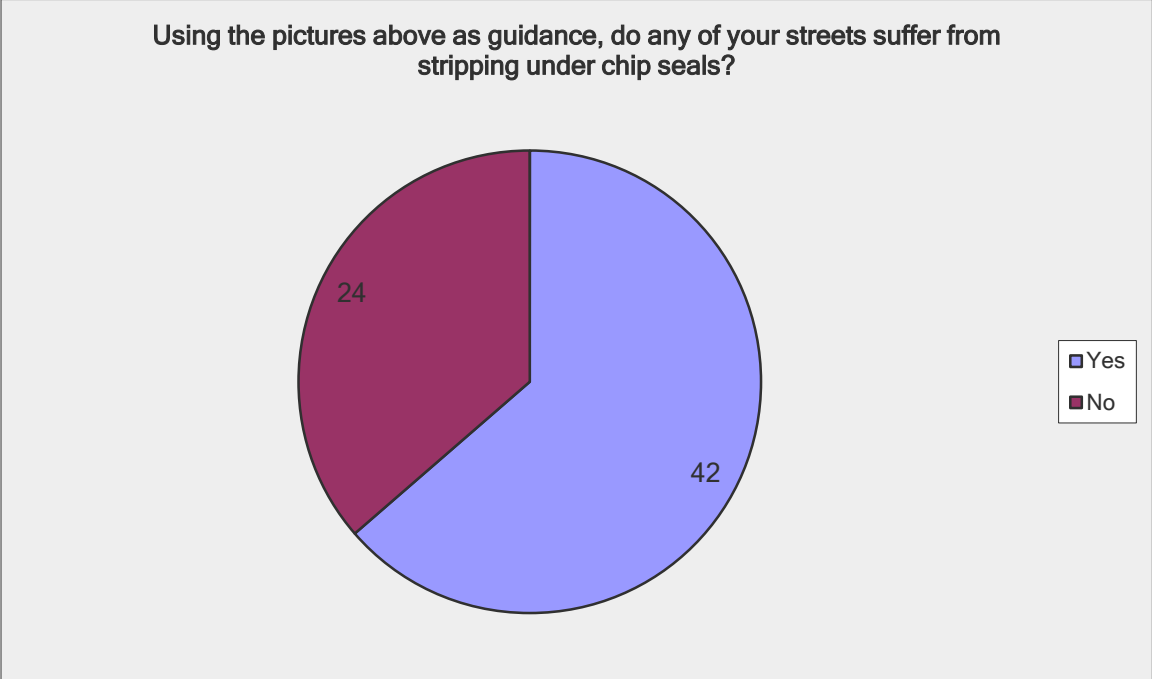
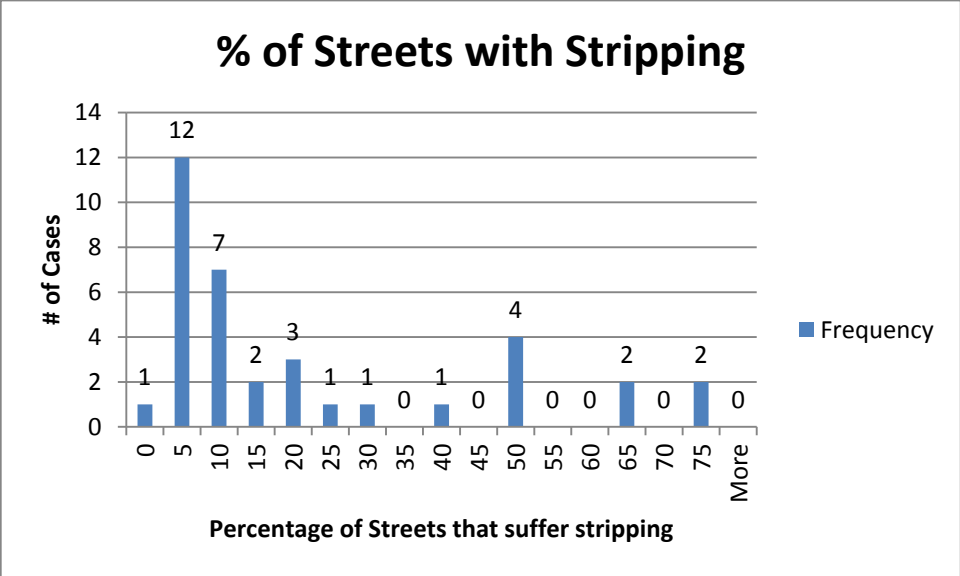


Figure 2 Picture used in survey

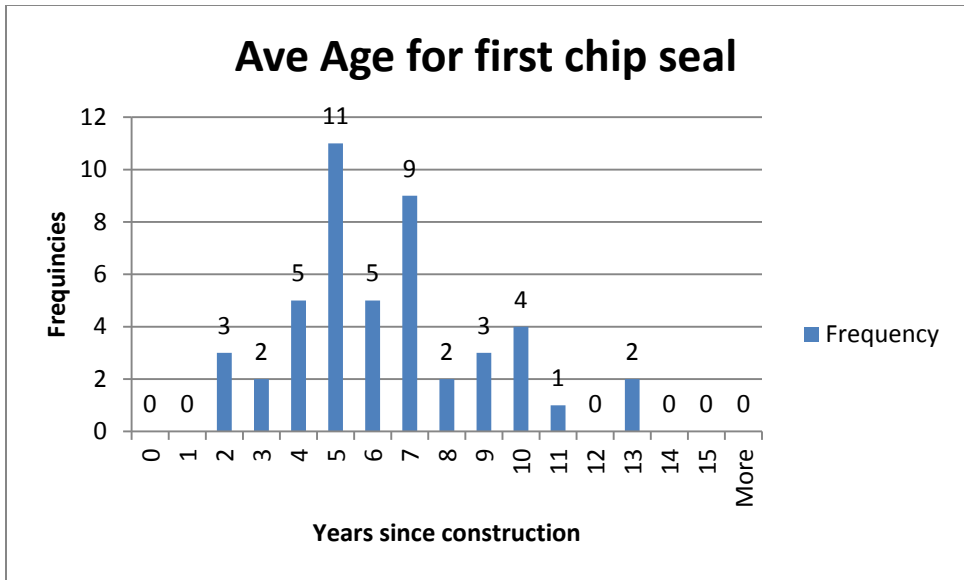
Question 3: **Using the pictures (Figure 2) above as guidance, do any of your streets suffer from stripping under chip seals?** 42 agencies reported yes and 24 reported No



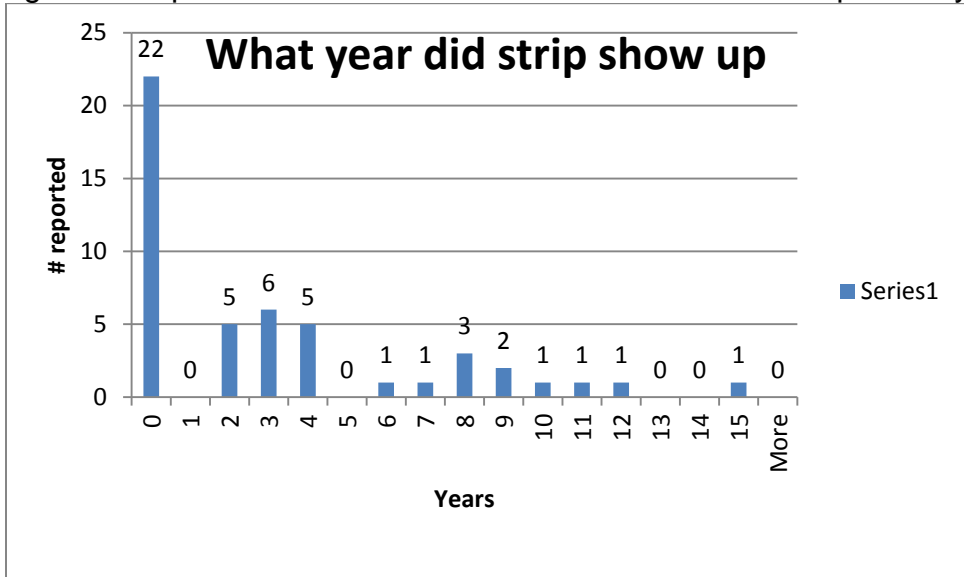
Question 4: **What percentage of streets does it happen on?** 40 out of 66 supplied answer to this question. See below histogram for breakdown of data. Most of the agencies reported a percentage but four (4) reported in format that did not give an answer easily converted to percentage.



Question 5: **On average, what is the age of the street when the first chip seal is placed?** 52 responded to question see histogram for data below. Five (5) agencies reported in a different format which could not be captured by the histogram.



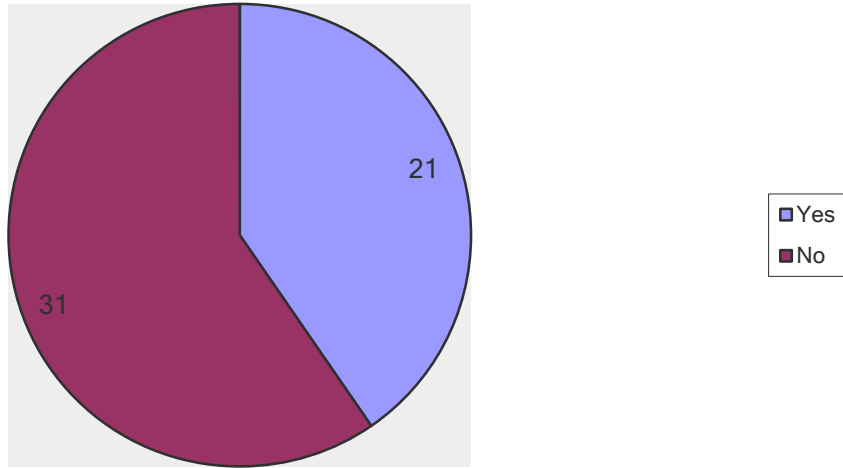
Question 6: **How long after the chip seal is placed does the stripping problem show up?** 52 responded to this question, see histogram below for data. Three (3) agencies reported in different format which could not be captured by the histogram.



The responders that listed year zero have not seen any damage to their streets.

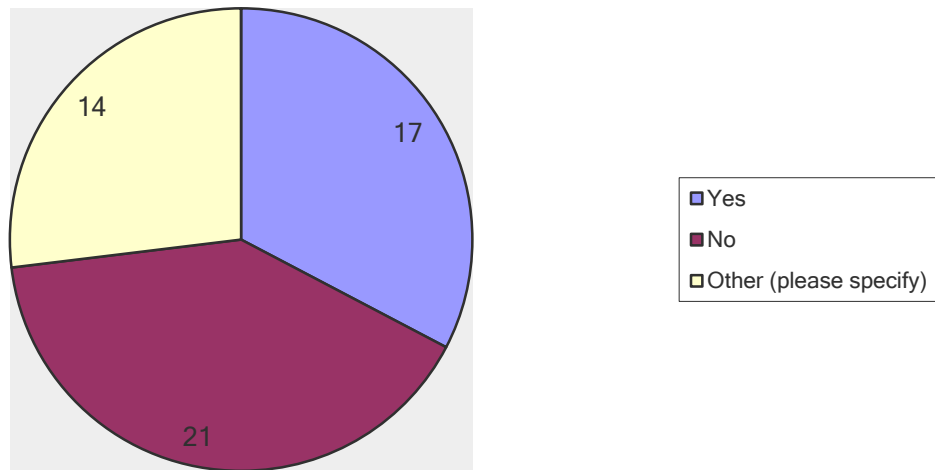
Question 7: **Does your city have any streets that are the same age where some have been chip sealed and some have not?** 52 responded. 21 replied yes and 31 replied no.

Does your city have any streets that are the same age where some have been chip sealed and some have not?



Question 8: **Does your city have complete construction records for street construction that suffer from these distresses?** 17 replied yes, 21 said no, and 14 replied with other answers.

Does your city have complete construction records for street construction that suffer from these distresses?



Question 9: **Are there any comments or additional information that you need or would like to share?** 16 responded with additional comments or information. See comments below.

- *I'm going to pass this on to my Public Works guys, as they have noticed this problem for several years. I will have them reply too, as they can offer more*

details. I would encourage everyone that this study include street maintenance personnel (field people) in addition to City engineers/Public Works Directors (office people).

- *As a rule of thumb, we will seal coat a street twice over a 15 to 20 year period prior to mill and overlay. Stripping more common after second seal coat.*
- *We have one road we sealed when it was only a year old and the stripping has not occurred on that road yet*
-
- *You know all our comments about the chip seal material on sticking to our truck engines and tranny's...*
-
- *The City has been very consistent over the last 10 years or more about seal coating and keeping up with the 5 year timing. To date we have not noticed any problems with the surface coat below the chip seal.*
- *We use MC oil and no emulsifiers which helps prevent this from happening.*
- *Our experience is limited to stripping on 61 wear course roads, we haven't seen other significant stripping issues on other roads.*
- *We have attributed the problem more to the wear course being chip sealed than the chip seal itself*
- *Maplewood, like other metro cities is dealing with this issue and there are a number of state aid roadways with this problem.*
- *We are currently formulating an approach to fix these streets since it is very difficult to patch the great number of thin failures areas.*
- *According to our Street Superintendent the issue could be a result of using trap rock which is left for only 2-3 days before being swept up.*
- *Streets with pea rock left down for 2-3 weeks such as North Saint Paul and Lake Elmo don't seem to be having the failures.*
- *We have not seen this problem in Faribault County.*
- *Marshall County has not completed a chip seal.*
- *So far this has only shown up in our first recycled asphalt wear courses installed from 1996 to 1998. We have heard that there was a problem with the Mn/DOT formula that hopefully has been corrected.*

- *In response to the question seven, we have not determined the ages for all occurrences of this type of stripping. We have however, noted that the stripping occurs in certain areas, where presumably the pavement is of approximately same age and sealing is also conducted at the same time (sealing is performed on an area basis). We seal streets on an 8-year cycle, and do not perform “early sealing” on new pavement after 2-3 years as some cities do. This program was initiated in the early 80s. We have started to examine the practice of early sealing, and would like to determine whether this would be more effective for our City.*
- *We think this is occurring in pavements put down in the early 1990’s where they first started to use RAP in the mix.*
- *Just a quick glance revealed two areas with most noticeable stripping were built around 1994- 1999 and mostly likely had two seal coat applications to date. Also these are areas of clay soils.*
- *Most problems appear where there are just thin overlays.*
- *One of the segments is approximately 15 years and the problem is pretty much continuous for the 10 mile segment. The problem is occurring in the center of lane and appears as a stripping problem created in the original mix placement. Possibly a segregation problem created by the paver during placement.*

Appendix B: Task 2 Report

Stripping of Hot-Mix Asphalt Pavements under Chip Seals

Development of a Methodology to Assess Potential at Risk Streets

LRRB 10-0142, 2010-042 Interim (Task 2) Report

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April 2011

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Minnesota Department of Transportation at the time of publication. This report does not constitute a standard, specification, or regulation.

Acknowledgements

The bituminous trial mix lab is gratefully acknowledged for their assistance in preparing and testing the bituminous mixtures. The TAP is gratefully acknowledged for their technical guidance.

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Executive Summary

This report represents task 2 of the Minnesota Local Road Research Board (LRRB) project number (Investigation) 2010-042, entitled, “Stripping of Hot Mixed Asphalt Pavements (HMA) under Chip Seals”. The goal of this specific task report is to identify, or develop a methodology that can be used to assess potential at-risk streets before they are treated with a surface treatment. The preliminary methodology being investigated by the research team involves testing the in-place pavement for air void content, or permeability (either in-situ or laboratory). If the pavement is found to have excessive permeability and/or air void content, then caution should be exercised before placing a chip seal surface treatment; a fog seal surface treatment may be more appropriate. These recommendations are preliminary and need to be validated with more testing of laboratory and plant produced (in-place) pavement mixtures in accordance with the work plan.

Based on previously completed forensic investigations, and survey responses the research team has hypothesized that low density (high-interconnected air voids) are a contributing factor to the observed stripping distresses. Thus, the experimental plan investigated the influence of various air void contents (7, 10 and 14%) on a mixture’s susceptibility to moisture induced damage. The mixtures susceptibility was tested with: permeability tests, Mn/DOT modified Lottman, Asphalt Pavement Analyzer (APA) tested under wet and dry conditions, and a modified Iowa Boiling Test.

Permeability testing indicated that the mixtures became significantly more permeable when the air void content was near 14%. The Lottman test did not show any visual evidence of stripping and all tensile strength ratios (TSR) were above 70%. However, the mixtures with the highest air void content had the lowest TSR at 74% and the mixture with the lowest air void content had the highest TSR at 84%. The change in air void content had the most dramatic influence on tensile strength values; a doubling of the air voids from 7% to 14% corresponded with a reduction of 52% and 58% in the dry and wet tensile strengths respectively. APA test results were mixed as the greatest difference in rutting rates between ‘wet’ and ‘dry’ testing conditions were at the 10% and 7% air void contents; the mixture with 14% air void content showed little difference. None of the mixtures showed signs of visual stripping. In the modified Iowa boiling test, the specimens with 14% air voids lost an average of 12.2% of their initial weight and the specimens with 7% air voids lost an average of 3.4% of their initial weight. In addition, empirical observations after the test showed that the specimen with the higher air voids (14%) was much less intact than the comparable specimens with lower air voids (7%).

There was no test that explicitly showed asphalt stripping away from mixtures with higher air voids; however, the results of the laboratory testing did indicate that the higher voids do contribute to reduced pavement durability through reduced strength, increased susceptibility to rutting and increased permeability. The permeability and the modified Iowa Boiling test results indicate that pavements with higher air void contents may be more susceptible to moisture induced damage than pavements constructed with the proper amount. These factors will also reduce the life of a chip seal that’s placed on top of a compromised pavement. Future testing within this project will entail conducting the same tests (permeability, Mn/DOT modified Lottman, wet and dry APA, and modified Iowa Boiling) but on sealed specimens of varying density to more closely simulate field conditions. In addition, the research team intends to modify the laboratory Permeameter to examine whether or not moisture (from the bottom) can penetrate a chip seal or a fog seal surface treatment.

Chapter 1. Introduction

Objectives of Report and Research

This report represents task 2 of the Minnesota Local Road Research Board (LRRB) project number (Investigation) 2010-042, entitled, “Stripping of Hot Mixed Asphalt Pavements (HMA) under Chip Seals”. The overall goal of this research project is to determine why stripping distresses are observed in the underlying HMA pavements of some streets and not others. Identify which pavements are at greatest risk and implement risk mitigation strategies that include improved specifications and practices. The goal of this specific task report is to identify, or develop a methodology that can be used to assess potential at-risk streets before they are treated with a surface treatment. This methodology (in the form of a laboratory test) is designed to provide guidance on the susceptibility of the proposed pavement section to the stripping under chip seal distress, which would allow agencies to make informed decisions on the application of preventive maintenance (PM) treatments.

Stripping Under Chip Seal Distress

This problem has been observed for more than twenty years; however recently, Mn/DOT has received increased reports of stripping of the upper ½ to 1 inch of hot mixed asphalt (HMA) pavements under chip seal surface treatments. This stripping distress (Figure 1.1) usually starts out as a small blister and develops to small potholes, at which point the chip seal delaminates from the pavement. These stripping distresses can become an expensive maintenance problem.



Figure 1.1. Early stage of HMA deterioration under a chip seal (251 Reid).

The distress appears to be limited to local, low speed roads (30 - 40 miles/hour) with curb and gutter and Task 1 of this research project (1) surveyed local agencies and found that (60% of 66 respondents) have this problem. Due to the relative widespread nature of the phenomenon the study will not focus on material specific causes of the stripping, such as aggregate/asphalt incompatibility. The focus of the study will be on the stripping phenomenon as it relates to the pavement structure as a whole, specifically, it is theorized that pavements with poor drainage, low density and traffic action are at an increased risk of stripping when a chip seal is applied. The basis for this theory is that many observed cases have been local streets (with presumably higher density) and curb and gutter (no edge drains for water to escape).

Review of Published Literature

The vast majority of the literature found focused on a “microscopic” investigation of the problem, namely the properties/performance of the asphalt and aggregate, or the mixture as a whole. The following paragraph is an excerpt from Kiggundu and Roberts (2), “Hubbard states

that stripping effects have been observed since the advent of paving with bituminous. Since this phenomenon has been detected, there have been numerous technical papers, articles, and presentations. Stripping is a complex problem to which there is no definitive, qualitative and quantitative solution towards understanding and predicting the stripping potential of HMA. There currently are a number of hypothesized mechanisms, including: detachment, displacement, spontaneous emulsification, film rupture, pore pressure, and hydraulic scouring. There are a number of postulated theories, which include: mechanical interlock, chemical reaction, molecular orientation, or Interracial phenomenon, none of which are universally accepted.”

Aschenbrener (3) reported on several pavements in Colorado which required complete rehabilitation at less than two years old and often less than one year old. The pavements designed to be a rut resistant composite pavement that used a plant mixed seal coat placed over an HMA layer; however the underlying HMA layer experienced severe moisture damage as shown below.

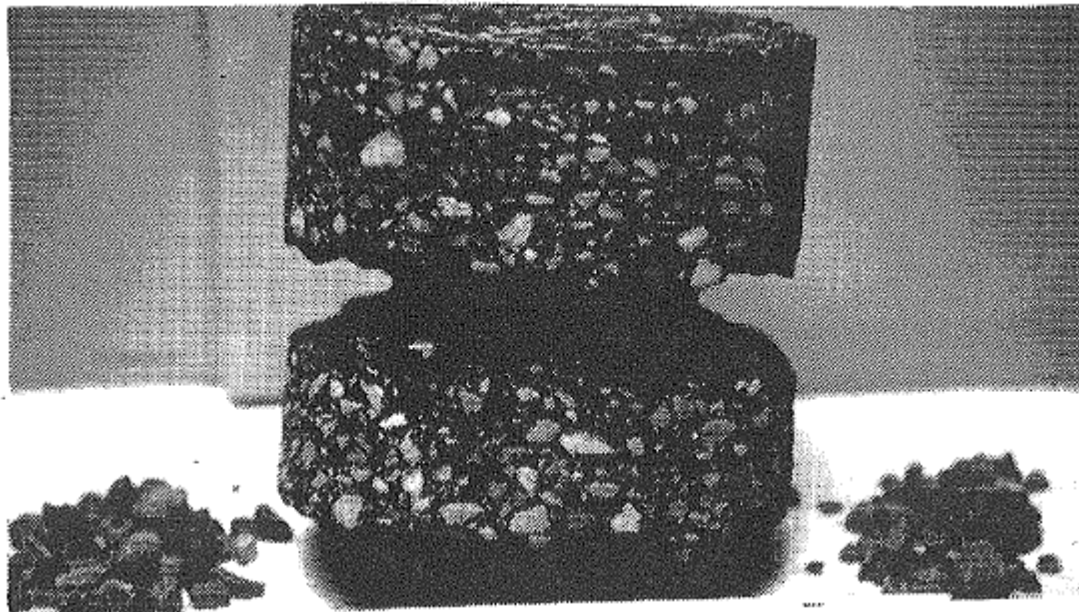


Figure 1.2. A Core showing Stripping below the surface (3)

Although the plant mixed seal coat was reported a contributing factor, the HMA mixtures were also deemed to be susceptible to moisture induced damage (the only reason to explain the rapid failures), and it was observed, through analysis of weather conditions, that the failures occurred during high levels of precipitation during the hottest part of the summer. The severe moisture damage did not correspond to freezing conditions. The failures were attributed to high temperatures, high moisture and high traffic.

Kandhal and Rickards (3) was another reference that discussed the stripping problem in context of the pavement system and not in isolation. The researchers presented case histories of premature stripping of asphalt overlays due to stripping. The researchers observed that, “In each of the observed cases, saturation was the cause of the problem; stripping was the outcome.” They also noted that, “If subsurface drainage of the pavement is inadequate, moisture and/or moisture vapor can move upwards due to capillary action and saturate the asphalt courses.” The researchers hypothesized that, “In addition to high air void content, there are three essential ingredients to promote stripping: the presence of water, high stress and high temperature.” Furthermore, the researchers argued that if the concept of mat “breathing” (ingress of moisture

balanced by the egress of moisture in the form of water vapor) wasn't true, there would be substantially more stripping problems.

The current investigation is concerned with stripping of generally older pavements with chip seals applied 'late' (>7 years) in the pavement's service life. So, it is interesting to note that stripping almost universally occurs from the bottom up, or at the interface of two layers outward, so, based on this, it is logical to be concerned with the application of a chip seal over an HMA pavement, as the new pavement is now a "lower layer". In addition, section 7 (surface treatments) of the Texas DOT Pavement Design Guide (5) recommends testing HMA mixtures for susceptibility to stripping before the application of a chip seal because, "A surface treatment will generally seal off the vertical escape of moisture migrating upward out of a pavement which can set up accelerated stripping in the existing HMA layer beneath the seal". The sealing off of the vertical escape of moisture will not increase the pavement's stripping susceptibility if there isn't moisture, in other words if the moisture can escape through the sides (edge drains), or if the moisture is intercepted with a permeable base layer. Thus this implies that the stripping mechanisms of the pavement were already in-place, merely accelerated by the presence of the chip seal surface treatment.

Texas currently, as of 2011, has two standard methods for testing moisture susceptibility of HMA mixtures:

1. Placing a 200g sample of prepared HMA, no more than one aggregate thick in a beaker which is immersed in boiling oil
2. Modified Lottman Test which involves comparing the Tensile Strength Ratio of moisture conditioned specimens with that of non-conditioned specimens.

Aschenbrener and McGennis () reported on using the boiling water test and seven versions of the modified Lottman test (AASHTO T 283) to predict the stripping of materials extracted from twenty sites of known field (stripping) performance. They reported that two levels of severity for conditioning laboratory samples correlated well with what was observed in the field; the most severe conditioning cycle included a 30-minute vacuum (610 mm HG) saturation a 15 hour freeze, followed by a 16 hour soak in a high temperature water bath, the milder conditioning consisted of: 55-80% saturation and no freeze, followed by a 16 hour soak in a high temperature water bath. They recommended the severe conditioning for mixtures placed under high traffic, high temperature, high moisture and possibly freeze conditions and milder laboratory conditioning for mixtures placed on low traffic sites. They went further, stating that it is critical that the conditioning in the laboratory (vacuum saturation, freeze, hot-water soak) be equal, or greater than the severity expected in the field. The authors did not recommend the boiling test as it is a very severe test that does not consider important factors of: gradation, void structure, or permeability, all of which influence field performance related to moisture susceptibility.

Chapter 2. Laboratory Testing and Evaluation

Introduction

There is no one test that is universally accepted as an indicator of stripping potential, some tests worked well on some materials and not on others. One of the goals of this project is to provide a test(s) that can be performed relatively inexpensively and provide results quickly and accurately. With this in mind, excessive conditioning, such as multiple freeze-thaw cycles in the Lottman test, is not being considered. Preference was given to accepted tests and methodologies which could be implemented/performed with little investment.

In addition, an experimental plan was formulated based upon recent data findings from forensic investigations of local streets. These forensic investigations revealed that pavements with stripping problems also seemed to have high in-place air voids. All of them had in-place voids greater than 10%, up to as high as 14%, other samples were unable to be tested due to disintegration of the core during the coring operation. This led the researchers to hypothesize that reduced density would lead to an increased susceptibility of the pavement to experience moisture induced damage.

The hypothesis was tested by utilizing the current standard employed by Mn/DOT (Lottman test with Mn/DOT modified conditioning), experimenting with the Asphalt Pavement Analyzer (APA), or rutting test conducted on saturated and dry specimens as well as a new method proposed by the researchers that involves immersing a sample into boiling water for a pre-determined period of time (referred to as the modified boiling test)".

Laboratory Procedure and Test Results

Laboratory Permeameter (Karol-Warner flexible wall Permeameter)

The laboratory testing was conducted on a level 3 SuperPave mixture, derived from a relatively common Minnesota job mix formula. This mixture has not been observed to be susceptible to stripping problems. The samples were sampled from the field and prepared in the laboratory by trained Mn/DOT personnel using a SuperPave gyratory compactor. The mixture had 30% RAP content, with 4.8% new asphalt binder and it conformed to Mn/DOT's gradation requirements.

Permeability testing was accomplished using the laboratory Permeameter (Figure 2.1), also known as the Karol-Warner flexible wall permeameter. The coefficient of water permeability, k was found using the relationship described in Figure 2.1.

The coefficient of permeability provides an indication of the ease with which water can pass through the specimen, higher values indicate that it's easier for water to flow through the specimen and lower values indicate that it's more difficult for water to flow through the specimen. According to the Mn/DOT pavement design manual, permeability for class 5 aggregate base is approximately 4.8 inches per day (in/day) and drainable bases have permeability values between 3,600 to 12,000 in/day.

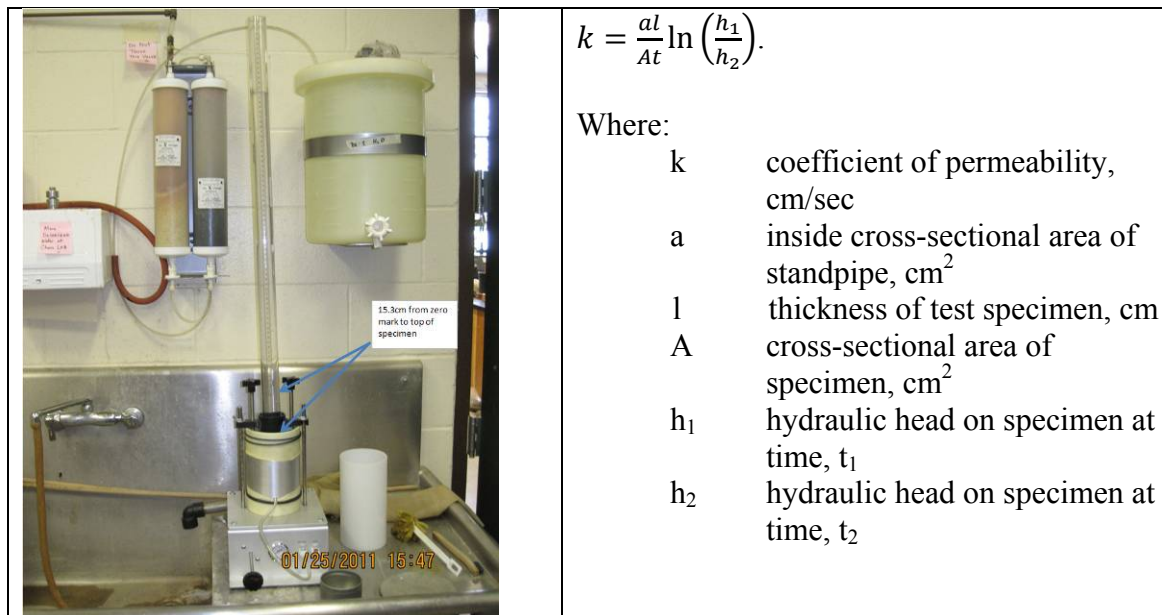


Figure 2.1. Laboratory Permeameter (Left) and Permeability Calculation (Right)

Figure 2.2 shows the graphical relationship between permeability and air voids. As the air voids are increased greater than 9.6%, the permeability increases dramatically. Although the permeability of the mixture with 13% air voids is still much lower than that of permeable bases, it is still approximately six times more permeable than class 5 aggregate base. This relationship was also found by Cooley, Brown and Maghsoodloo (2001) who reported that coarse, dense graded SuperPave mixtures with a nominal maximum aggregate size of 3/4" (19.0 mm) became excessively permeable at approximately 5.5% in-place air voids, which corresponded to a field permeability value of 40.82 in/day. They also observed that permeability appeared to increase exponentially with in-place voids (Figure 2.3).

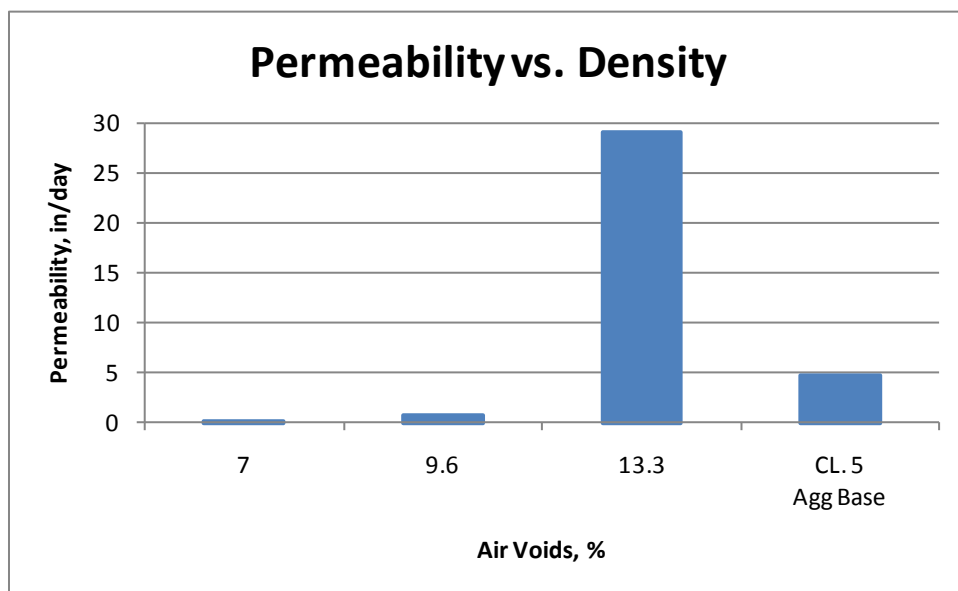


Figure 2.2. Permeability vs. Air Voids

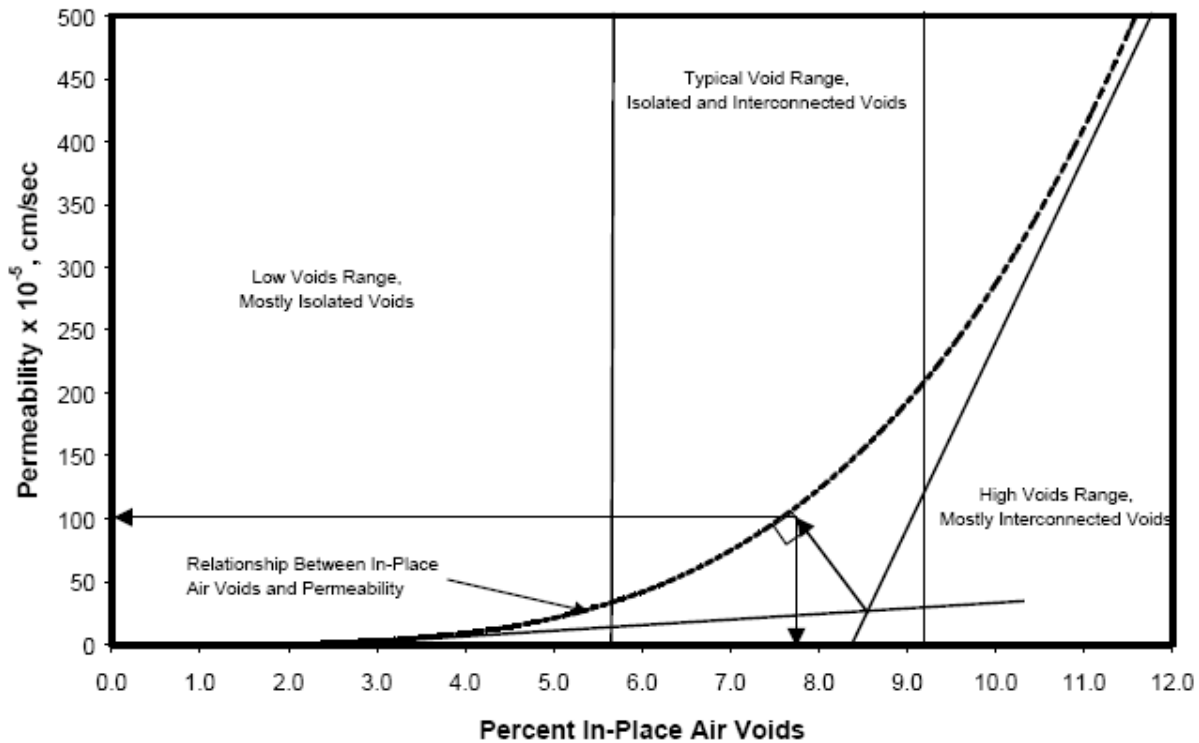


Figure 2.3. Permeability vs. In-Place Air Voids (Cooley Jr., Brown and Maghsoodloo, 2001).

Lottman Test (Mn/DOT Modified)

The moisture sensitivity was ascertained by performing modified Lottman tests in accordance with ASTM D 4867, Mn/DOT modified (See Appendix A). The moisture sensitivity was gauged by comparing splitting tensile test (Figure 2.4) results of control, or non-moisture conditioned specimens (dry strength) against those of moisture conditioned specimens (wet strength). The ratio of the wet strength to the dry strength represents the tensile strength ratio, or TSR. The generally accepted minimum threshold value for TSR is 70%.

Figure 2.5 shows the TSR values vs. the air void content of the mix. All three TSR values are above the 70% criterion; however, the increase in air voids appears to correspond with a decrease in the TSR, which suggests reduced resistance to moisture induced damage. In addition, the apparent relationship appears to suggest that a mixture with 17% air voids, would have a TSR value of 70%. Figure 2.5 compares the visual appearance of the 'wet' and 'dry' specimens after testing. From this figure, there does not appear to be a relationship between air void content and stripping potential as all three sets appear to be relatively the same.



Figure 2.4. Lottman Testing

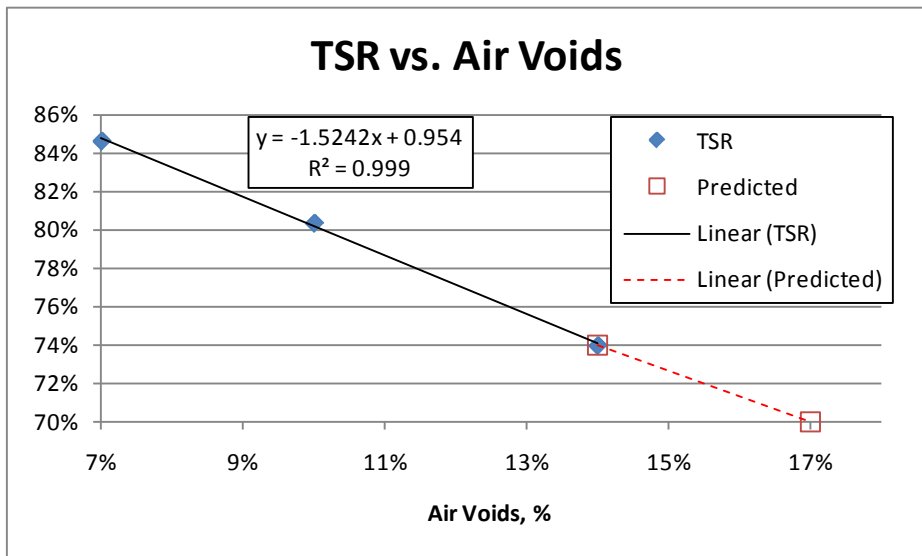


Figure 2.5. Tensile Strength Results (TSR) vs. Air Voids

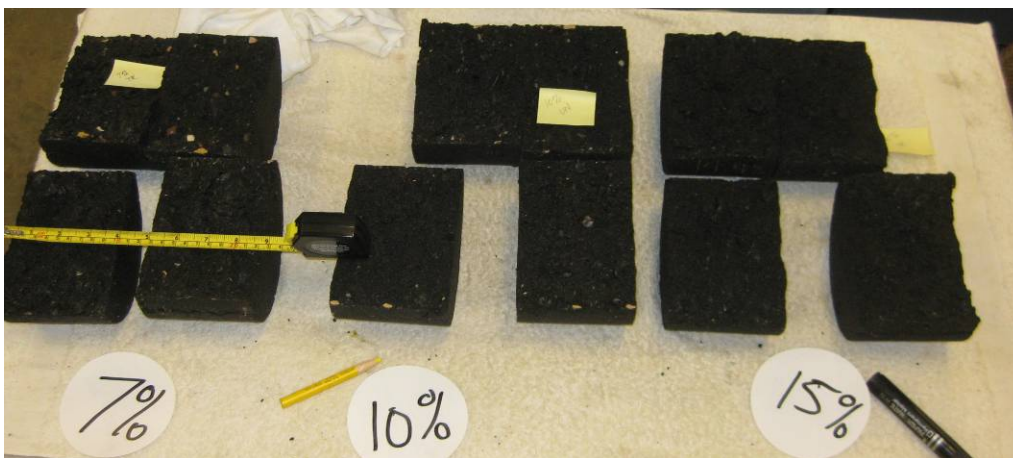


Figure 2.6. Visual Examination of TSR specimens

Figure 2.7 shows the dry and wet tensile strength values of the three mixtures. There is a much more noticeable impact on these strength values due to the increase of air voids than there was on the TSR. Generally speaking, a doubling of the air voids from 7 to 14 corresponds with a reduction of 52% and 58% in the dry and wet tensile strengths respectively. These reduced strength values could be expected to contribute to a less durable pavement. It should also be considered that the tests were conducted on newly prepared mixtures; pavements in the field degrade and loose strength and durability over time. A pavement that has initial TSR value near the borderline, will most likely reach a compromised state sooner than one that has a higher initial TSR value.

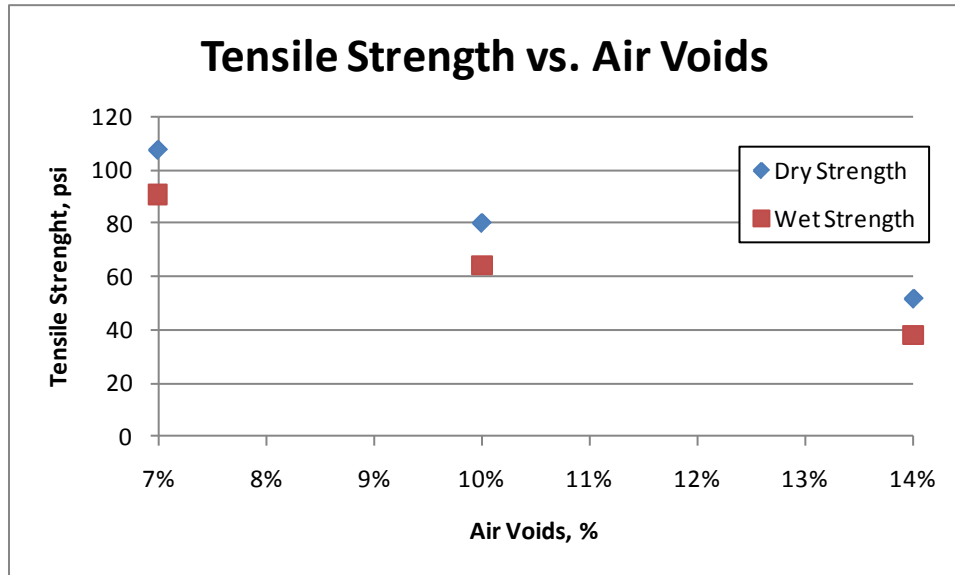


Figure 2.7. Tensile Strength vs. Air Voids

Asphalt Pavement Analyzer (APA) Test “Wet” (Mn/DOT Modified).

The asphalt pavement analyzer (APA) device, as shown in Figure 2.8, was used to experimentally evaluate the mixture’s susceptibility to rutting. The “dry” test consisted of applying 8,000 cycles of 100 lbf strokes to the lab-compacted gyratory specimens at 137 °F (58°C), which is approximately equivalent to 1,000,000 ESALS. The “wet” test consisted of applying a number of cycles until the mixture reached a set rutting value while immersed in water. A mixture’s susceptibility to rutting is typically dependant upon the binder (content and stiffness) as well as the gradation of the mixture and air void content. Higher rut depths indicate a softer mixture where lower rut depths indicate a stiffer mixture; typical level three mixtures evaluated by Mn/DOT have rut depths between 6 – 10mm.



Figure 2.8. Asphalt Pavement Analyzer (APA), or Rut Tester

This test was performed under dry and wet (submerged) conditions. The wet APA was intended to simulate the three factors identified in the literature search as contributing to the stripping phenomenon: presence of water (saturation), high stress and high temperatures. Figure 2.9 and Figure 2.10 show the rut depth vs. the number of applied cycles for the wet and dry tests respectively. Table 2.1 shows the average rutting rate in mm per hour (mm/hr) for the three air void contents in the two different testing conditions (wet and dry). For consistency purposes the average rutting rate (measured rutting/number of cycles) was computed based upon the same number of cycles for both testing conditions, the test conditioned that governed the number of cycles appears as bold in the table.

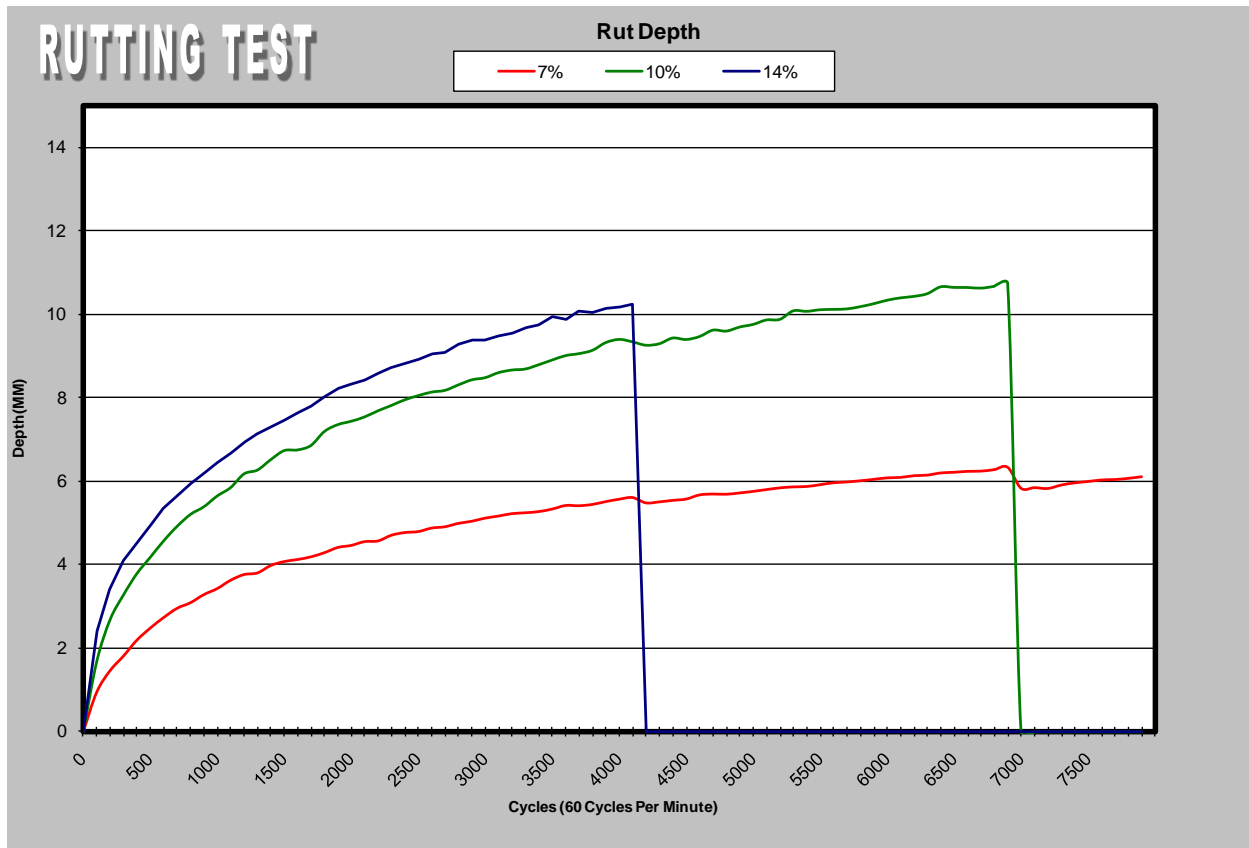


Figure 2.9. Asphalt Pavement Analyzer (APA) Test Results of Dry Test

Table 2.1. Average Rutting Rates (mm/hr)

AV	Test	Cycles	Rutting (mm)	Avg. Rate (mm/hr)	% Difference
7	wet	8,000	7.275	3.27	16.5
	dry	8,000	6.164	2.77	
10	wet	6,965	8.92	4.61	19.3
	dry	6,965	10.822	5.59	
14	wet	3,404	9.799	10.36	0.2
	dry	3,404	9.781	10.34	

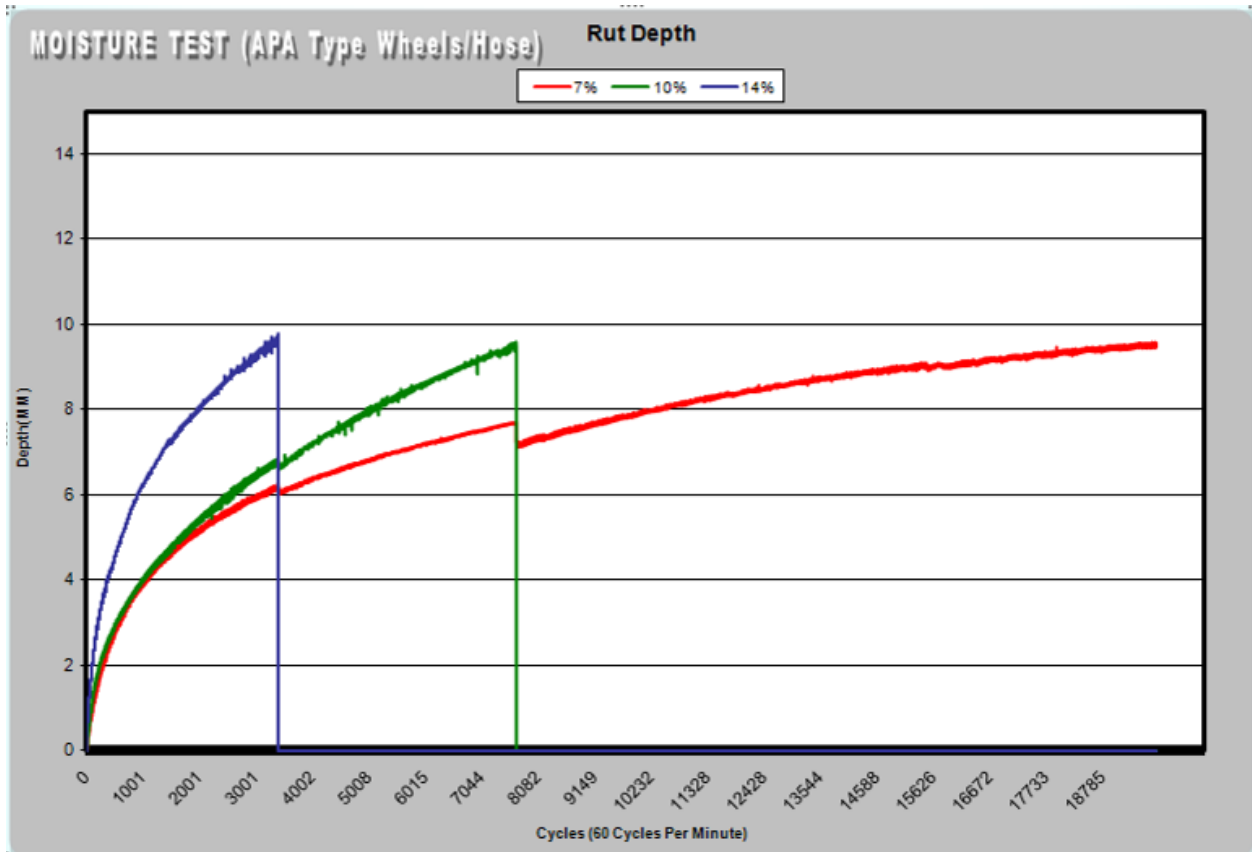


Figure 2.10. Asphalt Pavement Analyzer (APA) Test Results of Wet Test

The mixtures with the higher air void contents rutted at a faster rate than those with smaller air void contents. The greatest difference in rutting rates between ‘wet’ and ‘dry’ testing conditions were at the 10% and 7% air void contents; the mixture with 14% air void content showed little difference. After testing in the wet condition the specimens were broken open and examined for any visual evidence of stripping (Figure 2.11); there was no visual evidence of stripping among any of the test specimens, although there did appear to be some evidence of stripping where the hose interfaced with the mixture surface.



Figure 2.11. Visual Examination of APA ‘wet’ specimens

Modified Boiling Test (Proposed by Research Team)

One half of the sample left over from the dry indirect tensile strength tests was used in the modified Iowa boiling test. A total of four samples were tested, two that had the highest air voids (14%) and two that had the lowest air voids (7%). These samples were weighed, placed in a pot of boiling water for 6 minutes, allowed to cool and reach an air dried state and the final weight was measured. Neither of the specimens showed any visual cues of stripping (asphalt removed from aggregate particles) as the before test condition (Figure 2.12) looked similar to the after test condition (Figure 2.13).

However, the specimens with 14% air voids lost an average of 12.2% of their initial weight and the specimens with 7% air voids lost an average of 3.4% of their initial weight. In addition, empirical observations after the test showed that the specimen with higher air voids was much less intact than the comparable specimens with lower air voids (Note the distorted shape in Figure 2.13). The 14% air void specimens crumbled after the test and had to be handled very delicately and the 7% air void specimens were still intact and could be handled 'normally'.

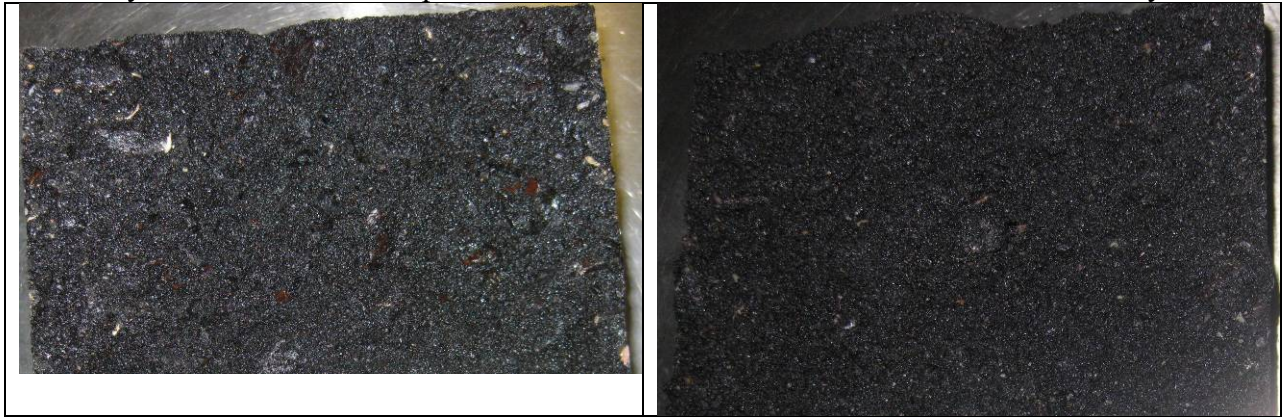


Figure 2.12. 7% and 14% Air Void Specimens (left and Right) *before* Modified Boiling Test

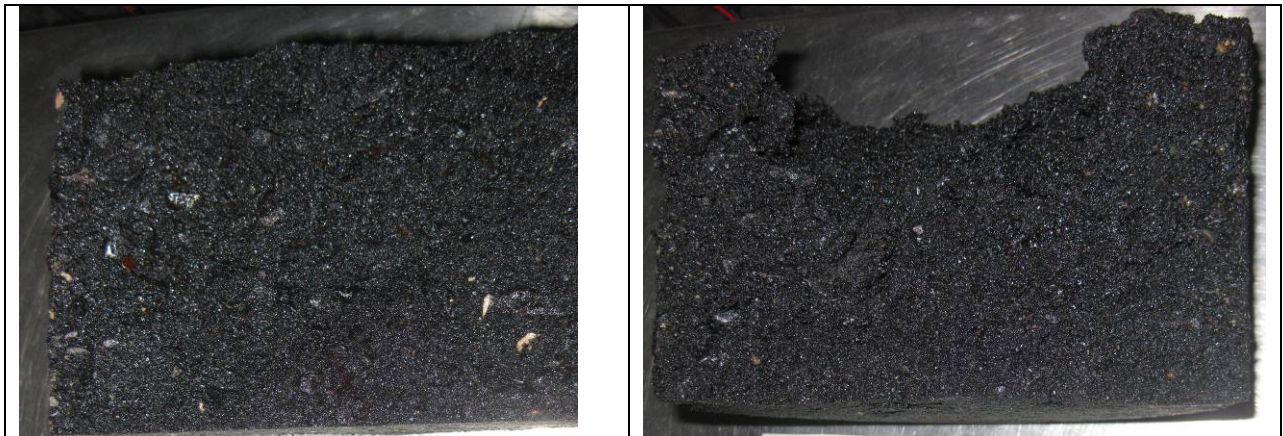


Figure 2.13. 7% and 14% Air Void Specimens (left and Right) *after* Modified Boiling Test

Chapter 3. Conclusions

This report represents task 2 of the Minnesota Local Road Research Board (LRRB) project number (Investigation) 2010-042, entitled, “Stripping of Hot Mixed Asphalt Pavements (HMA) under Chip Seals”. The goal of this specific task report is to identify, or develop a methodology that can be used to assess potential at-risk streets before they are treated with a surface treatment. Based on previously completed forensic investigations, and survey responses the research team has hypothesized that low density (high-interconnected air voids) are a contributing factor to the observed stripping distresses. Thus, the experimental plan investigated the influence of various air void contents (7, 10 and 14%) on a mixture’s susceptibility to moisture induced damage. The mixtures susceptibility was tested with: permeability tests, Mn/DOT modified Lottman, Asphalt Pavement Analyzer (APA) tested under wet and dry conditions, and a modified Iowa Boiling Test.

Permeability testing indicated that the mixtures became significantly more permeable when the air void content was near 14%. The Lottman test did not show any visual evidence of stripping and all tensile strength ratios (TSR) were above 70%. However, the mixtures with the highest air void content had the lowest TSR at 74% and the mixture with the lowest air void content had the highest TSR at 84%. The change in air void content had the most dramatic influence on tensile strength values; a doubling of the air voids from 7% to 14% corresponded with a reduction of 52% and 58% in the dry and wet tensile strengths respectively. APA test results were mixed as the greatest difference in rutting rates between ‘wet’ and ‘dry’ testing conditions were at the 10% and 7% air void contents; the mixture with 14% air void content showed little difference. None of the mixtures showed signs of visual stripping. In the modified Iowa boiling test, the specimens with 14% air voids lost an average of 12.2% of their initial weight and the specimens with 7% air voids lost an average of 3.4% of their initial weight. In addition, empirical observations after the test showed that the specimen with the higher air voids (14%) was much less intact than the comparable specimens with lower air voids (7%).

There was no test that explicitly showed asphalt stripping away from mixtures with higher densities; however, the results of the laboratory testing did indicate that the higher air voids do contribute to reduced pavement durability through reduced strength, increased susceptibility to rutting and increased permeability. The permeability and the modified Iowa Boiling test results indicate that pavements with higher air void contents may be more susceptible to moisture induced damage than pavements constructed with the proper amount. These factors will also reduce the life of a chip seal that’s placed on top of a compromised pavement. Future testing within this project will entail conducting the same tests (permeability, Mn/DOT modified Lottman, wet and dry APA, and modified Iowa Boiling) but on sealed specimens of varying density to more closely simulate field conditions. In addition, to the research team intends to modify the laboratory Permeameter to examine whether or not moisture (from the bottom) can penetrate a chip seal or a fog seal surface treatment.

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2. . Kiggundu, Badru M and Roberts, F. *Stripping in HMA Mixtures: State-of-the-Art and Critical Review Of Test Methods*. National Center for Asphalt Technology of Auburn University, Auburn, AL, September, 1988.
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<http://onlinemanuals.txdot.gov/txdotmanuals/pdm/surface_treatments.htm>, accessed on December 13, 2010.

Appendix C: Task 3 Report



Chapter 2. Minnesota Department of Transportation

Chapter 3. Memo

Office of Materials

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Office Tel: 651/366-5573

Fax: 651/366-5461

TO: Tom Tesch

DATE: July 17, 2012

SUBJECT: Task 3 memo for LRRB 904 Stripping Under Chip Seal Study

This memo will document what was completed in Task 3 of the LRRB Research Project INV. 904 *Stripping of Hot-Mix Asphalt Pavements under Chip Seals*. Task 3 was to test cores from city streets to test the hypothesis developed in Task 2. The hypothesis states that areas of low density or high air voids in the asphalt pavements are the major contributing factor to stripping of the Hot Mix Asphalt (HMA) after a chip seal has been placed.

Numerous streets were reviewed and three (3) cities were picked for study, Brooklyn Center, Eden Prairie and Woodbury. These cities were selected based on a significant amount of streets having stripping issues. Selection of streets to evaluate and the evaluation procedures are described below.

First a visual review with City Street Department personnel was conducted. Based on this review, areas were selected for further evaluation. On the streets that had previously received a chip seal, the following methods were used for evaluation. A nuclear density gauge was used to perform a nuclear density test (NDT). The gauge was placed on pavement close to the area of stripping ensuring uniform contact from gauge and the street. Two (2) readings were taken at 90° to each other (Figure 1). Then the gauge was placed as close to the stripped area as possible that showed no sign of damage. Two (2) more tests were performed similarly as previously described. This process continued until the complete paving pass had been tested. Then cores were cut at same location as the NDT readings (Figure 2)



Figure 14 Nuclear Density Gauge

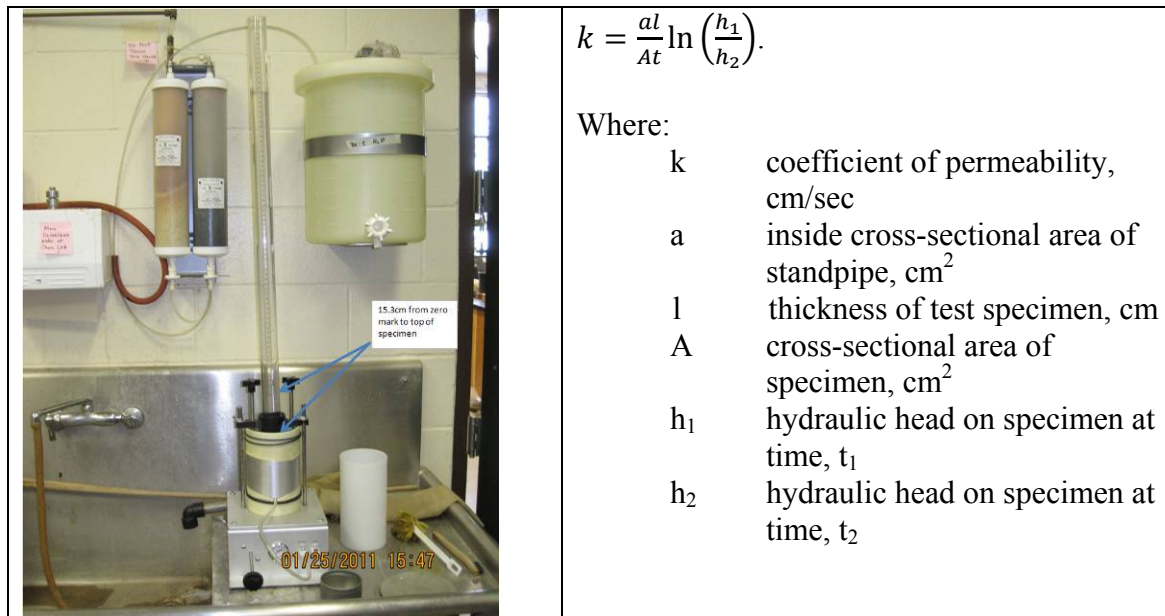


Figure 15 Coring at NI location

The cores were then taken to the MnDOT Materials Lab. The chip seal was sliced off the samples, then air voids (ASTM T269, T166 & T209) and permeability were measured using the Flexible Wall Permeameter ASTM PS 129-01.

The streets that did not have a current chip seal were evaluated using the nuclear density gauge to measure density, then field permeability with NCAT Field Permeameter tester, sample coring, lab permeability ASTM PS 129-1 and in place air voids same as chip sealed streets.

Non chip sealed streets were evaluated in hopes of determining a method to predict the possibility of stripping of the street after it was chip sealed. Task 5 will analyze the data collected develop recommendations on how to evaluate existing streets for a chip seal.



$$k = \frac{al}{At} \ln \left(\frac{h_1}{h_2} \right).$$

Where:

- k coefficient of permeability, cm/sec
- a inside cross-sectional area of standpipe, cm²
- l thickness of test specimen, cm
- A cross-sectional area of specimen, cm²
- h₁ hydraulic head on specimen at time, t₁
- h₂ hydraulic head on specimen at time, t₂

Figure 16 Lab Permeameter

Conclusions:

Field testing: Based on ease of use and quick results, the nuclear density gauge is the best test method to used test and evaluates a large number of locations. The negative to this method of evaluation is the gauge requires a trained and licensed operator and has special storage requirements. The NCAT Field Permeameter tester is a slow test taking over 20 minutes to complete on test location in field. The result can vary from operator to operator. Some pavement surfaces are more difficult to seal the tester to which can give false readings. One interesting observation was that in areas of stripping under chip seal, we had difficulty in obtaining cores. The action of the core barrel and water in many cases completely destroyed the remaining pavement. Areas close to site of destroyed cores had air voids up to 11% this leads us to believe that areas with worst stripping have even higher voids. See figure 4 & 5 below.



Figure 17 Destroyed cores



Figure 18 Pavement in area of stripping

Figure 6 is graph of some of the data obtained for field samples. Base on the information gathered both NDI and Lab permeability correlate and are acceptable tools to determine variability in density.

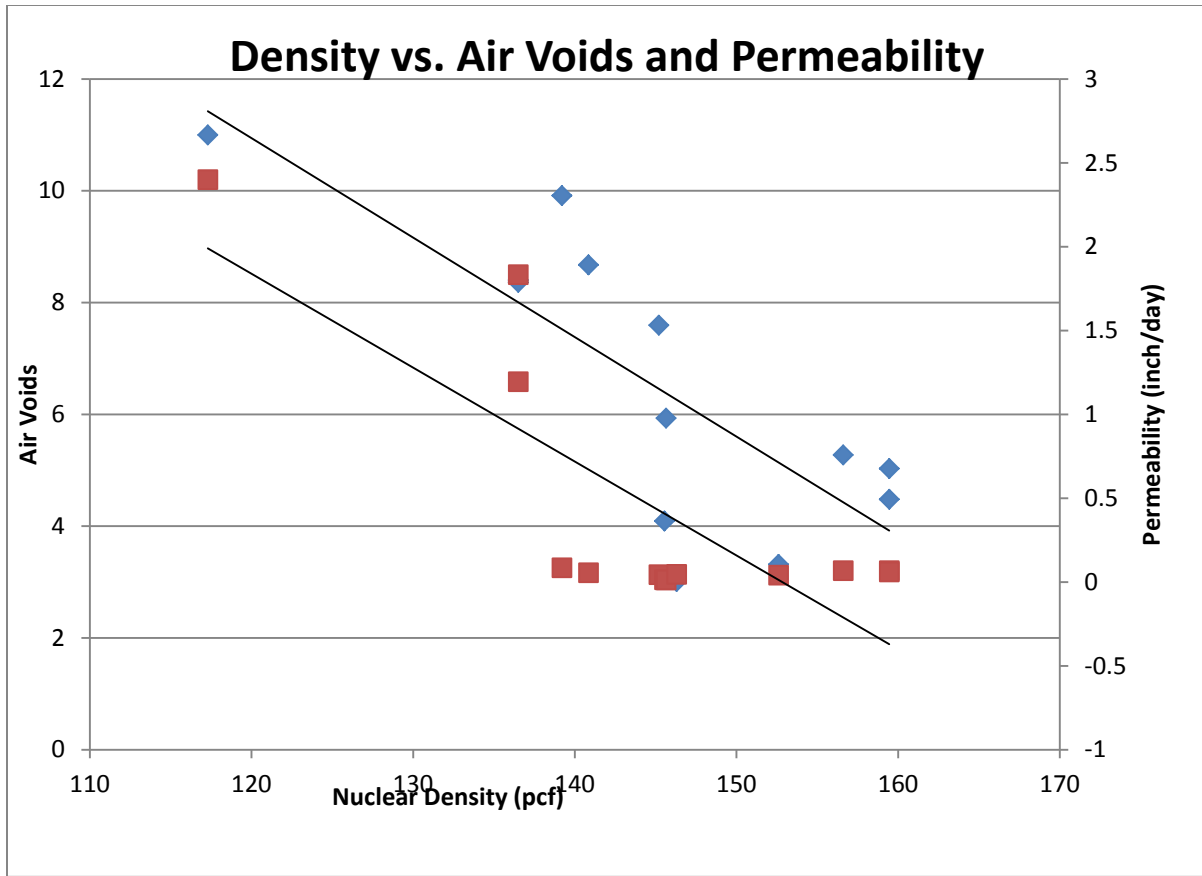


Figure 19 Graph comparing Density vs. Air Voids & Permeability

The results from different test methods will be discussed in-depth in Task 5.

Appendix D: Task 4 Report



Chapter 4. Minnesota Department of Transportation

Chapter 5. Memo

Office of Materials

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Fax: 651/366-5461

TO: Tom Tesch T.L.

DATE:

SUBJECT: Task 4 for LRRB 904 Stripping Under Chip Seals

In Task 4 we will discuss the different construction practices used for streets among many Cities. Some of the areas discussed are the following: history of the MnDOT HMA specification, type of mixes used, construction methods.

Hot Mix Asphalt (HMA) Mixtures History in Minnesota

Please see below for a brief history of the HMA specifications:

- Specification 2331 (Pre 1988)
- Specification 2340 (1988)
- Specification 2340 Modified (1997)
- Specification 2350 (1998)
- Specification 2360 (1998)
- Combined 2350/2360 (2003)

2331

MnDOT Specification 2331 was the standard HMA specification prior to 1988. In this specification the MnDOT designed the mixes for the contractor, process control and acceptance testing was performed by MnDOT. The Contractor's only role was to produce and place the HMA mix.

2340

MnDOT Specification 2340 was implemented as a quality management specification in 1988 and modified in 1997. This specification addressed problems with rutting, flushing, and raveling. In this specification, the Contractor was responsible for the mix design and the Quality Control (QC) testing. Air voids was used as the primary acceptance criteria.

2340 was modified in 1997 to include new mixture quality measurements. These were Voids in Mineral Aggregate (VMA) and Tensile Strength Ratio (TSR) testing. TSR testing is a measure of moisture susceptibility in the HMA.

2350/2360

The Minnesota Department of Transportation (MnDOT) adopted Super-Pave mix designs (MnDOT Specification 2360) in 1998. Some cities continue to use older mix methods such as MnDOT Specification 2331, 2340, and 2350. The table below gives a brief comparison between old specification 2340 and the newer Super Pave 2360 mixes:

2340 Mixes	2360 Super Pave
Crushing	
Type 31 No crushing requirement	Level 2 30% + 4
Volumetric	
Air Voids	Air Voids
	4%
	VMA*
	AFT**
No TSR***	TSR Required
Compaction	
Ordinary Compaction	Max Density
Modified specified	Higher Requirements

* Void in mineral aggregate

**Asphalt Film Thickness

*** Tensile Strength Ration (TSR) - Stripping Test

Crushing:

Requiring minimum amount of crushed aggregates increases the structural stability of the HMA. This allows resistance to the traffic loadings without rutting occurring. During the 1980's rutting in HMA pavements was common due to the lack of crushed aggregates.

Air Voids

Air voids requirement for Super Pave mixes (2360) are stricter than the older 2340 mixes. Some of the volumetric for 2360 deal with voids in mineral aggregate which insures proper density and amount of asphalt without issues of rutting and flushing that 2340 mixes had.

Asphalt Film Thickness (AFT)

In late 1980's, to help reduce the rutting in the HMA the asphalt binder content was decreased, creating drier HMA mixes. The theory was that the drier mix would be more stable. However, the drier mixes were more susceptible to stripping, cracking, and other forms of water damage. These problems did not occur as frequently in the 1970's and the early 80's as it did later in the 80's.

AFT is a requirement to help insure proper amount of asphalt in the HMA to deal with durability issues. AFT came about to make sure that high Recycled Asphalt Pavement (RAP) used in new HMA have enough new asphalt to perform properly.

TSR

TSR is tested to determine how likely the HMA is to suffer water damage. Since this study is looking at stripping i.e. water damage. It is recommended that TSR be tested on all new HMA projects.

General Discussion

In discussion with some of the HMA Contractors and mix Suppliers, normally they see little to no cost differences between 2340 mixes and 2360 level 2. This can be explained because suppliers are do the quality control (QC) testing for 2360 mixes daily as it is the current specification. QC testing for 2340 mixes is not, thus some extra time is needed from the supplier to review the older specification. Suppliers are also producing 2360 Level 2 & 3 mixes on most other jobs throughout their area, i.e. county and state occurring at the same time and using the similar mix designs, increases the plant production rates.

Based on finding from samples and testing in Task 3, it is apparent that variability in density is a major factor in stripping under chip seal. Air voids ranged from 5% in great performing streets to over 11% on streets that are showing severe stripping.

In Task 2 it was demonstrated that an asphalt mixture that has not had issues with stripping when properly constructed would strip when the air voids were greater than 8%. This shows that a better job of compaction during construction the asphalt pavement is needed. Ordinary compaction when done properly would not have had these issues. If the test strip was properly constructed and represented the true condition of the paving job then uniform density would have been achieved. The main issue with the ordinary compaction method is lack of enforcement of the established rolling pattern. The inspector needs to be present at all times to ensure that the pavement receives proper number of passes with the roller and to make sure the temperature of the mix is with in the specified requirements during compaction. The benefit of maximum density is the ability of the agency to test density in areas that may not meet minimum requirements.

Many of the projects that were looked at as part of this study were originally constructed in the 1990's. At this time the 2340 specification was the current specification and required ordinary compaction methods. See Appendix A for bituminous specifications from the City of Brooklyn Center from the time the streets studied were constructed and also the cities current bituminous specification.

One city that switched from ordinary compaction to maximum density stated that the asphalt pavement was the same price. The contractor used two 20 to 25 ton double drum steel roller and a pneumatic roller when maximum density was specified. Prior to specification using the maximum density contractor on an ordinary compaction job had only one 6 to 8 ton roller on the job.

Recommendations

1. Switch from 2340 mixture requirements to 2360 level 2 or 3 as need for traffic.
2. Use specified density for compaction
 - a. The use of the MnDOT's incentive program is optional.
3. Pay close attention to areas that are difficult to pave and compact.
 - a. Sharp radius, skewed intersections, cross streets etc...
4. Spend more time and effort on inspection of paving
5. If doing a mill and over lay then the existing street should be cored to determine quality of base course before designing project.
6. Chip seal earlier in pavement life.

Additional Needs for Research

1. Bond strength of tack coat bond strength
 - a. In coring many streets as part of this project, the lack of bonding of base course to wear course of HMA is very apparent.
 - b. It is hypothesized that the lack of strong bond reduces the durability of the wear course because it is independent of the underlying layers, causing movement between layers. This movement could increase the stripping effect.
2. Study priming granular base materials before paving to waterproof bottom of the asphalt pavements.
3. Develop quick setting fog sealing product.
 - a. Lab testing done as part of this study shows that a fog seal will keep water out but still all water vapors to migrate out of the HMA.
4. Study using lower air voids design mixes
 - a. Maybe as low as 1 to 2%
5. Use softer based asphalt binder
 - a. PG -34

Appendix E: Task 5 Report



Chapter 6. Minnesota Department of Transportation

Chapter 7. Memo

Office of Materials

1400 Gervais Avenue, Mail Stop 645
Maplewood, MN 55109

Office Tel: 651/366-5573

Fax: 651/366-5461

TO: Tom Tesch T.L.

DATE: September 20, 2012

SUBJECT: Task 5 for LRRB 904 Stripping Under Chip Seals

Background

Analysis of the data collected in Task 3 will be discussed and presented in Task 5. It was shown in task 3 that all the tests, permeability, air voids, and density, correlated. The data showed that streets had high variability in density from 7 to 12 percent air voids in areas close to the stripped areas.

In the areas with severe stripping cores were not able to be retained for testing. This was due to the cores disintegrating into many pieces after pulling the core from the pavement. Nuclear density testing showed great amount of variability in the mix density from areas of not stripping to areas suffering from stripping. One street had the density varied from 145 lbs/ft³ in areas of the street with no issues to a low of 117.3 lbs/ft³ in areas experiencing stripping. For field evaluation of streets the nuclear density tester is the fastest and easiest to use of method tested. After discuss with experts from around the country it is recommend to not chip seal a street if the variability in density varies more than 6 lbs. per cubic foot as measured with nuclear density tester.

Data

Figure 1 shows that that when comparing the density to either air voids or lab permeability, the correlation is similar. This indicates density, air voids, and lab permeability are correlated to each other. As density increased and lab permeability and air voids decreased, less stripping was observed.

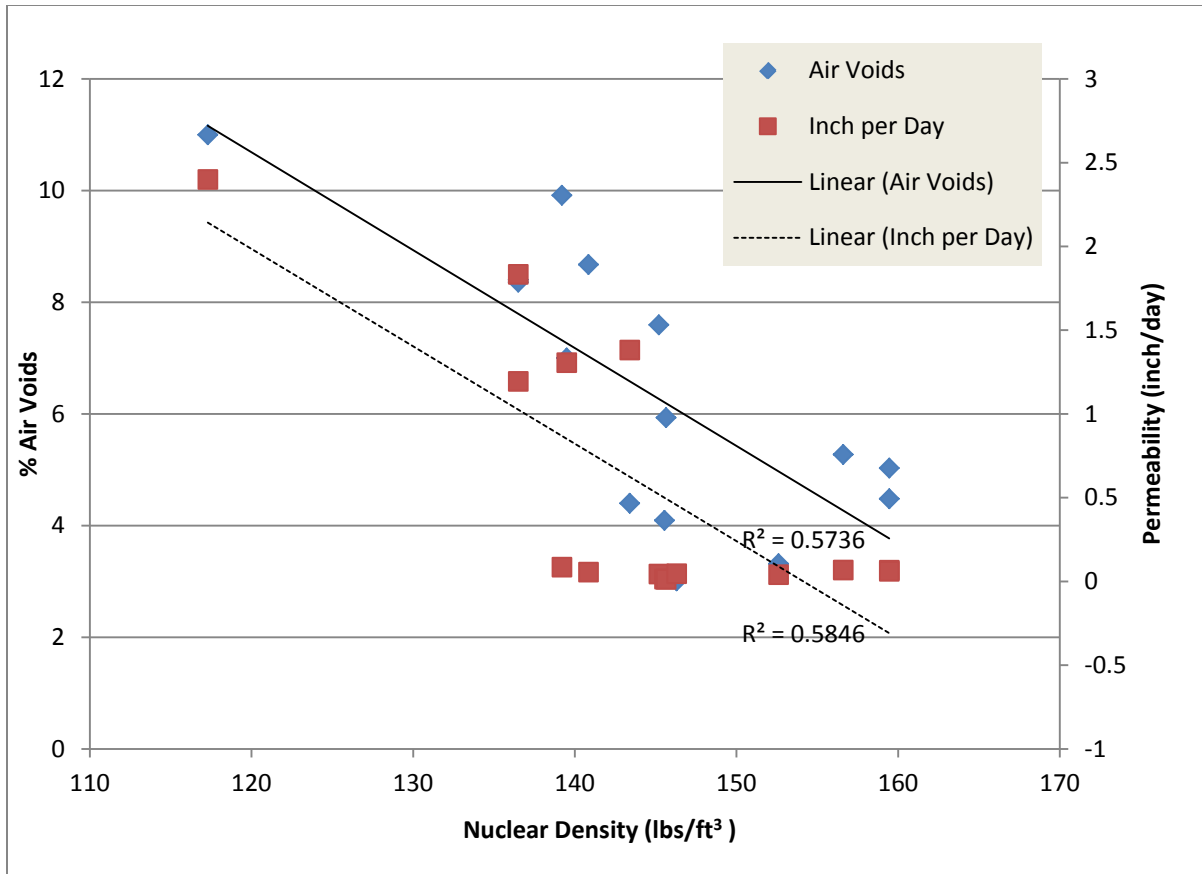


Figure 20 Air Voids and Permeability vs. Density

Figure 2 was made to compare it to the results found in a report from Cooley Jr., Brown and Maghsoodloo, “Development of Critical Field Permeability and Pavement Density Values for Coarse Graded Super Pave Pavements.” In this report the authors compared lab permeability to air voids. We saw similar results, it is important to note in this study the mixes tested are dense graded. Our results show a similar curve but less permeability.

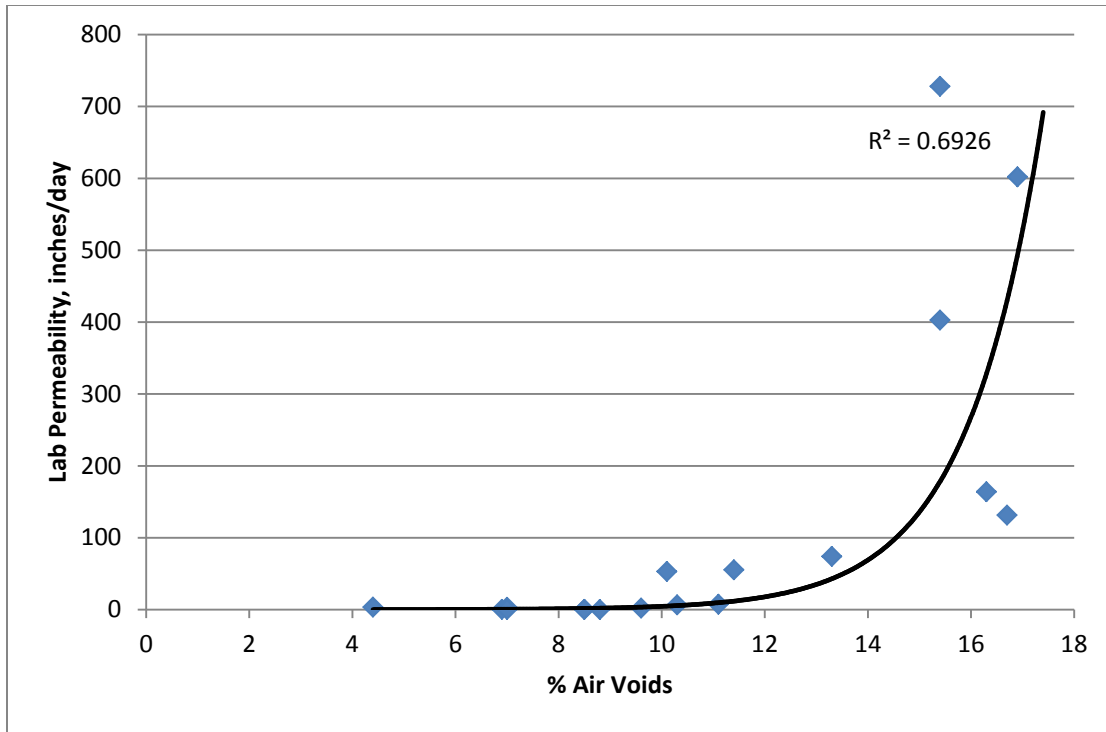


Figure 21 Air Voids vs. Lab Permeability

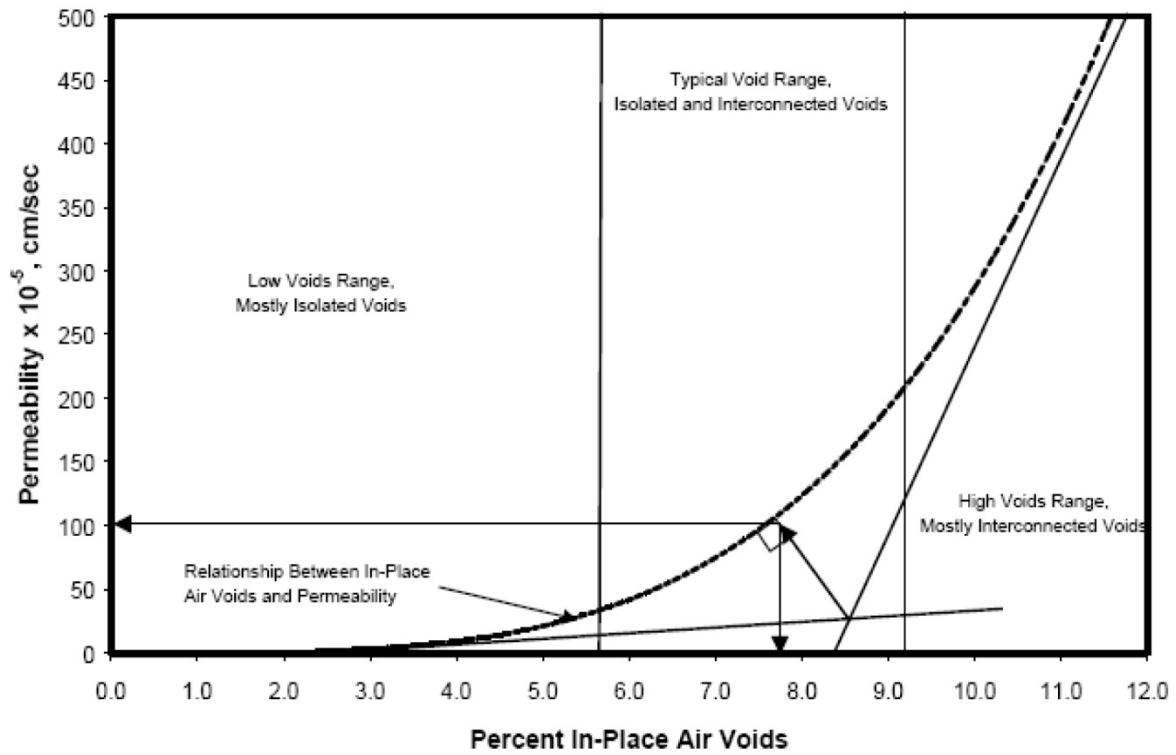


Figure 22 Permeability vs. In-Place Air Voids (Cooley Jr., Brown and Maghsoodloo, 2001).

Conclusions / Recommendations

Based on the field testing from this research project, it was determined that all three field test evaluated in this task are valid tests to perform to help predict if streets may strip after placement of a chip seal. All three evaluations correlated to each other and to stripping.

The easiest and least invasive test for agencies to perform to predict if the streets will strip is a nuclear density test. The air voids and lab permeability test require cores to be taken from the pavements and brought back to a lab for evaluations. After discuss with experts from around the country it is recommended to not chip seal a street if the variability in density varies more than 6 lbs/ft³ as measured with nuclear density gauge.