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Fog Seal Performance on Asphalt Mixture Longitudinal Joints

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16. Abstract

Due to the nature of construction, it is common for longitudinal joints in asphalt pavements to have lower densities and higher permeabilities than the main portions of the pavement lanes. To address this concern, many states employ joint sealant techniques such as fog seals or void reducing asphalt membranes (VRAM). Qualitative evidence in Indiana appears to indicate that longitudinal joint lives have been improved by the use of joint sealers and adhesives, but the specific materials and application rates used to treat longitudinal joints has not been quantitatively investigated. This research aims to specifically investigate the fog seal materials and application rates specified for use on longitudinal joints in Indiana and to compare the performance of fog seal and VRAM treatments in order to provide guidelines for future joint sealant treatments. These objectives were accomplished by employing laboratory testing of both laboratory prepared specimens and field samples.

The research performed on the laboratory specimens found the application of fog seals can improve the performance of the longitudinal joints with respect to permeability. While the permeability was affected by the presence of a fog seal treatment, the benefits were irrespective of the specific fog seal material. The results also indicate that the fog seal should be reapplied at 5-7 year intervals.

The data from the field samples indicated that the VRAM samples had on average higher air void contents than did the SS-1h fog seal samples. Additionally, the VRAM samples had permeability coefficients that were statistically higher than the SS-1h fog seal samples. These differences may be attributable to the lack of VRAM migration up into the asphalt surface mixture. While the SS-1h fog seal treatment appears to have better performance than the VRAM, the effectiveness of the treatments over time is not known.

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EXECUTIVE SUMMARY

FOG SEAL PERFORMANCE ON ASPHALT MIXTURE LONGITUDINAL JOINTS

Introduction

Due to the nature of construction, it is common for longitudinal joints in asphalt pavements to have lower densities and therefore higher permeability than the main portions of the pavement lanes. To address this concern, many states employ joint sealant techniques such as fog seals or void reducing asphalt membranes. Qualitative evidence in Indiana appears to indicate that longitudinal joint lives have been improved by the use of joint sealers and adhesives, but the specific materials and application rates used to treat longitudinal joints in Indiana have not been quantitatively investigated.

This research aims to specifically investigate the fog seal materials and application rates specified for use on longitudinal joints in Indiana to provide guidelines for future joint sealant treatments. The specific objectives of the project are to determine if applying fog seals to the longitudinal joints of new asphalt surface mixtures improves the performance of the joints; determine the preferred type of fog seal material for use in sealing the longitudinal joints; determine if fog seals need to be reapplied to the longitudinal joints, and if so, at what intervals; and compare the performance of longitudinal joints receiving fog seal and void reducing asphalt membrane treatments. These objectives are accomplished by employing laboratory testing of both laboratory prepared specimens and field samples.

Findings

- Fog seals can lower the permeability of longitudinal joints in asphalt pavements. Lower permeability should increase longitudinal joint performance.
- Either SS-1h or AE-NT, applied as fog seals, can be used to lower longitudinal joint permeability.
- Fog seal applications should be reapplied to longitudinal joints every 5 to 7 years, for maximum effectiveness.
- The SS-1h fog seal treatment did a better job of sealing the pavement surface than the void reducing asphalt membrane treatment did. However, this result may be attributable to the late-season paving operation.

Implementation

Given the findings of the research, the Indiana Department of Transportation (INDOT) should continue the use of fog seals on the longitudinal joints of asphalt surface mixtures, using either SS-1h or AE-NT asphalt emulsions at the currently specified rates. Additionally, the department should consider reapplying the fog seals to the surface of the longitudinal joints every 5 to 7 years.

While the results and recommendations presented here are specific to the asphalt material, joint sealant materials, and application rates used in this research, they can be applied generally to other asphalt pavements, materials, and situations as well. However, additional research is recommended to provide greater quantitative support and guidelines for fog seal implementation. Specifically, a comparison of SS-1h and AE-NT field test sections would provide additional support for and verification of the conclusions and recommendations presented in this research. Additional testing of the SS-1h and void reducing asphalt membrane test sections over time would also provide greater insight into the performance of these joint sealant treatment methods.

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1. INTRODUCTION

Due to the nature of construction, it is common for longitudinal joints in asphalt pavements to have lower densities and higher permeabilities than the main portions of the pavement lanes. This condition causes the pavement at the joint to be more susceptible to air and water penetration and thus have an accelerated potential for deterioration. To address this concern, the Indiana Department of Transportation (INDOT), as part of placing new asphalt surface mixture on SR-38 near Lebanon in 2009, required the longitudinal joint of the asphalt pavement surface mixture to be fog sealed. The success of this project led INDOT to require, beginning in 2012, the fog sealing of longitudinal joints on newly constructed or overlaid asphalt pavement surface mixtures. The fog seals were required to be in a 0.6 m (2 ft) wide band centered on the longitudinal joint.

A fog seal is defined as "a light spray application of dilute asphalt emulsion used primarily to seal an existing asphalt surface to reduce raveling and enrich dry and weathered surfaces" (The Asphalt Institute, 2008). It is believed that fog seals can reduce the penetration of air and moisture in asphalt pavements, thus enhancing the pavements' waterproofing abilities and decreasing its susceptibility to oxidation and moisture-induced damage (Prapaitrakul, Freeman, & Glover, 2005).

For a fog seal to reduce asphalt mixture permeability it must be able to penetrate the voids of the surface mixture. It is therefore important to ensure the fog seal material is of the proper viscosity. If it is too thick it will simply remain on the surface causing potential friction problems. Consequently, a slow set emulsion diluted with water is most often used (Prapaitrakul et al., 2005). To fog seal the longitudinal joint, INDOT originally specified a 50/50 diluted SS-1h material at an application rate of 0.3 + 0.1 L/m^2 (0.06 $\pm$ 0.02 gal/yd^2), which is twice the normal rate for an SS-1h tack material. However, this required two distributors on a project, so contractors requested, and INDOT approved, the use of normal tack material for fog sealing of the longitudinal joint. Currently, undiluted tack materials such as an SS-1h (50% residual) or AE-NT (trackless tack) are being used for the longitudinal joint fog seal at a rate of 0.13 L/m^2 (0.03 gal/yd^2).

To address the accelerated deterioration of longitudinal joints, some states are using another joint sealant product known as a void reducing asphalt membrane (VRAM). Rather than being sprayed on top, this asphalt product is placed beneath the asphalt pavement surface mixture such that when overlaid with hot asphalt, the VRAM is intended to achieve 50 to 75% migration into the surface mixture to fill in air voids, thus increasing the density and reducing the permeability of the longitudinal joints. VRAM is applied in a 0.3 to 0.46 m (1 to 1.5 ft) wide band, centered on the joint (Asphalt Materials, Inc., n.d.; Winkelman, 2004).

Since beginning the practice of fog sealing the longitudinal joints of new asphalt surface mixtures in Indiana, qualitative evidence appears to indicate the lives of the longitudinal joints have been improved. However, no data has been collected to quantitatively support this observation. Additionally, the question of how often a fog seal material should be re-applied, if at all, has arisen. Additionally, no study has been conducted to determine the best materials to use for such fog seal applications in Indiana. Given the lack of quantitative evidence related to these issues and the mixed results obtained by studies in other states, the objectives of this project were to:

1. Determine if applying fog seals to the longitudinal joints of new asphalt surface mixtures improves the performance of the joints,
2. Determine the preferred type of fog seal material for use in sealing the longitudinal joints,
3. Determine if the fog seals need to be reapplied, and if so, at what intervals, and
4. Compare the performance of longitudinal joints receiving fog seal and VRAM treatments.

These objectives were accomplished by employing laboratory testing of both laboratory prepared specimens and field samples.

2. BACKGROUND

2.1 Longitudinal Joints

In the process of asphalt pavement construction, multiple lane roadways are typically paved one lane at a time. The disadvantage of this type of construction operation is that the free edge of the previously paved lane cannot be fully compacted without sufficient confinement. As a result, construction joints formed during asphalt paving may be less dense (containing more air voids) than the interior of the lane (The Asphalt Institute, 2008). To address this concern, joint quality specifications are normally used. The two most common requirements for joint construction are: (1) a minimum joint density of 90% of the maximum theoretical density; and (2) a joint density not more than 2% below the density at center of the paving lane (Prapaitrakul et al., 2005).

Construction joint quality has been considered critical to the successful performance of asphalt pavements since the 1960s (Foster, Hudson, & Nelson, 1964), and although asphalt density has been the primary measure of joint quality, the fundamental failure mechanisms are more directly related to permeability. Permeability is a mixture's ability to transmit air and water and is influenced by the air void content and interconnectedness of the air voids. The entrance of air and water into the asphalt mixture directly contribute to oxidation, moisture damage, cracking, raveling, and joint separation. Therefore, water related measurements, such as permeability, should be considered when determining the quality of asphalt pavements (Daniel, Mallick, & Mogawer, 2007; Huang, Chen, & Shu, 2010; Killingsworth, 2004; Mallick & Daniel, 2006; Mallick, Kandhal, Alrich, & Parker, 2007; Williams, 2011a, 2011b; Williams, Pervis, Bhupathiraju, & Porter, 2009).

Over the years, studies have been done to determine how asphalt mixture permeability affects the performance

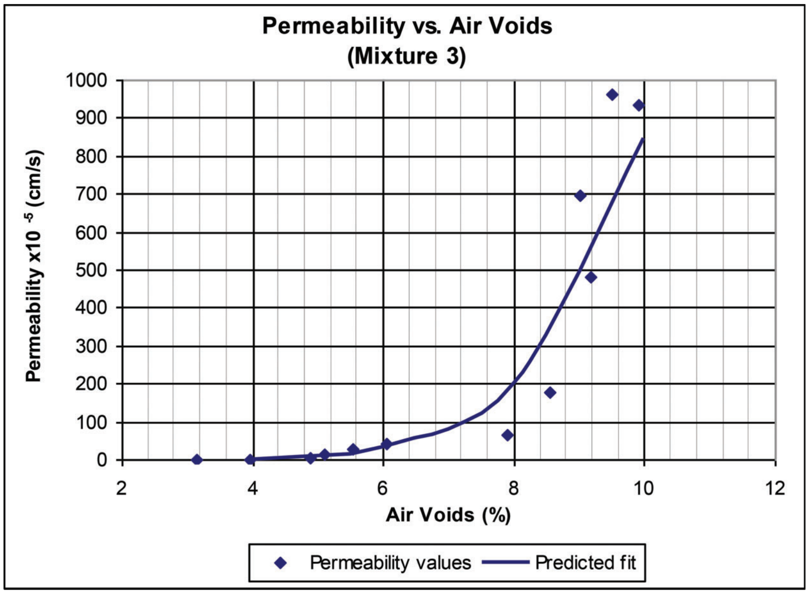

Figure 2.1 Effect of asphalt mixture air voids on mixture permeability (del Pilar Vivar & Haddock, 2006).

and durability of flexible pavements. Some researchers have indicated that asphalt mixture permeability has a tremendous influence on how the mixture will perform when placed in the field as part of a flexible pavement. Shown in Figure 2.1, as air voids contents increase (or density decreases) in an asphalt mixture, permeability increases. Several studies have shown that asphalt mixtures generally become permeable at a critical air voids content of approximately 8% (Brown, Collins, & Brownfield, 1989; Santucci, Allen, & Coats, 1985; Zube, 1962). When asphalt mixture air voids rise to this level, air and water are able to penetrate the mixture and can accelerate oxidation and moisture damage. The asphalt mixture permeability corresponding to the critical air void content is typically thought to be 150×10^{-5} cm/s (59×10^{-5} in/s) (del Pilar Vivar & Haddock, 2006).

Due to difficulty in achieving adequate densities of the longitudinal joints, the asphalt mixture at the joints can often have densities of 90% (10% air voids) or lower (higher air voids), thus making them permeable to air and moisture. This makes the longitudinal joints the most vulnerable part of the asphalt pavement surface (Williams, Chen, Ahmed, & Hosin, 2013).

To improve the performance of longitudinal joints, several construction methods have been implemented with varying degrees of success. Such methods include joint sealants, joint makers, joint heaters, wedge construction, edge restraint, and cutting wheels (Brown, 2006; Kandhal, Ramirez, & Ingram, 2002; McDaniel, Shah, & Olek, 2012; Prowell, 2009; Zinke, Mahone, Jackson, & Shaffer, 2008). Because application of joint sealants is easy, does not delay construction, and requires less labor and heavy equipment than other construction techniques, many types of joint sealants have been used on longitudinal joints with the primary intention of preventing the entrance of air and water, thus preserving joint integrity (Williams, 2011a).

2.2 Joint Sealant Experience

A search of the literature identified several state departments of transportation (DOT) with joint sealant experience. The products and materials used by the various DOTs can be categorized into two groups: (1) joint sealers, which are applied to the pavement surface after both sides of the joint have been compacted, and (2) joint adhesives, which are applied to the face of the unconfined free edge prior to placing one or both lanes. This is done with the expectation that when the hot lane is placed the heat will cause the adhesive to migrate upward through the joint, thus eliminating many of the interconnected void spaces. Fog seals fall into the first category of joint sealers and VRAMs fall into the second category of joint adhesives.

Arkansas DOT evaluated a joint adhesive product, Crafco Pavement Joint Adhesive; a post-applied polymerized maltene-based emulsion product, JointBond; and a standard tack coat, SS-1h, in their study. They concluded that: (1) the use of the Joint Adhesive resulted in the lowest joint density, while the JointBond and tack coat only resulted in moderate joint densities; (2) the JointBond was more effective than the other two materials in reducing absorption, permeability, and infiltration levels; and (3) The Joint Adhesive and tack coat did not perform as well as expected in terms of joint densities and water-related responses (Williams, 2011a).

Illinois DOT used two joint adhesive products, J-Band by Heritage Research Group, and QuickSeam by Hendy Products, Inc., on four projects to evaluate their ability to reduce the permeability of longitudinal joints. The test results were mixed. Two of the projects showed both products were able to reduce permeability, but the other two projects showed no significant improvements (Winkelman, 2004).

Maine DOT has used a rubberized asphalt joint adhesive from Koch Materials Company, and high-float asphalt emulsion as joint sealants. They observed that the rubberized asphalt began to show separation in the first year after construction, which they attributed to poor construction rather than material failure. Even though the separation increased over the next five years, the overall performance was reported as good. The asphalt emulsion also performed well with little joint separation. After five years, there were no significant differences in the performance of the materials (Colson, 2006).

New York State DOT applied three different sealing products (XJB eXtruded Joint Bond, Crafco Pavement Joint Adhesive, and Deery Cold Joint Adhesive) on three different projects. Although conclusive evidence has not yet been reported regarding joint performance, they did report that the use of longitudinal joint sealant materials for HMA pavements did not negatively affect HMA paving and compaction on the three projects (Denhey, 2005).

Tennessee DOT conducted a study comparing the performance of a control section with four different joint adhesives and two joint sealers. The study concluded that the use of polymerized and basic emulsions resulted in the lowest air voids contents. Additionally, the use of highly polymerized emulsion containing SBR polymer and resins, polymerized emulsion, and basic emulsion resulted in significantly lower permeability coefficients. Finally, the use of highly polymerized emulsion containing SBR polymer and resins, polymerized maltene emulsion, and liquid mixture of agricultural oil containing SBS polymer exhibited significantly lower absorption rates meaning that they are effective in preventing water penetration into longitudinal joints (Huang et al., 2010).

While these several states show experience with a variety of joint sealers and adhesives, the specific materials and application rates used to treat longitudinal joints in Indiana has not been investigated.

3. EXPERIMENTAL METHODS

3.1 Laboratory Specimens

A quantity of field produced 9.5 mm asphalt mixture meeting applicable INDOT specifications was obtained with assistance from INDOT. The mixture was used to prepare several 150 mm (6 in) diameter Superpave Gyratory Compactor (SGC) specimens in accordance with American Association of State Highway and Transportation Officials (AASHTO) T312, "Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor." The specimens were then cored and cut to obtain fifteen, 100 mm (4 in) diameter by 38 mm (1.5 in) tall specimens with air voids contents of 7 $\pm$ 1%. This range was selected because it contains the critical air void content corresponding to permeable asphalt mixtures (del Pilar Vivar & Haddock, 2006).

Figure 3.1 Permeability testing apparatus.

3.1.1 Permeability Testing

The initial permeability of each of the fifteen specimens was determined in accordance with FM5-565, "Florida Test Method for Measurement of Water Permeability of Compacted Asphalt Paving Mixtures." This process involved soaking the specimen, applying a thin layer of petroleum jelly to the specimen sides, placing the specimen in the testing apparatus shown in Figure 3.1, pressurizing the specimen, filling the graduated cylinder with water, and measuring the head loss corresponding to a specified time or measuring the time corresponding to a specified head loss.

The permeability of each specimen was calculated using Equation 3.1.

$$k = \frac{aL'}{At}\ln\left(\frac{h_1}{h_2}\right) * t_c \qquad (3.1)$$

where:

k = coefficient of permeability (cm/s),
a = inside cross-sectional area of the buret (cm^2),
L = average thickness of the test specimen (cm),
A = average cross-sectional area of the test specimen (cm^2),
t = elapsed time between h_1 and h_2 (s),
h_1 = initial head across the test specimen (cm),
h_2 = final head across the test specimen (cm),
t_c = temperature correction for viscosity of water (reference table provided in FM5-565)

Following initial permeability testing, the fifteen specimens were divided into three groups of five such that each group had the same average air voids content and as

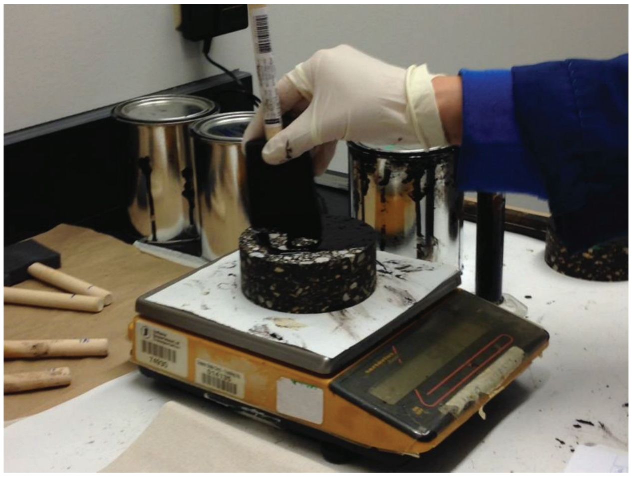

Figure 3.2 Fog seal application.

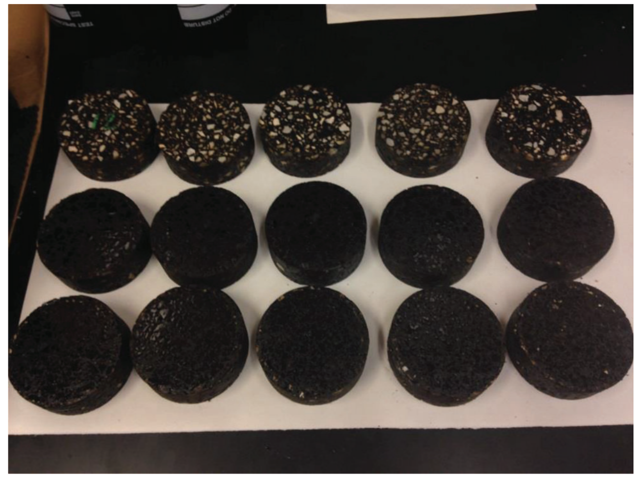

Figure 3.3 Asphalt mixture specimens after first conditioning treatment.

similar standard deviations as possible. Additionally, the groups were selected such that the average permeability and standard deviations were as similar as possible.

3.1.2 Fog Seal Application

The first group of five specimens was the control group and did not receive a fog seal application. The second group of five specimens received an SS-1h fog seal application, at a rate of 0.13 L/m^2 (0.03 gal/yd^2) and the third group of five specimens received an AE-NT trackless tack as a fog seal at an application rate of 0.13 L/m^2 (0.03 gal/yd^2).

For an application rate of 0.13 L/m2 (0.03 gal/yd^2) the appropriate mass of SS-1h and AE-NT for 100 mm (4 in) diameter specimens were determined and applied evenly with a foam brush over the specimen surface, as shown in Figure 3.2, to achieve the desired application rate. The specimens were allowed to sit at room temperature for a minimum of 24 hours to allow the emulsion to cure fully. Permeability testing was then repeated.

3.1.3 Specimen Conditioning

After fog sealing and the second permeability test, all fifteen specimens were subjected to long-term mixture conditioning for 5 days at 85°C (185°F) in accordance with AASHTO R30, "Mixture Conditioning of Hot Mix Asphalt (HMA)," which simulates the aging that occurs over the service life of a pavement. It is estimated that this long-term conditioning treatment simulates 5 to 7 years of asphalt aging that occurs in the field (Singh, Zaman, & Commuri, 2011).

After allowing the specimens to cool, they were again tested for permeability, as previously described. A second long-term conditioning treatment was then performed and a final permeability test was performed. Figure 3.3 shows the specimens after the first conditioning treatment with the top row being the untreated specimens, the middle row being the SS-1h fog sealed specimens, and the bottom row being the AE-NT tack fog sealed specimens.

3.1.4 Statistical Analysis

After all laboratory testing was complete, the average permeability and standard deviation was calculated for each treatment group (no treatment, SS-1h, and AE-NT) and each asphalt mixture condition (initial, after treatment, after the first conditioning treatment, and after the second conditioning treatment).

A two-way analysis of variance (ANOVA) was performed to determine if significant differences existed between the three treatment types, between the asphalt mixture conditions, and if there were significant interactions between the treatment types and mixture conditions. In this research, the *p*-values determined in the ANOVA were compared to the standard p-value of 0.05, meaning that *p*-values greater than 0.05 indicated that insufficient evidence existed to detect a significant difference between the variables, while *p*-values less than or equal to 0.05 indicated a significant difference.

3.2 Field Samples

Two abutting test sections were constructed on SR 26 near Portland, Indiana. One test section had the typical Indiana standard of an SS-1h fog seal emulsion applied in a 0.6 m (2 ft) wide band centered on the longitudinal joint after both lanes of asphalt surface mixture were placed. The second test section had a VRAM product applied in a 0.46 m (1.5 ft) wide band centered on the longitudinal joint before both lanes of asphalt surface mixture were placed. Figure 3.4 shows the VRAM application.

Within two weeks of construction, thirty 150 mm (6 in) cores were taken from the longitudinal joint (fifteen cores for each test section). The cores were taken in six groups (three for each test section) of five with the cores in each group taken at a 0.6 m (1 ft) spacing. The core samples were then transported to the laboratory for testing. Photographs of the top and sides of the cores are shown in the Appendix.

Figure 3.4 VRAM application on SR 26 in Indiana.

The asphalt pavement surface mixture for both test sections was 32 mm (1.25 in) thick. Therefore, to evaluate the effect of the two treatments on air voids and permeability in the surface mixture (the fog seal permeating the surface mixture from the top down and the VRAM migrating into the surface mixture from the bottom up), the top 32 mm (1.25 in) was saw cut from each core. The bulk specific gravity of the cut samples were determined in accordance with AASHTO T166, "Bulk Specific Gravity (G_{mb}) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens." During coring and transport to the laboratory, some of the core samples were deformed such that they were not compatible with the permeameter. Therefore, two of the deformed samples from each test section were used to determine the maximum specific gravity of the mixtures in accordance with AASHTO T209, "Theoretical Maximum Specific Gravity (G_{mm}) and Density of Hot Mix Asphalt (HMA)." The resulting data were used to calculate the air voids corresponding to each un-deformed surface mixture core.

3.2.1 Permeability Testing

The permeability coefficient for each of the un-deformed core samples was determined in accordance with FM5-565, "Florida Test Method for Measurement of Water Permeability of Compacted Asphalt Paving Mixtures" as previously described.

3.2.2 Statistical Analysis

After the permeability testing of the field core samples was complete, basic statistics were calculated for both the SS-1h and VRAM samples including the average and standard deviation of both air voids and permeability.

To compare these two treatments, statistical *t*-tests were performed. The null hypothesis was that the average air voids, or permeability, of the SS-1h and VRAM groups were equal. The alternative hypothesis was that the average air voids, or permeability, of the two treatment groups were not equal. For this research, a statistical significance value of 0.05, which corresponds to 95% confidence, was used.

4. RESULTS

4.1 Laboratory Specimens

Table 4.1 presents the division of the 15 test specimens into three groups directly following the initial permeability test. Note that while a treatment is listed in the left column, no treatment had yet taken place at the time of grouping. The treatment column simply indicates the treatment group to which the set of samples was assigned. Regarding air voids, each treatment group had the same average air voids content and similar standard deviations. In terms of permeability, the average and standard deviations for each treatment group were as similar as possible, which provided for comparison between groups following the fog seal treatments and asphalt mixture conditioning. All of the initial permeability coefficients were well below the common accepted critical value of 150×10^{-5} cm/s (59×10^{-5} in/s). This result is logical considering the average air voids were also below the critical value of 8%.

The coefficient of permeability was determined for each specimen initially, after treatment, and after both conditioning treatments. These values, as well as the averages for each treatment and condition group are listed in Table 4.2. As evidenced in Figures 4.1 and 4.2, there was a reduction in permeability associated with the application of both the SS-1h and AE-NT emulsion treatments. Specifically, the SS-1h and AE-NT treatments exhibited an immediate average reduction in permeability of 24 and 63%, respectively.

After mixture conditioning, all three treatment types showed an increase in permeability, with the untreated samples showing a larger increase in permeability than the treated samples. For all three treatment groups, the permeability measurements were quite similar after the first and second conditioning treatments. Additionally, the permeability of the emulsion treated specimens after both conditioning treatments were comparable to the initial permeability of the specimens.

The ANOVA indicated that treatment type was a statistically significant independent variable with a *p*-value of 0.002. The asphalt condition was also a statistically significant independent variable with a *p*-value of 0.005. However, the interaction between the two independent variables (treatment type and asphalt condition) was

TABLE 4.1
Specimen Treatment Groups

Treatment	Sample	Air Voids (%)	Permeability Coefficient, k (10^{-5} cm/s)
No Treatment	1	7.0	14.3
	2	7.2	19.0
	3	6.7	12.9
	4	7.8	22.9
	5	6.3	10.5
	Average	7.0	15.9
	Std Dev	0.6	5.0
SS-1h	6	6.3	10.8
	7	7.2	7.2
	8	6.8	15.0
	9	7.5	17.2
	10	7.0	25.6
	Average	7.0	15.2
	Std Dev	0.5	7.0
AE-NT	11	6.1	11.1
	12	6.9	20.9
	13	7.3	16.1
	14	7.6	5.7
	15	7.3	25.8
	Average	7.0	15.9
	Std Dev	0.6	7.9
Average		7.0	15.7
Std Dev		0.5	6.3

not statistically significant with a p-value of 0.441. While these p-values indicate generally that the two independent variables were statistically significant, Tables 4.3 and 4.4 show the pairwise comparison results of the ANOVA, which breaks down each relationship between treatment types and asphalt mixture conditions, respectively.

As evidenced by the low p-values of 0.19 and 0.002, the two fog seal treatment types (SS-1h and AE-NT) were statistically different from the control group. However, the high p-value of 1.000 evidences the lack of statistical difference between the two treatment types. This means that the presence of the fog seal does improve the performance of the asphalt mixture in terms of permeability, but a preferred treatment type is not identified. Increasing the number of samples may provide sufficient statistical power to differentiate between the two treatments, but the current results indicate no significant difference.

With respect to the asphalt mixture condition, the only significant differences in permeability were between the specimens after fog seal treatment with the specimens after both conditioning treatments. The p-values associated with the specimens after fog seal treatment with the samples after the first and second conditioning treatments were 0.019 and 0.008, respectively. This means that the fog seal treatment loses its effect as the asphalt mixture conditions.

Although the p-value comparing the initial permeability with the permeability after fog seal treatment was not significant, the pairwise comparison of treatment type indicated that there was a statistical difference

TABLE 4.2
Permeability of Laboratory Specimens

Treatment	Sample	Permeability Coefficient, k (10^{-5} cm/s) Initial	After Treatment	After Conditioning 1	After Conditioning 2
No Treatment	1	14.3	14.3	26.5	19.1
	2	19.0	19.0	22.2	27.9
	3	12.9	12.9	25.2	22.3
	4	22.9	22.9	40.5	36.7
	5	10.5	10.5	14.8	20.9
	Average	15.9	15.9	25.8	25.4
	Std Dev	5.0	5.0	9.3	7.1
SS-1h	6	10.8	9.5	10.2	12.4
	7	7.2	7.0	12.9	15.6
	8	15.0	11.8	19.5	18.0
	9	17.2	15.5	14.0	15.8
	10	25.6	13.5	22.5	20.1
	Average	15.2	11.5	15.8	16.4
	Std Dev	7.0	3.3	5.0	2.9
AE-NT	11	11.1	4.0	6.3	10.0
	12	20.9	12.1	9.0	15.2
	13	16.1	3.4	14.1	16.3
	14	5.7	1.8	11.4	9.3
	15	25.8	8.0	30.8	32.0
	Average	15.9	5.8	14.3	16.6
	Std Dev	7.9	4.2	9.7	9.2

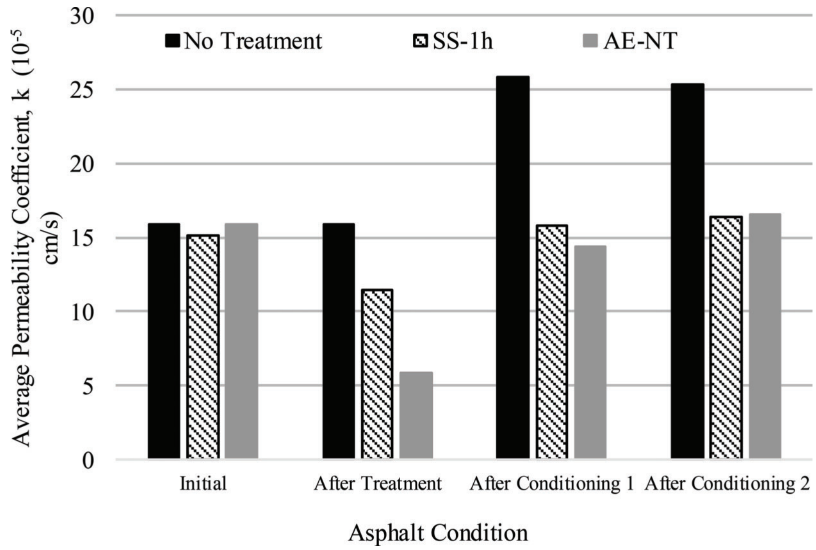

Figure 4.1 Laboratory specimen average permeability.

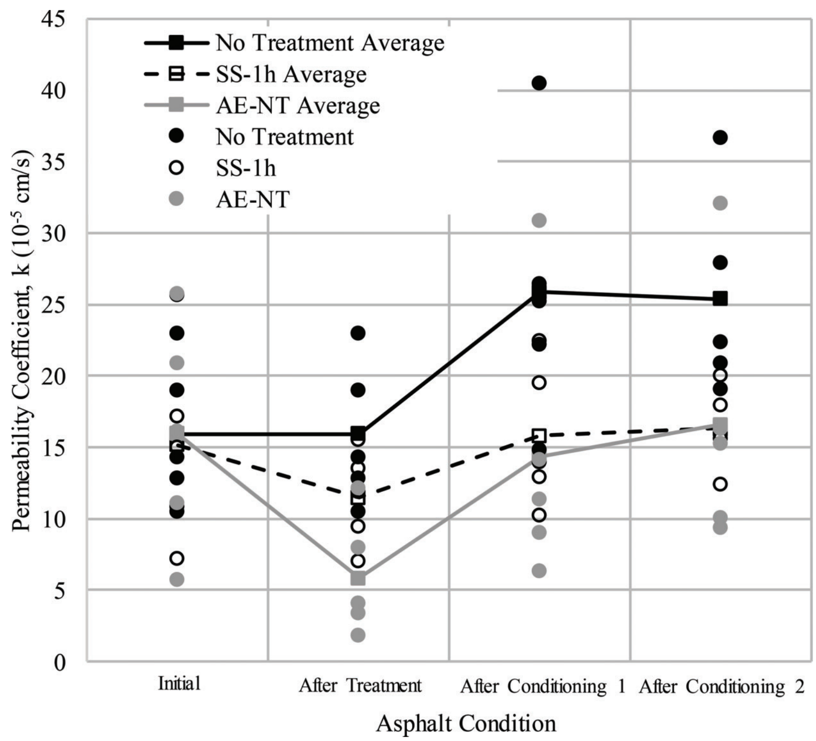

Figure 4.2 Laboratory specimen permeability distribution.

between the specimens that received an emulsion treatment and those that did not. The fact that the initial permeability is not statistically different from the permeability after fog seal treatment can be attributed to the control specimens having the same initial and after fog seal treatment permeabilities.

4.2 Field Samples

During construction, the VRAM migration was observed to be only about 13 mm (0.5 in). For a surface mixture that is 32 mm (1.25 in) thick, this represents less than 50% migration, which is less than the desired 50–75% migration (Asphalt Materials, Inc., n.d.). However, during construction the contractor noted the presence of a desirable soft spongy characteristic in the VRAM.

Table 4.5 presents the air voids and permeability for the two joint sealant treatments evaluated. The SS-1h fog seal treated samples had an average air voids content of 11% while the VRAM treated samples had an average air voids content of 13%. Both sets of samples had standard deviations around 0.9%. While the average

TABLE 4.3
Fog Seal Treatment Type Pairwise Comparison

Treatment Comparison		*p*-value
No Treatment	SS-1h	0.019
	AE-NT	0.002
SS-1h	No Treatment	0.019
	AE-NT	1.000
AE-NT	No Treatment	0.002
	SS-1h	1.000

TABLE 4.4
Asphalt Condition Pairwise Comparison

Asphalt Mixture Condition		*p*-value
Initial	After Treatment	0.400
	After Conditioning 1	1.000
	After Conditioning 2	0.775
After Treatment	Initial	0.400
	After Conditioning 1	0.019
	After Conditioning 2	0.008
After Conditioning 1	Initial	1.000
	After Treatment	0.019
	After Conditioning 2	1.000
After Conditioning 2	Initial	0.775
	After Treatment	0.008
	After Conditioning 1	1.000

TABLE 4.5
Permeability of Field Samples

Treatment	Sample	Air Voids (%)	Permeability Coefficient, k (10^{-5} cm/s)
SS-1h Fog Seal	1-1-1	10.7	179.0
	1-1-2	10.1	145.8
	1-1-3	10.0	177.7
	1-1-4	10.6	292.0
	1-1-5	9.8	125.0
	1-2-4	12.2	381.3
	1-2-5	12.0	383.9
	1-3-1	11.2	197.5
	1-3-2	11.1	120.3
	1-3-3	11.4	103.0
	1-3-4	12.2	243.1
	Average	11.0	213.5
	St Dev	0.9	100.2
VRAM	3-1-1	12.4	496.8
	3-1-3	11.1	483.6
	3-1-5	12.1	522.2
	3-2-1	13.4	736.4
	3-2-2	14.1	266.8
	3-2-3	13.5	394.7
	3-2-4	13.2	897.3
	3-3-1	13.2	651.8
	3-3-3	14.1	831.4
	3-3-4	13.1	431.2
	Average	13.0	571.2
	St Dev	0.9	201.9

permeability of the VRAM samples was about 2.5 times larger than the average of the SS-1h samples, all the permeability coefficients for both test sections were higher than the generally accepted critical permeability of 150×10^{-5} cm/s (59×10^{-5} in/s). This result is logical considering the average air voids were also above the critical value of 8%.

According to previous research presented in Figure 2.1 (del Pilar Vivar & Haddock, 2006), untreated samples with air void contents greater than 10% would be expected to exhibit permeabilities greater than 850×10^{-5} cm/s (335×10^{-5} in/s). However, both the SS-1h and VRAM samples were below this upper limit despite their high air void contents. Using the relationship presented in Figure 2.1, the SS-1h fog seal treated samples, which had an average permeability of 210×10^{-5} cm/s (83×10^{-5} in/s), had an average effective air void content of just over 8%, despite having an actual average air void content of 11%. Similarly, the VRAM samples, which had an average permeability of 571×10^{-5} cm/s (225×10^{-5} in/s), had an average effective air void content of just over 9%, despite having an actual average air void content of 13%. Therefore, both treatments were effective in reducing the permeability of the asphalt mixtures.

The distribution of the field sample air voids and permeability are shown graphically in Figures 4.3 and 4.4, respectively. In these figures, the higher air voids and permeability of the VRAM samples is visually apparent. Both of the *t*-tests comparing the air voids and permeability of the two joint sealant groups resulted in highly significant *p*-values of less than 0.001. This means that that both the air voids content and the permeability of the two treatment methods was significantly different. The average difference between the air voids was 2.0% while the average difference in permeability was 358×10^{-5} cm/s (141×10^{-5} in/s). This difference may be attributed to the contractor's observation that the VRAM did not migrate as much as anticipated. Additionally, the fog seal treatment had the advantage of gravity aiding the downward penetration of the emulsion, while the VRAM did not.

Considering the ranges of air voids and permeability coefficients represented by the two joint sealants, the relationship between air voids and permeability is shown in Figure 4.5. The data support the anticipated relationship between air voids content and permeability: as the air voids content increases the permeability also increases. The data also shows the variability of the observed permeability coefficients increasing as the air voids contents increase.

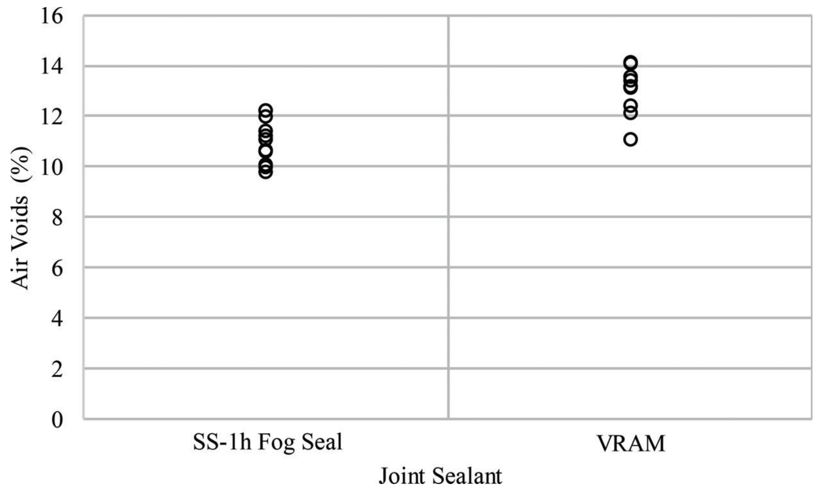

Figure 4.3 Field sample air voids.

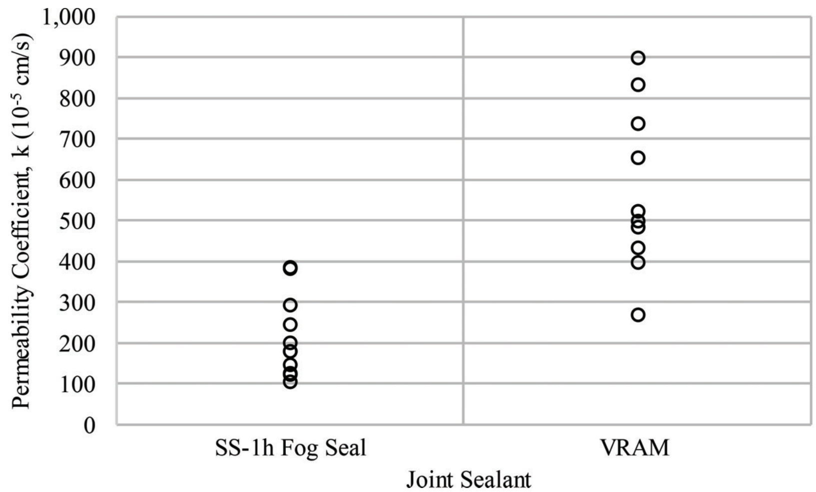

Figure 4.4 Field sample permeability.

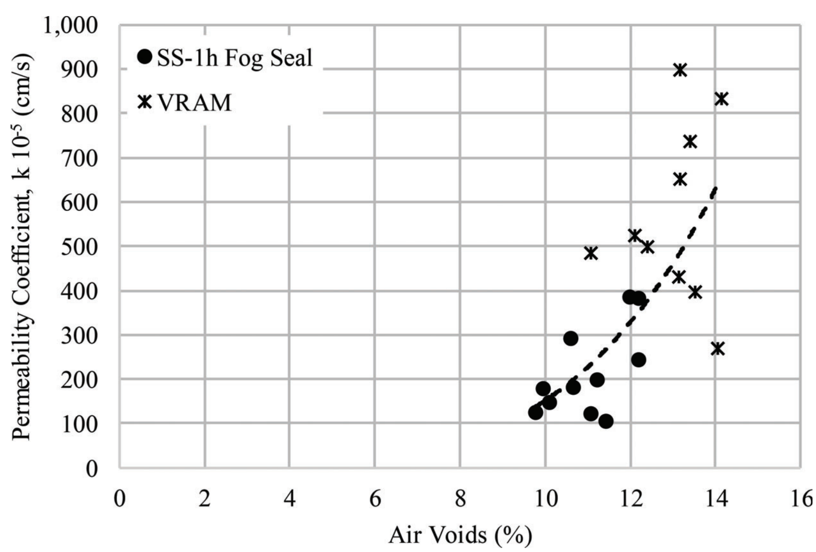

Figure 4.5 Permeability as a function of air voids.

5. CONCLUSION AND RECOMMENDATIONS

Due to the nature of construction, it is common for longitudinal joints in asphalt pavements to have lower density and higher permeability than the main paving lanes. To address this concern, in 2012 INDOT began requiring the fog sealing of longitudinal joints on newly constructed or overlaid asphalt pavement surface mixtures.

While several states have experience with a variety of joint sealers and adhesives, and qualitative evidence appears to indicate that the lives of the longitudinal joints have been improved by the use of joint sealers and adhesives, the specific materials and application rates used to fog seal longitudinal joints in Indiana has not been investigated. This research was designed to specifically investigate the fog seal materials and application rates specified for use on longitudinal joints in Indiana and to compare the performance of fog seal and VRAM treatments in order to provide guidelines for future joint sealant treatments in Indiana. This was accomplished by employing laboratory testing of both laboratory prepared specimens and field extracted samples from newly constructed pavement sections.

The research found that application of fog seals can improve the performance of the longitudinal joints with respect to permeability. The laboratory samples receiving SS-1h and AE-NT treatments exhibited an immediate average reduction in permeability of 24 and 63%, respectively. The use of these treatments kept the permeabilities after conditioning comparable to the initial permeabilities of the specimens.

The statistical analyses performed on the data collected from the laboratory prepared specimens indicated that there was a significant difference between the specimens that received a fog seal treatment and those that did not receive a fog seal treatment. However, there was not a statistically significant difference between the two fog seal materials. This indicates that the permeability was affected by the presence of a fog seal treatment, but was irrespective of the specific material type. Therefore, a fog seal emulsion is recommended for application on longitudinal joints, and either material, SS-1h or AE-NT, is acceptable.

The fog seal treatments did affect the performance of the samples with respect to permeability as the specimens were conditioned. However, the lack of a statistically significant differences between the specimens after the first and second conditioning treatments indicates the benefits of the fog seal treatment was no longer in effect by the second conditioning treatment. Since it is estimated that long-term laboratory oven conditioning simulates intervals of 5 to 7 years of in-service asphalt aging, it is recommended that fog seal applications be reapplied at 5 to 7 years. Additional field and laboratory research is recommended to verify and support this recommendation.

The results of the statistical analyses performed on data collected from field samples, which were taken shortly after construction, indicated there was a statistically significant difference between the air voids contents for the SS-1h fog seal treated samples and the VRAM treated samples. There was also a statistically significant difference between the permeability coefficients for the two sample groups (SS-1h and VRAM). The VRAM samples had on average an air voids content that was 2.0% higher than the SS-1h samples. This difference may be attributed to the contractor's observation that the VRAM did not migrate as much as was anticipated. While the SS-1h fog seal treatment appears to have better performance than the VRAM, the effectiveness of these two treatments over time is not known. Taking additional cores from the same test sections over time and performing additional laboratory permeability testing is recommended to further compare and understand the performance of the SS-1h fog seal and VRAM treatments over time.

While the results and recommendations presented here are specific to the asphalt material and joint sealant materials and application rates used in this research, they can be applied generally to other asphalt pavements as well. However, additional research is recommended to provide greater quantitative support and guidelines for fog seal implementation. Specifically, additional testing of asphalt specimens exhibiting a wider range of air void contents and permeabilities would enhance the understanding of fog seal performance. A comparison of SS-1h and AE-NT field test sections would provide additional support and verification of the conclusions and recommendations presented in this research. Additional testing of the SS-1h and VRAM test sections over time would also provide greater insight into the performance of these joint sealant treatment methods.

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APPENDIX: FIELD SAMPLE PHOTOGRAPHS

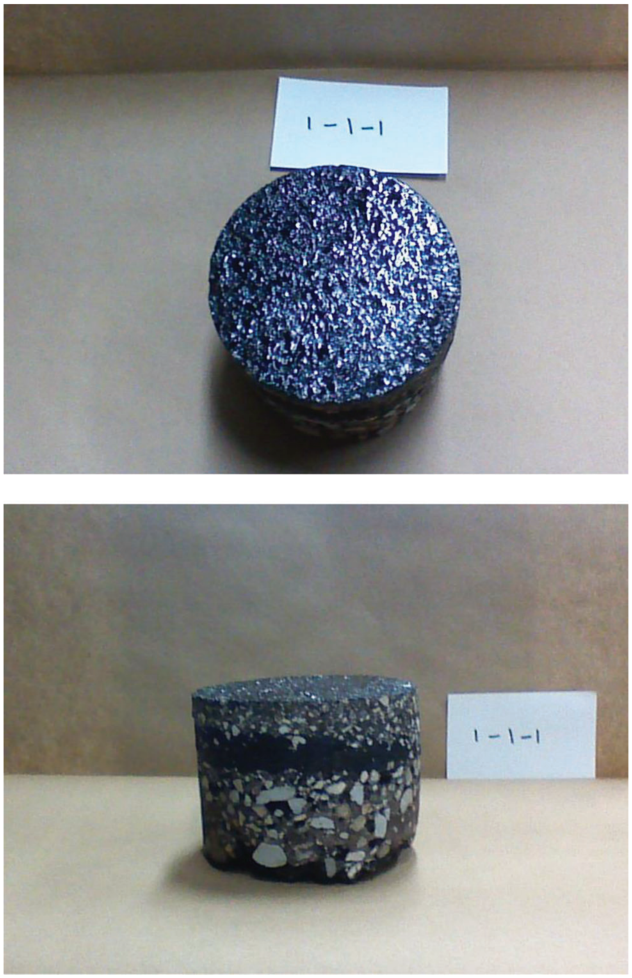

Figure A.1 Field Sample 1-1-1.

Figure A.2 Field Sample 1-1-2.

Figure A.3 Field Sample 1-1-3.

Figure A.4 Field Sample 1-1-4.

Figure A.5 Field Sample 1-1-5.

Figure A.6 Field Sample 1-2-1 *deformed.

Figure A.7 Field Sample 1-2-2 *deformed.

Figure A.8 Field Sample 1-2-3 *deformed.

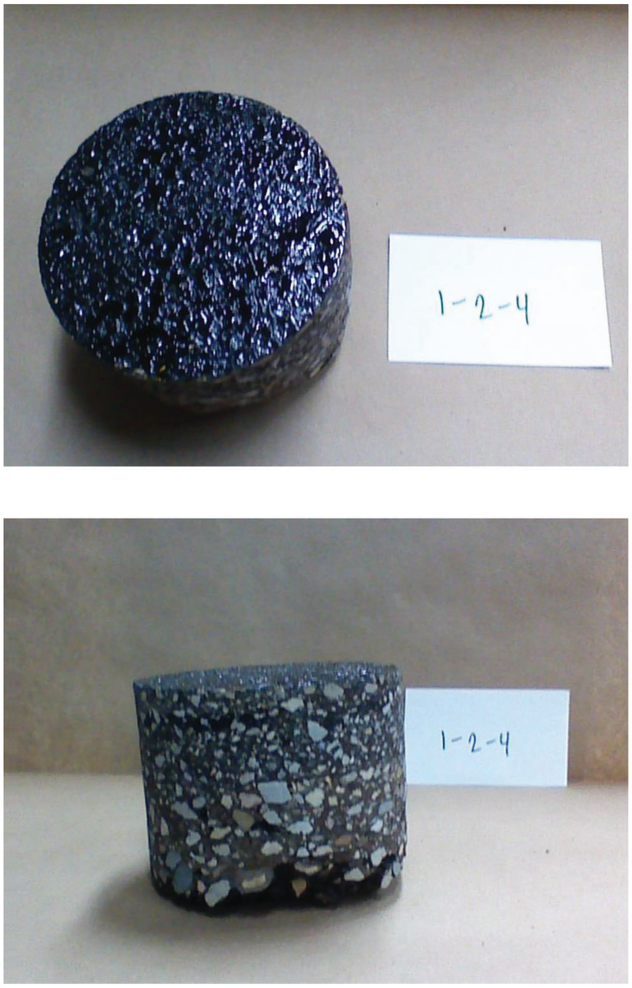

Figure A.9 Field Sample 1-2-4.

Figure A.10 Field Sample 1-2-5.

Figure A.11 Field Sample 1-3-1.

Figure A.12 Field Sample 1-3-2.

Figure A.13 Field Sample 1-3-3.

Figure A.14 Field Sample 1-3-4.

Figure A.15 Field Sample 1-3-5 *deformed.

Figure A.16 Field Sample 3-1-1.

Figure A.17 Field Sample 3-1-2 *deformed.

Figure A.18 Field Sample 3-1-3 *deformed.

Figure A.19 Field Sample 3-1-4.

Figure A.20 Field Sample 3-1-5.

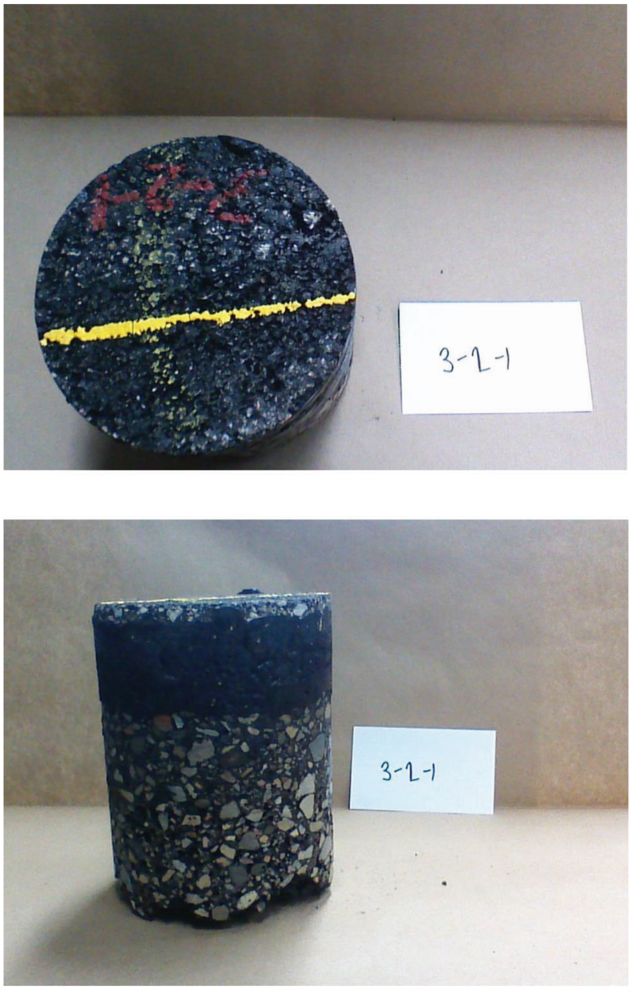

Figure A.21 Field Sample 3-2-1.

Figure A.22 Field Sample 3-2-2.

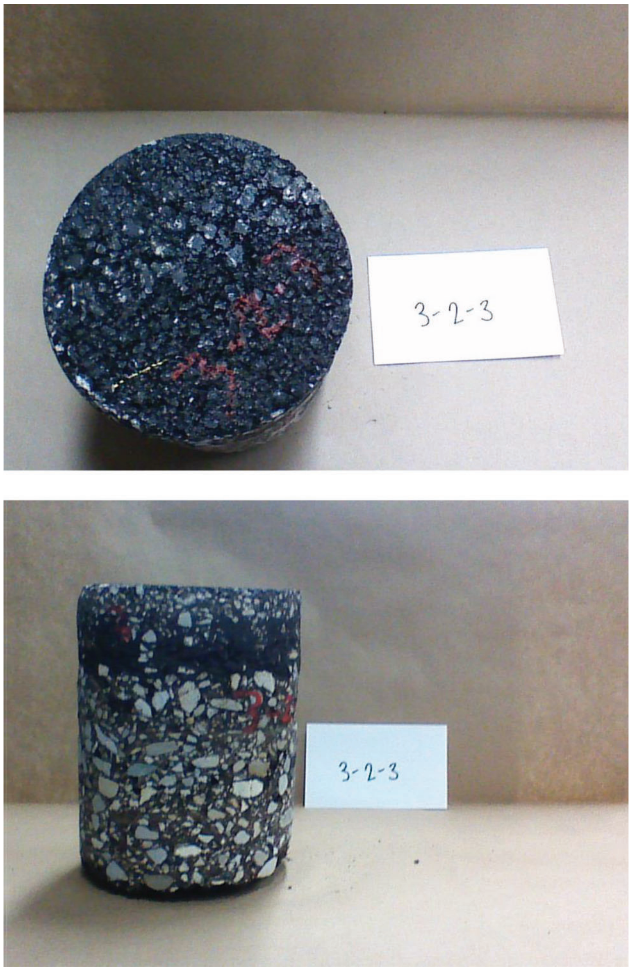

Figure A.23 Field Sample 3-2-3.

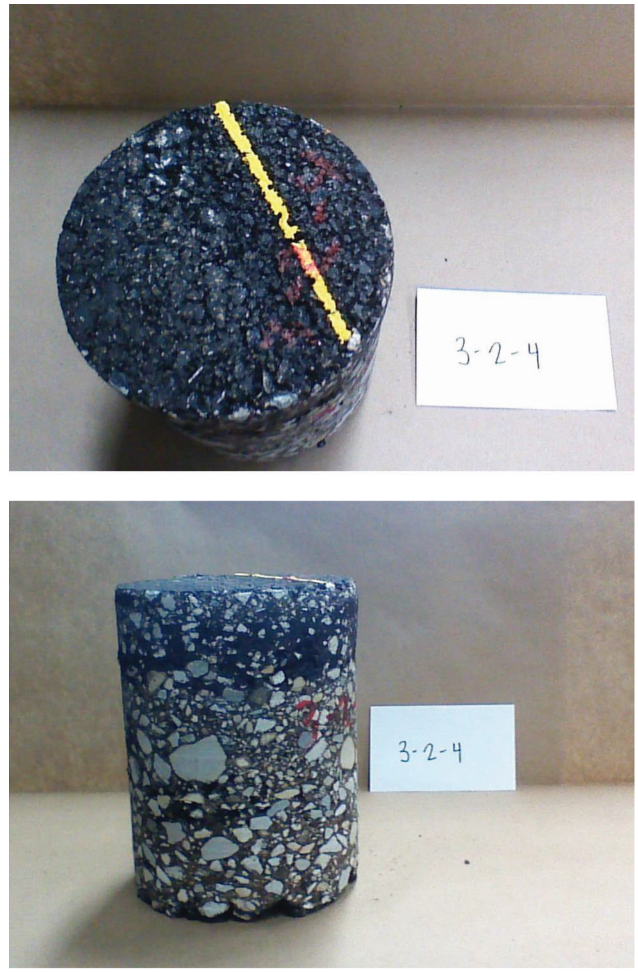

Figure A.24 Field Sample 3-2-4.

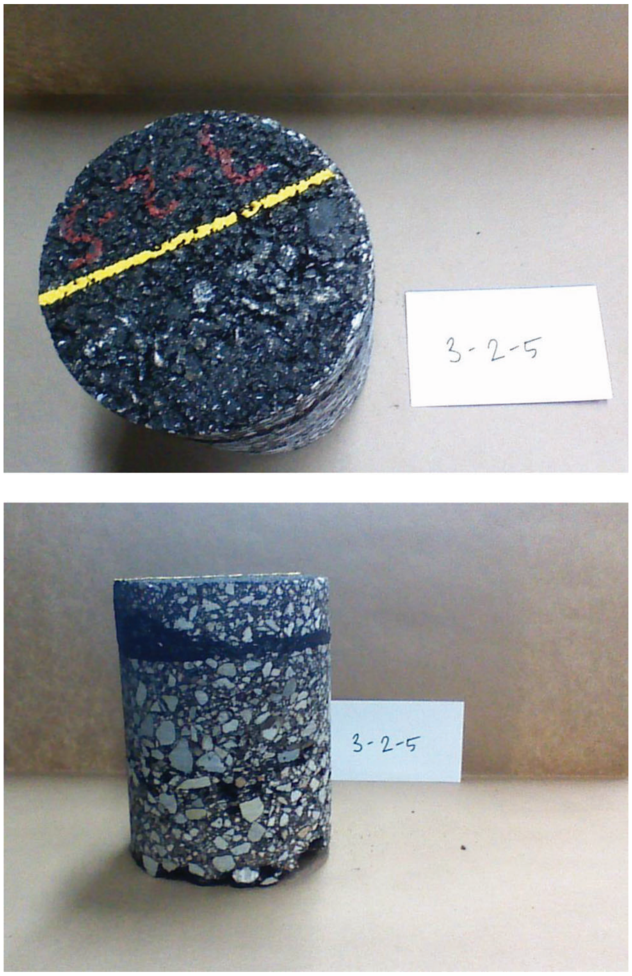

Figure A.25 Field Sample 3-2-5.

Figure A.26 Field Sample 3-3-1.

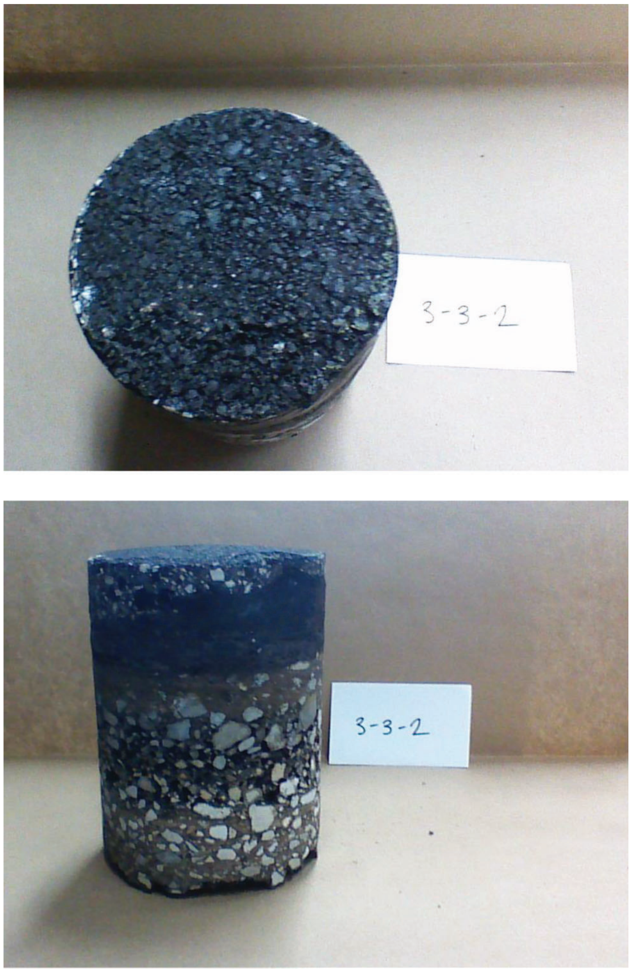

Figure A.27 Field Sample 3-3-2 *deformed.

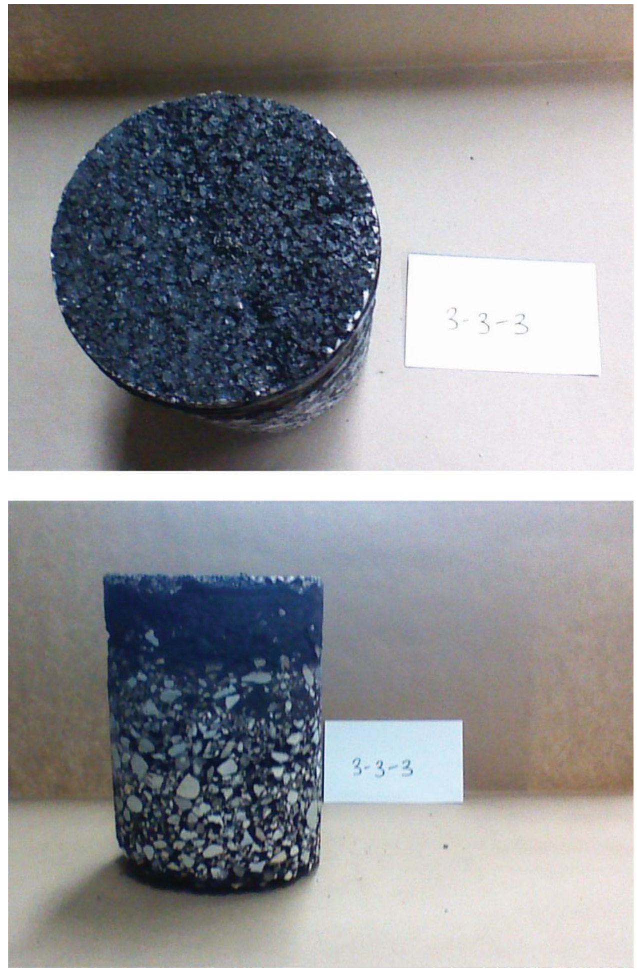

Figure A.28 Field Sample 3-3-3.

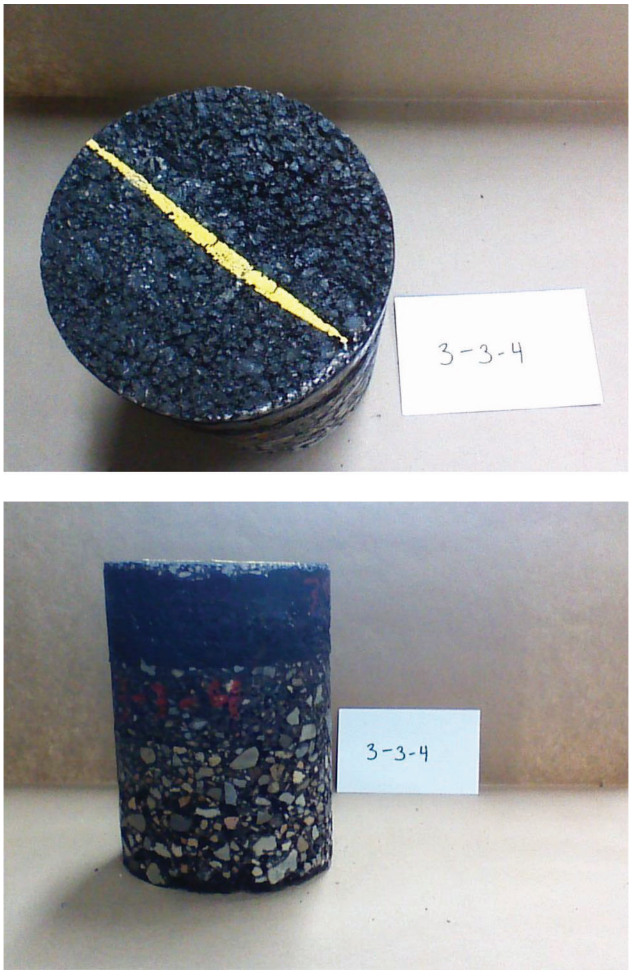

Figure A.29 Field Sample 3-3-4.

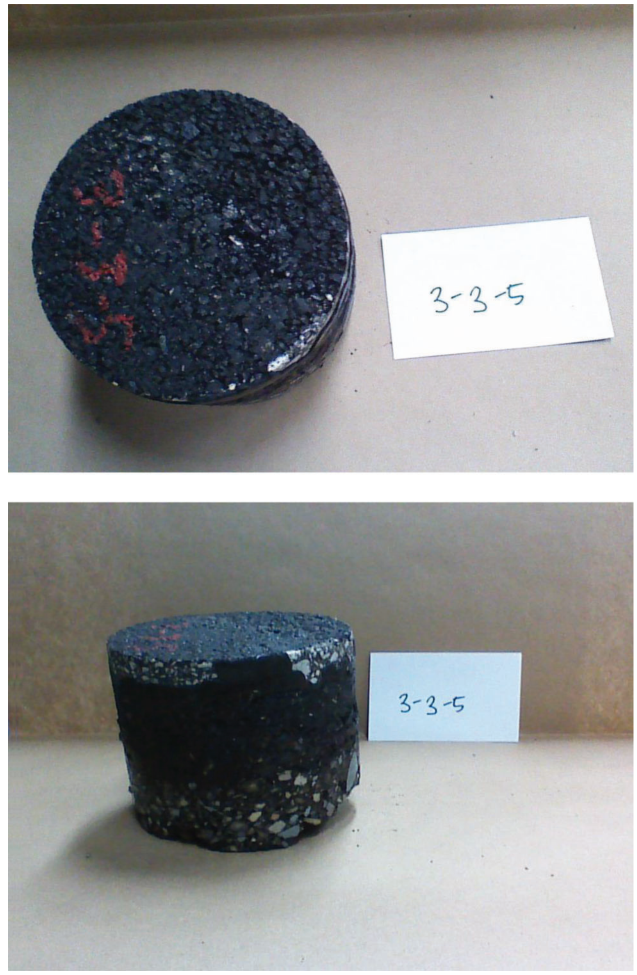

Figure A.30 Field Sample 3-3-5.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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