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Development of a Performance-Related Test for Designing Seal Coats

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TxDOT's seal coat program is critical to preserving its existing roadway infrastructure and ensuring roadways retain adequate skid resistance. However, sometimes seal coats fail prematurely due to factors such as incompatibility between aggregate and binder and/or binder that has poor durability while meeting other specification requirements. Seal coat design methods focus on the application rates and volumetric approaches to ensure that they are optimal. However, these methods typically do not address the compatibility of and adhesion between binder and aggregate. The overall goal of this project was to identify and develop a laboratory test(s) that can be used to evaluate the expected binder-aggregate adhesion performance and as a screening tool for any seal coat project based on its specific materials (aggregate and asphalt binder or emulsion). The study used modifications of a Sweep Test and Vialit Test to measure seal coat aggregate adhesion and performed these tests in multiple experiments to investigate the effects of binder type, dust, certain types of binder modifiers, and liquid antistrip agents on adhesion characteristics using four different aggregates mineralogies. The lab testing program and a field section evaluation indicated that the Sweep Test best evaluates the binder-aggregate adhesion. The testing also lead to recommended limits for aggregate loss.</td></tr>
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ABSTRACT

TxDOT's seal coat program is critical to preserve its existing roadway infrastructure and ensure roadways retain adequate skid resistance. However, sometimes seal coats fail prematurely either due to factors such as incompatibility between aggregate and binder and/or binder that has poor durability while meeting other specification requirements. Seal coat design methods focus on the application rates and volumetric approaches to ensure that the application rate is optimal. However, these methods typically do not address the compatibility and adhesion of between binder and aggregate. The overall goal of this project is to identify and develop a laboratory test(s) that can be used to evaluate the expected performance in terms of binder-aggregate adhesion and used as a screening tool for any given seal coat project using materials (aggregate and asphalt binder or emulsion) from that specific project. The study used modifications of a Sweep Test and Vialit Test to measure seal coat aggregate adhesion and performed these tests in multiple experiments to investigate the effects of binder type, dust, certain types of binder modifiers, and liquid antistrip agents on adhesion characteristics using four different aggregates mineralogies. The lab testing program and a field section evaluation indicated that the Sweep Test best evaluates the binder-aggregate adhesion. A limit for aggregate loss from this testing is recommended.

EXECUTIVE SUMMARY

TxDOT's seal coat program is critical to preserve its existing roadway infrastructure and ensuring roadways retain adequate skid resistance. However, sometimes seal coats fail prematurely either due to factors such as incompatibility between aggregate and binder and/or binder that has poor durability while meeting other specification requirements. The overall goal of this project is to identify and develop a laboratory test(s) that can be used to evaluate the expected performance in terms of binder-aggregate adhesion and used as a screening tool for any given seal coat project using materials (aggregate and asphalt binder or emulsion) from that specific project.

Summary

A summary of the complete study is outlined by the following.

Literature Review and Survey

In this project, a survey of TxDOT districts and other DOTs was conducted. The results from the survey are summarized below.

- Seal coats are a mainstay for pavement maintenance.
- TxDOT and many other DOTs use seal coats as a tool to maintain their roadway network.
- TxDOT is unique in that it is one of only a few that construct a majority of seal coats with hot applied binders. Many other DOTs use only asphalt emulsions.
- Many TxDOT districts and other DOTs mainly use historical knowledge in setting asphalt and aggregate rates and a minority stated they use a seal coat design process.
- The survey informed some of the decisions in this study, particularly on materials to be included in a number of experiments. The survey results are in Appendix A.

A review of literature was conducted and the key relevant findings were as follows.

- Most design methods related to seal coats focus on the application rates and volumetric approaches to ensure the optimal application rate. These methods implicitly assume that the aggregate-binder adhesion is durable and will last the intended service life of the seal coat.

- The literature review also identified a few test methods that can potentially be used for this purpose.

Method Development and Establishment of Test Protocols

Candidate test methods to measure adhesion compatibility were evaluated. The candidate tests included the Sweep test (with different variations), Vialit test, Cantabro test, and a Pull-Off test. Based on the findings, the Sweep test and Vialit tests were considered as final candidates for further development and use with the remainder of the test matrix.

Material Selection

The materials selected for laboratory evaluation included a variety of combinations of binder (commercially available and synthesized), including hot applied asphalt cements and asphalt emulsions, and four aggregate mineralogies (limestone, sandstone, gravel, and rhyolite). Binders in particular were chosen based in information acquired from the survey of TxDOT Districts. Also, materials for evaluation of field sections were obtained from over 30 construction sites and were available for testing.

Results from Laboratory Tests

A set of experiments was conducted using the Sweep and Vialit tests using several combinations of base binders and aggregate types. For hot applied binders, all aggregates were precoated, and for emulsified asphalt all aggregates were uncoated, as they would be in the field. The experiments were developed to address the impact to Vialit and Sweep testing adhesion results from:

- Binder and aggregate type
- Dust
- Recycled Engine Oil Bottoms (REOB) and Polyphosphoric Acid (PPA)
- Liquid Antistrip Agent

Binder type and dust proved to have the most impact. Binder types showed that polymer modification improved adhesion. Some emulsions showed better aggregate retention than some hot applied binders. REOB, PPA, and Liquid Antistrip Agent had some minor impact.

Vialit testing (performed at low temperature) seemed to be indicative of low temperature binder performance. Sweep testing seemed to be more indicative of higher temperature performance of the binder-aggregate combination.

Results from Field Sections

For a number of TxDOT seal coat field test sections, texture measurements from 3-D laser or an imaging photogrammetry after construction and one to two years after construction were acquired, analyzed, and used to quantify the change (loss) of texture over time. Visual assessment and a 1 to 5 rating was made along with comments on the general condition of each section. In all measured sections, texture decreased substantially.

The visual assessment found that for most sections the reduction in texture was not due to aggregate loss, but to aggregate "punching-in" or embedment of the aggregate particles into the surface of the pavement. For many of the field test sections, binder and aggregate collected construction allowed laboratory testing of these materials with the Vialit and Sweep tests. Most sections showed less than 30% aggregate loss on both tests. Comparison of field and lab testing suggest a Sweep test loss criterion to be set at 25%.

Conclusions

This study supports the following conclusions:

- Vialit tests performed using both lab materials and field materials seem to be more variable and indicative of binder fracture than adhesion. This phenomenon might best be managed in a binder specification, especially one that contains low temperature testing, similar to the PG binder specification. The specification for AC-20-5TR, for instance, contains some of these tests.
- The Sweep test seems more indicative of early age aggregate loss, which is of immediate concern to TxDOT district personnel.
- Field evaluations indicate that aggregate "punch-in" to the pavement is more of a problem than aggregate loss.
- Sweep testing of materials obtained from field sections, where aggregate loss was not a significant problem (punch-in was the major problem) when informed by laboratory testing suggest a Sweep test loss criterion to be set at 25%.

Recommended Guidelines

Based on this study, it is recommended to:

- Include a Sweep test in the specification for seal coats as a check on the compatibility of the project material with a 25% loss of aggregate as the maximum allowed. This test could be performed by TxDOT, but a more efficient way may be to require the contractor to secure a commercial lab certified to perform this test.
- Vialit testing should be reserved for use in a forensic analysis and not implemented on a routine basis.

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CHAPTER 1. INTRODUCTION

1.1 PROBLEM STATEMENT

TxDOT's seal coat program is critical to preserve its existing roadway infrastructure and ensuring roadways retain adequate skid resistance. However, sometimes seal coats fail prematurely either due to incompatibility between aggregate and binder or to binder that has poor durability or adhesive characteristics while meeting specification requirements. The goal of this study is to identify or develop and validate a test method(s) to evaluate seal coat materials as system to avoid poor material combinations.

1.2 STUDY OBJECTIVES

Since the goal of this study is to identify test(s) that can be used to indicate and assure performance of seal coats, objectives of this study include:

- Conduct a literature review and survey TxDOT districts and other DOTs on the use, problems, and successes associated with seal coat application
- Identify and/or develop test methods for seal coat material compatibility and establish testing protocols,
- Conduct a preliminary validation of the method based on accuracy, sensitivity, and repeatability by conducting factorial tests,
- Validate the proposed method using field performance data using a unique approach to sampling field materials to ensure robust validation
- Propose a final test method(s) and acceptance criteria.

1.3 STRUCTURE OF THE REPORT

This report includes seven chapters to address the problem statement. Chapter 1 provides the problem statement and objectives. Chapter 2 presents a literature review and results of a survey of TxDOT Districts and other state DOT personnel. Chapter 3 identifies, develops, and selects test methods to evaluate the performance of seal coats. Chapter 4 identifies materials for a set of lab experiments and field sections for field evaluation and lab validation Chapter 5 presents results from the laboratory experiments. Chapter 6 presents the results of the field evaluation. Chapter 7 presents a summary of the work with proposed guidelines and acceptance criteria.

CHAPTER 2. LITERATURE REVIEW AND SURVEY

The main goal of this study was to identify, develop, and validate a method that can be used as a screening tool to detect potentially problematic material combinations. Specifically, such a method or tool would be used to evaluate aggregate-binder compatibility or seal coats as a system. This chapter presents a summary of findings from a literature review of past and recent studies on potential test methods that can be used to assess aggregate-binder compatibility as well as other studies that have investigated the influence of different material combinations on the performance and durability of seal coats. An appendix to this document provides a summary of findings from a survey disseminated to TxDOT districts and other State DOTs to include current practices and concerns related to this topic.

2.1 BACKGROUND AND SIGNIFICANCE

Effective pavement asset management includes a preventative maintenance program focused on applying the right treatment at the right time, often under budgetary constraints. This means that when treatments are selected for funding, design, and construction, decisions must be based on the best available information to ensure that the selected treatment and design results in the expected service life of the surface and pavement structure.

Seal coats are a type of preventive maintenance treatment that typically consist of a thin application of liquid asphalt or asphalt emulsion followed by a single layer of aggregate, which is pressed into the wet asphalt by pneumatic tire rollers to achieve aggregate embedment. Other variations of this basic process that involve the construction of one or two applications of asphalt and aggregate are also used but are not as common. Typically the initial application of asphalt is placed directly on the existing pavement surface. Seal coats help restore pavement friction, seal minor cracks, and can address other pavement surface conditions such as loss of aggregate, flushing, and bleeding (TxDOT, 2017).

As a part of this project, researchers conducted a recent survey of State DOTs and TxDOT Districts that shows a substantial use of seal coats as a preventive maintenance tool (See Appendix A.1). In Texas, based on responses of all 25 districts, the seal coat program is estimated to cost more than $300 million for 2020, covering more than 10,000 lane-miles. On a national level, based on the responses from 29 State DOTs, the total cost is estimated to be over $800 million distributed over 32,000 lane-miles. Clearly, these numbers would be much higher when extrapolated to include all states. Furthermore, these numbers do not include seal coats used by entities that are not state DOTs (e.g. city and other local governments) and typically use DOT standards for contracting and execution. It is possible that the annual volume of seal coats on non-state owned network is similar or even higher than the state owned networks. These large volumes for the use of seal coats as a surface treatment are due to their simplicity and low cost. Seal coats are also considered to be highly effective if proper care and guidance are taken during the planning and execution of the work.

2.2 OVERVIEW OF SEAL COAT DESIGN METHODS

Seal coats have been in use since the 1920s (Hinkle, 1928). Over almost a century, there have been several design methods developed for the construction of seal coats. Some of these methods are based on volumetric measurements whereas other methods also include laboratory tests to assess the expected performance of the seal coat. A review of these design methods with emphasis on the use of a performance based approach to evaluate the expected performance of a seal coat are described in the following subsections.

2.2.1 Hanson Design Method

Hanson (1934) developed one of the earliest known design method for seal coats. This method was designed originally for cutback liquid asphalt, and it is based on the average least dimension (ALD) parameter of the aggregate used in the mix. The ALD is calculated by using calipers on a representative sample from the aggregate source (at least 200 pieces or more) to obtain a value that represents the thickness of the aggregate layer in its rolled and compacted state. Hanson observed that when sufficient amount of aggregate are placed onto newly applied fresh asphalt binder or emulsion, the voids between the aggregate particles are approximately 50%, meaning 50% of the available aggregate voids are filled with the binder or emulsion. He proposed that when the layer is compacted, this value is reduced to 30%, and it is reduced further to 20% when the aggregate is compacted under traffic loading. Hanson specified that 60-75% of the voids between aggregates should be filled by residual binder, depending on the type of aggregate and traffic level. He also stated that after opening to traffic, due to the shape of the aggregate particles, aggregates tend to lay on their flattest side and therefore, ALD is approximately the average thickness of a single layer of aggregates after construction.

Although, traces of Hanson's method can be observed in all major seal coat designs, this is a volumetric based design method that does not necessarily evaluate the aggregate-binder interaction in the seal coat as a system. Simply put, this is a volumetric method that is focused on the application rate.

2.2.2 McLeod Design Method

After Hanson's work (1934) on asphalt seal coat, McLeod created a new design procedure for seal coats that was based on Hanson's study. McLeod's goal was to find aggregate and binder application rates that should be applied during construction while taking into account the in-situ pavement surface conditions (McLeod, 1969). McLeod used Hanson's theory and accepted that for optimal performance the inter-particle voids in loose condition should be 50%, which after rolling and trafficking reduced to approximately 30% and 20%, respectively. Voids between aggregates after a certain volume of traffic are 20%, which means that aggregates cover 80% of the seal coat surface. His method covered both single and multilayer surface treatments. He determined the aggregate application rate based on specific gravity, gradation, shape, a wastage factor, and binder application rate by considering the type of asphalt, the aggregate gradation, existing pavement condition, and traffic volume.

The equations used to determine the quantity of aggregate needed for a given surface treatment course are based on the assumption that 80% of the aggregate will ultimately be embedded into the pavement, the aggregate is single-sized (with a slight modification to the equation for graded aggregate), and that the aggregate will ultimately be arranged so that the thickness of the aggregate layer is equal to approximately the ALD of the aggregate source. The equation used to determine the quantity of asphalt emulsion is based on several assumptions. One assumption is that 20% of the total surface treatment will be comprised of asphalt (80% embedment of aggregate). Also, it is assumed that the aggregate is single-sized, as with the determination of the aggregate quantity (there is a modification to the equation for graded aggregate). The appropriate asphalt type and grade to be used depends on the aggregate size and surface temperature at the time of application and are determined by a chart developed by McLeod. Furthermore, McLeod introduced correction factors for the amount of binder lost through absorption of aggregates and the texture of existing pavement surface.

The Asphalt Emulsion Manufacturers Association (AEMA) and the Asphalt Institute (AI) have adopted variations of this method and made recommendations for choosing binder types and grades based on aggregate gradations. This method implicitly assumes that there are no issues with binder-aggregate adhesion and relies more heavily on volumetrics as a performance indicator.

2.2.3 Kearby's Design Method

One of the initial efforts in the United States to develop a seal coat mix design was made by Jerome P. Kearby (1953). He recognized that calculations for filling a specific percentage of the void between aggregates are not adequate to guarantee satisfactory results and there is a need for visual inspection in the field and use of judgment in choosing the application rate for materials. Kearby's work (1953) resulted in the development of a nomograph that provides binder application rates based on three variables: average size of aggregate, percent aggregate embedment, and percent voids between the aggregates. One of the drawbacks of Kearby's design method is that void percentage and percentage embedment depth range is limited. Further, the range of aggregate size varies between 1/8" and 1". Another drawback is that the influence of traffic and aggregate toughness are not included in the nomograph and as in the case of previous methods it is implicitly assumed that all aggregate-binder pairs have acceptable and level of adhesion.

2.2.4 Modified Kearby Method

An attempt to modify and improve on the Kearby Method was made by Epps and Gallaway (1974). They tried to change the Kearby design nomograph so that synthetic aggregates having high porosity could be used in the design. Based on the high porosity of synthetic aggregate, (Epps, J.A., and Gallaway, 1974) proposed a curve showing approximately 30% more embedment than the Benson-Gallaway curve (Benson, F.A., and Gallaway, 1953). The rationale for this increase is that high friction lightweight aggregate may turn over and subsequently ravel under traffic.

In a separate research effort, Epps and Finn (1980) continued the work done in Texas by Kearby (1953) and Benson and Gallaway (1953) by undertaking field validation of Kearby's design method. During this study, it was observed that Kearby's design method predicted lower asphalt application rates than those used in practice in the state of Texas. As a result, Epps and Gallaway (1974) proposed two changes to the design procedure. The first change was a correction to the asphalt application rates based on the level of traffic and existing pavement conditions. The second change was to support the shift of the original design curve proposed by the Kearby and Benson-Gallaway methods, as suggested for lightweight aggregate. Since then, practitioners and researchers refer to this design approach as the modified Kearby method.

The aggregate application rate in modified Kearby method is calculated by using the measurement of a laboratory test method referred to as the "board test". The board test is used to determine the quantity of aggregate that results in a layer of aggregates that is one particle thick spread over one square yard. The result from this test is expressed in terms of aggregate quantity in lb/yd^2 and is obtained by dividing the weight of aggregate to the aggregate application area (half square yard is generally used).

According to Epps and Gallaway (1974) for seal coats with lightweight aggregate, the modified Kearby method appears to be the most effective method to predict the aggregate application rate for lightweight aggregates. As with the previous design methods, the focus of this method was on the application rates and not necessarily on the quality of the aggregate-binder bond.

2.2.5 Other Seal Coat Design Methods

The review of other design methods outside the United States shows that most methods involve the use of volumetric approach and do not involve explicitly measuring the durability of the aggregate-binder bond. Some of these methods are described in the following sections.

2.2.5.1 Road Note 39

The design procedure Road Note 39 was developed by the United Kingdom's Transport Research Laboratory (Roberts, C., and Nicholls, 2008). This design procedure was developed by evaluating different kinds of systems based on parameters simulating different conditions and traffic on the pavement (Colwill et al., 1995). The design procedure is basically a computerized decision tree that is based on a number of user defined variables. This design procedure can be used for different types of seal coats: single dressing, pad coat plus single dressing, racked-in dressing, double dressing, and sandwich dressing. The basic inputs into the decision tree include the type of treatment and selection of grade and type of binder. This design uses a multitude of other input parameters: traffic level, road hardness, surface condition, site geometry, skid-resistance requirements, and likely weather conditions.

In summary, this design method does not rely on a laboratory test or performance evaluation. Rather, researchers evaluated several different variations of materials and surface conditions to develop a decision tree or algorithm that provides the application rate. Such a process is perhaps the easiest to implement and use by field engineers. However, developing such a decision tree for a state such as Texas would involve a significantly larger effort owing to the larger variety of materials (Texas is roughly 3 times in area compared to the United Kingdom). Also, given the current and dynamic nature of asphalt binder chemistry from different producers, it is impossible to guarantee that even the same grade of binder from the same producer with a similar mineral aggregate would result in the same level of bonding characteristics year after year. In fact, the main focus of this study is to address this gap.

2.2.5.2 Austroads Design Method

The Austroads method, (Sprayed Seal Design Project Group, 2001) considers many factors in the calculation of binder and aggregate application rate. This design procedure is also identified by the NCHRP 680 report as a recommended design method for seal coat applications in the United States. The Austroads method is based on certain assumptions related to aggregate, traffic, and embedment consideration (Sprayed Seal Design Project Group, 2001).

Aggregates are assumed to be one stone layer thick with a flakiness index between

15% and 25%. This design procedure is valid for less than 10% heavy traffic and when the percent embedment depth is assumed to range from 50% to 60% after about two years from construction. This method uses a large number of input parameters to determine the aggregate and binder application rates: aggregate angularity, traffic volume, road geometry, average least dimension (ALD) of aggregate, aggregate absorption, pavement absorption, and texture depth. It should be noted that this design also considers geometric features and recommends adjustments to the binder application rate. These geometric features include narrow lanes, climbing lanes, and turning locations.

2.2.5.3 South African Method, TRH3

The South African design method, TRH3, can be described as a hybrid of the Austroads' method and the Road Note 39 method. The South African design method was developed for different kinds of seal coats such as single and double seal coat (with either conventional or modified binder), cape seal, slurry seal, and sand seal. South African designs for different seal coat types are mostly based on Hanson's design concept, where asphalt binder fills the voids between aggregates and average least dimension determines these voids (The South African National Roads Agency, 2007). One of the assumptions this design method makes is that in order to prevent aggregate loss, approximately 42% of voids between aggregates (which is equivalent about 30% of height) should be filled by the binder.

There are two different binder rates described in the South African design method; cold and hot binder application rates. Hot binder application rate is the net binder application rate used in construction; whereas, the cold binder application rate is the application rate before subtracting extra part such as water in the emulsions before evaporation. Residual binder application rate is referred to as the net cold binder rate. The input parameters for cold binder application rate are: average least dimension of the aggregate, traffic level, road stiffness measured by ball penetration test and desired texture. Other inputs to adjust cold binder application rate are: climate, existing surface condition determined by sand patch test, road geometry in terms of slope (Beatty et al., 2002). Multiplication of the net cold binder rate and conversion factor depending on the binder type gives the hot binder application rate used in the construction. The design chart in the which average least dimension, flakiness index, and type of seal coat information are inputs gives the aggregate spread rate.

2.2.5.4 2005 New Zealand Design Method

This method was developed as a performance-based seal coat design method that considers the aggregate loss during the first winter after construction as well as the seal coat voids reduction model (Transit New Zealand, 2005). One of the significant difficulties involved in the design of material application rates, which is addressed in the 2004 New Zealand Method, is the non-uniformity of the substrate. The 2004 New Zealand employs a substrate correction factor using the sand circle (sand patch) test for the texture depth of the substrate and the ball penetration test to measure the substrate hardness.

2.3 PERFORMANCE TEST METHODS

The aforementioned seal coat design methods are clearly based on volumetric analysis and focus on material application rates as well as a correction to such rates based on field conditions. Aggregate and asphalt binder compatibility are implicitly assumed and the quality of the aggregate-binder bond is not necessarily accounted for. The most common forms of failure in a seal coat are ravelling and bleeding. Based on the survey of different districts within TxDOT, all 25 districts identified ravelling as a potential cause of failure. Although bleeding and ravelling can occur due to inadequate application rate, ravelling can also occur due to lack of adhesion between the binder and the aggregate. The application rate is addressed in the previously discussed design procedures, however, aggregate-binder bond is not. Therefore, a summary of recent studies on different test methods focused on aggregate-binder adhesion or bond was conducted and is discussed in the following sections.

2.3.1 Cantabro Test

The Cantabro Test Tex-245-F(2019), has been identified by TxDOT in the past as a possible test to evaluate asphalt-aggregate bond (Karki et al., 2019). This test uses specimens fabricated according to Tex-205-F using a Texas Gyratory Compactor (TGC). After fabrication, the specimen is placed in an LA Abrasion machine with no charge (steel balls). The rotating action of the LA Abrasion drum abrades the specimen. The amount of specimen lost during this process can be measured and used as a metric for aggregate binder bond strength. This procedure requires the fabrication of a molded specimen using project specific aggregate and binder. Figure 2.1 shows a photograph of the LA abrasion device that is used for the Cantabro test.

Figure 2.1. Cantabro Test Equipment (TEX-245-F, 2019)

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Cox et al. (2017) compiled different studies and analyzed almost 1,200 mass loss measurements on specimens that were abraded using the Cantabro test to examine its validity for use in dense graded asphalt mixes. The analysis showed that the Cantabro test was sensitive to the binder grades, presence of polymer, and aggregate type. The authors recommended the Cantabro test to be used in evaluating durability of dense graded asphalt mixtures.

Karki et al. (2019) investigated the use of the Cantabro test (slightly modified) in evaluating seal coats. The main goal of their research was to establish a detection method for Re-refined Engine Oil Bottom (REOB) in asphalt binders. With reference to seal coats, the study involved investigating the effect of REOB on the aggregate-binder compatibility. The factorial experiment matrix included two types of mineral aggregates (limestone and gravel) with six REOB content percentages in an AC-10 modified binder with two specimen conditions, dry and soaked in water. On average, gravel aggregates resulted in more mass loss than limestone, which indicates poor performance in terms of adhesion. Furthermore, the gravel specimens conditioned in water were reported to fail in the water bath even before performing the test. It is worth mentioning that this study only evaluated the effect of REOB on seal coats without intention to validate use of the Cantabro test as an evaluation tool.

Results from both Cox et al. (2017) and Karki et al. (2019) suggest that the Cantabro test could be a candidate in evaluating seal coat performance.

2.3.2 Sweep Test

The ASTM D7000 Sweep Test (ASTM International, 2019) shown in Figure 2.2 was originally used to evaluate micro surfacing materials or slurry seals. This test can also be used to measure aggregate retention on a fabricated seal coat specimen. Two variations of Sweep tests are available and were used by other researchers in evaluating the performance of seal coats. The difference in the two variations is the type of fixture and material that is responsible for abrading the sample. Both variations measure aggregate retention but are intended to simulate different field conditions. The first type of Sweep test uses a brush accessory mounted on a planetary type mechanical mixer (eg: Hobart). The sample can be swept for a predetermined duration of time and temperature and measured for aggregate loss. In this case, the Sweep test is simulating the sweeping action of the broom that are used in the field immediately after seal coat construction and before opening to traffic. This sweeping practice is conducted to remove any excess aggregate from the surface of the seal coat. However, occasionally, this test not only sweeps excess particles but also dislodges particles that do not bond well with binder, which is referred to as short term raveling (Howard et al., 2011).

The second variation of the Sweep test uses a rigid rubber hose as an attachment instead of the brush. In this case the intent is to abrade the seal coat specimen, which is submerged in water and measure aggregate loss. Typically, the rubber hose is also used to determine the timing for breaking and curing in order to determine whether the emulsion-based seal coat section is sufficiently cured before opening to traffic (Shuler, 2011). Currently, the scope of ASTM D7000 is limited to an emulsion-based seal coat. This is because one of the challenges in using emulsion-based seal coat is the decision to open the section to traffic or allow brooms (Howard et al., 2011).

Johannes et al. (2011) used a Sweep test to conduct sensitivity analysis of emulsion application rates. They reported that the Sweep test is highly sensitive to emulsion rates. Also, to ensure accurate results it was recommended to use project specific materials when evaluating seal coats.

Figure 2.2. A photograph of the Sweep test shown with the brush attachment (ASTM International)

.

The following three studies were oriented towards correlating and investigating moisture content and its effect on seal coat performance using the Sweep test and its modified version.

Islam and Hossain (2011) included lightweight aggregates in their study and tested the influence of moisture on the aggregate loss with two types of emulsion-based binders. In their study they performed a comparative analysis between ASTM D7000 and a modified version of this procedure. The modified version is different in that the brush covers the seal coat sample while in the original version this is not the case. It was reported that the results from the modified version were adequate in determining aggregate loss because the brush rotates over the whole specimen. No validation with field performance was reported in the study.

Howard et al. (2011) and Shuler et al. (2011) focused on correlating moisture loss and strength gain in seal coats. They used three field test sections with different moisture contents to identify the conditions in which the seal coat section can resist brooming and traffic damage. The Sweep test correlated very well with field results when using the same project materials.

Wasiuddin et al. (2013) used the Sweep test in evaluating both cold and hot applied seal coats. Their study utilized 15 seal coat sections with two emulsions and one hot applied binder. The aggregates were precoated and represented five different mineralogies. The basis to evaluate the adequacy of the Sweep test was correlating the aggregate loss in the lab with the field distress. Overall, a very good correlation was observed in this study, and it was concluded the test could be an effective tool to evaluate the performance of seal coats with respect to aggregate mineralogy, precoating, and type of asphalt binder.

2.3.3 Vialit Test

The Vialit test shown in Figure 2.3 uses a test specimen fabricated using the project specific binder and aggregate in a metal tray. This tray can be cured and conditioned in various ways. Commonly used curing protocols include cooling, freezing, inundating under water, and freezing one or more times. The seal coat sample is ultimately brought to some chosen standard temperature, placed upside-down on the Vialit stand, impacted with a standard steel ball of known weight from a known height, and the loss of aggregate from the sample is measured (British Standards International, 2003).

Oregon has a standard method for Vialit test for aggregate retention in seal coats, also called the “French Chip” Oregon DOT (2016).

Jordan and Howard (2011) reported that the Vialit test is not very accurate as a performance evaluation tool because the results are not very sensitive to different binder types. However, their study did show that extended conditioning time, and temperature cycling helped to better differentiate between binder types and consequently their performance.

King and Johnston (2012) have shown that the Vialit test helps to identify risk of brittle failure of the seal coat during the first winter and that the use of modified binders significantly decreases this risk . The NCHRP synthesis on best seal coats practice (Gransberg and James, 2005) also presents the Vialit test as a tool for evaluating aggregate-binder compatibility.

In North Carolina, Adams et al. (2019) investigated the acceptance quality characteristics (AQCs) for seal coats. The motivation behind their study was to find a relationship between AQCs and Seal coat performance. An example of such AQCs would be the adhesion strength between emulsion binder and aggregate, which is directly related to the aggregate loss. Accordingly, Adams et al. (2019) correlated aggregate loss measured in the lab using the Vialit test with the adhesion strength that was measured using the PATTI (pneumatic adhesive tensile testing instrument). The data showed a negative relationship with a R^2 of 0.75 between the two performance metrics.

Figure 2.3. A photograph of the Vialit test apparatus (British Standards International)

2.4 FIELD PERFORMANCE MEASURES FOR SEAL COATS

Seal coated surfaces are different from asphalt pavement surfaces both in appearance and performance; therefore, their performance cannot be evaluated using the same tools used for asphalt pavement surfaces. A quantitative measurement approach should be able to measure the two most common distresses: bleeding and raveling. A review of such quantitative measures is necessary because one of the goals of this study is to use field performance as a basis for validating the final test method that is recommended for routine use. The existing literature suggests that skid resistance and texture depth are the most common, repeatable, and objective quantitative metrics.

2.4.1 Skid Resistance

Skid resistance, which is a functional measure for safety of a pavement surface, can also be used to measure the performance of seal coated surfaces (Roque et al., 1991).

In general, the skid resistance or friction is mainly a function of pavement macrotexture and microtexture. The microtexture is determined by the aggregate type (frictional properties), while the macrotexture is determined by the size, shape, and spacing of the aggregate particles. The most common method for measuring skid resistance on seal coated surfaces is based on the ASTM E274, Skid Resistance of Paved Surfaces Using a Full-Scale Tire (Seneviratne and Bergener, 1994). This method measures the sliding friction force between a locked-wheel and pavement surface. This test which is known as locked-wheel skid test (LWST) measures the skid number, SN. The rationale for using this measurement as an indicator of seal coat performance (thus the service life of the seal coats) is that friction reduces over time due to deterioration of the pavement's surface texture. Most agencies also use this tool to decide whether a road needs surface treatment.

Lee et al. (2012) demonstrated that there is a strong correlation between skid resistance measurements from British pendulum test (BPT) and the locked-wheel skid test (LWST). Therefore, the BPT in the laboratory can be used to predict the SN in the field.

2.4.2 Texture Depth

Texture depth, which is a function of pavement macrotexture, is another indicator of seal coat performance. In general, there are several methods to measure a pavement's macrotexture. The survey conducted by the NCHRP synthesis on best seal coats practice (Gransberg and Zaman, 2005) indicated that only the sand patch method (ASTM International, 2015) has a widespread acceptance. Roque et al. (1991) measured the mean texture depth (MTD) of seal coated surfaces by conducting the sand patch method, and found that MTD gives the best indication of seal coat performance. Roque et al. (1991) also found that the MTD, indicated by macrotexture, decreases with time as a result of both aggregate wear and embedment. In other words, aggregate retention and resistance to bleeding are both evident by evaluating MTD. Therefore, this measurement can be used to evaluate the effects of different variables on the expected life of a seal coat application.

Gransberg (2007) used the MTD measurements from a seal coat research project in Texas (before and after seal coat construction), and demonstrated that the roads with poor pre-seal surface conditions (low macrotexture) show early loss of macrotexture and premature flushing after a new seal coat been constructed.

Over the last few years, there have been several attempts to replace the sand patch method using image analysis to increase the rate of data collection. Gransberg and Zaman (2005) used Fast Fourier Transformation FFT for image analyses, and correlated the FFT number with the physical texture measurements. Hoyt (2012) used the aggregate imaging system (AIMS) to measure pavement macrotexture (pavement cores or small samples cut from fabricated slabs) in the laboratory. His analyses showed a good correlation between the mean profile depth, MPD, calculated from AIMS measurements on small specimens and the MPD measured on the pavement or on the large fabricated slabs using circular track meter.

Finally, a more recently developed method to obtain texture measurement of a pavement surface is using laser profiling. Walker (2001) used a dot laser profiler that carried out a raster scan along two perpendicular axis to obtain the microtexture of a pavement surface. Halil et al. (2008) used a commercial device from Ames to measure surface texture of the pavement. This device has a small footprint and is portable, so it can be carried to any field location. Vilaça et al. (2010) used a line laser with two cameras to measure the surface texture of asphalt pavements. In Texas, Huang et al. (2013b,a); Hong and Huang (2014) developed a texture measurement system based on continuous profiles using laser scanners to measure texture and condition of pavement surfaces including seal coats. Finally, Im (2013) also used a similar approach to evaluate performance of chip seals for high volume roads and developed a laser scanning system referred to as Robotex.

2.5 SUMMARY

A review of literature was conducted in the context of the main goals of this study. Most design methods related to seal coats focus on the application rates and volumetric approaches to ensure the optimal application rate. These methods implicitly assume that the aggregate-binder adhesion is durable and will last the intended service life of the seal coat. However, for a state as large as Texas, there is no guarantee that the chemical composition of the asphalt binder being procured from the same source and for the same grade will remain consistent year after year. As a result, despite using optimal application rate, there are instances of failure resulting from poor binder-aggregate adhesion. Such potentially expensive failures can be avoided by incorporating a simple binder-aggregate adhesion screening tool in the material selection and qualification process. The literature review summarized above also identified a few test methods that can potentially be used for this purpose and will be considered in the subsequent tasks of this study.

CHAPTER 3. METHOD DEVELOPMENT AND ESTABLISHMENT OF TEST PROTOCOLS

3.1 OVERVIEW

The main goal of this research project is to develop a laboratory test method or methods that can be used by engineers and contractors to evaluate the quality of bonding between the binder and aggregate in a seal coat. There are two main challenges to achieve this goal. First is the lack of reference or benchmark field performance data from different regions in Texas. This aspect was covered in a different task of this research project. Second is the lack of a standard test method to evaluate the quality of adhesion between binder and aggregates in a seal coat material for both hot applied and emulsion-based seal coats. The main goal of this part of the study was to develop and compare different candidate test methods that can potentially be used to evaluate the quality of adhesion in seal coat materials.

3.2 CANDIDATE TEST METHODS

Based on a review of the literature, the following candidate test methods were considered for further development and/or evaluation in this task:

- Sweep test (and variations)
- Vialit test
- Cantabro test
- Pull-off test

Testing protocols for each of the aforementioned candidate tests were developed using existing standards as a starting point, when available. When a standard method was used as a starting point, it was further modified to accommodate materials and achieve the specific goals of this project. For example, the existing protocol for the Sweep test (ASTM D7000) is based on an emulsified binder. In this case, the test method was modified and further developed to incorporate AC binders. Similarly, the Vialit test, which follows the EN 12272-3, was modified to account for emulsion-based asphalt binders by evaluating different curing times. The Cantabro test protocol required more development work since it has no existing standard that is specifically intended for use with seal coat materials. Finally, a new pull-off test protocol was also explored.

3.3 MATERIALS

Material selection for the current and future tasks was based on results from surveys prepared in Task 1. The materials included hot applied binders (AC-10, 20-5TR, 15P), emulsions (CRS-2, -2P), and cutbacks (RC-250); and aggregates representing two different mineralogy (limestone and sandstone). Asphalt binders with varying degrees of expected performance identified from the survey conducted in Task 1 were used in this and subsequent tasks of this project. For example, AC-10 is typically not used for seal coat application because it results in relatively poorer performance compared to AC-15P and AC-20-5TR. However, AC-10 was included in this part of the study by design to provide a relative qualitative baseline (i.e. expected to perform poorly) that could be used to evaluate the sensitivity of the test method. Similarly, CRS-2P is typically expected to perform better than CRS-2 on account of the polymer content. These relative, albeit qualitative differences in expected performance were used as a guide to assess the accuracy and sensitivity of the candidate test methods. Table 3.1 presents a summary of the material combinations used in this task (not all materials were evaluated with each test method). Additional details on these materials are provided in the subsequent sections.

Table 3.1. Material combinations used to evaluate different test methods

No.	Aggregate	Asphalt Binder
1	Limestone	AC-10
2	Limestone	AC-20-5TR
3	Limestone	AC-15P
4	Limestone	CRS-2
5	Limestone	CRS-2P
6	Sandstone	AC-10
7	Sandstone	AC-20-5TR
8	Limestone	RC-250 (Producer 1)
9	Limestone	RC-250 (Producer 2)
10	Lightweight	RC-250 (Producer 1)
11	Lightweight	RC-250 (Producer 2)

3.4 SWEEP TEST

Sweep test is a candidate test method that is typically used to evaluate compatibility of materials at the early stages of seal coat construction. The test was originally developed to evaluate cold applied seal coats (emulsion binders) and to evaluate the appropriate time to open a fresh seal coat to traffic. Specimens are fabricated using project materials and then cured in the oven for a certain duration of time. At the end of curing, specimens are subjected to abrasion in the Sweep test machine by using a nylon brush or a hose (rubber, pvc, or plastic) for one minute. To calculate aggregate loss, the weight of a specimen after abrasion is recorded and the difference in weight of the specimen before and after abrasion is used as an indicator of compatibility between the binder and the aggregate. For this study, it was hypothesized that this test could be extended to evaluate the quality of adhesion between the binder and aggregate for both hot applied and emulsion-based seal coats.

3.4.1 Material combinations and test variations

This section presents the material combinations and test variations used for this part of the study as well as the rationale for selection of these materials and variations. Table 3.2 presents the combinations of the different materials that were used to develop and evaluate the Sweep test method. Each material combination was evaluated using four different variations of the Sweep test: brush with slow speed, followed by brush with high speed, rigid tube with slow speed, followed by rigid tube with high speed.

Table 3.2. Material combinations used to develop and evaluate the Sweep test method

Binder	Limestone	Sandstone
AC-10	3	3
AC-20-TR	3	3
AC-15P	3	–
CRS-2	3	–
CRS-2P	3	–

The selection of AC binders and emulsions was based on the results from the survey in Task 1 that identified the most common binders used in seal coats and their expected performance in the field. Although several different types of aggregates are used in different parts of the state, for the purposes of this task, aggregates representing two different mineralogy, namely limestone and sandstone were selected to evaluate the Sweep test. The aggregates selected were Grade 4, which is also a common grade used in seal coat applications.

The three AC binders comprise one unmodified binder (AC-10) and two modified binders (AC-20-5TR & AC-15P). The two emulsions selected were cationic emulsions with designations of CRS-2 and CRS-2P. As discussed earlier, the choice of these materials covers the different types of seal coat applications (hot applied versus emulsion based) as well as different levels of expected performance. For example, AC-10 is generally not used for seal coats since it is expected to result in poor adhesion. Similarly, the polymer modified binders are generally (although not always) expected to perform better than the unmodified binders, at least on a qualitative basis (e.g. CRS-2P can be expected to perform better than CRS-2).

It is worth mentioning that the standard test method ASTM D7000 for the Sweep test is not intended for AC or hot applied binders. It is a test method that measures the curing performance characteristics of emulsified asphalt and effect of curing performance on compatibility between emulsion and aggregates.

However, one of the goals of this study was to develop and evaluate this method as a potential standard to evaluate compatibility of the binder and aggregate for both hot applied and emulsion-based seal coats. Also, evidence from the literature suggests that in some cases the Sweep test is incapable of differentiating between different materials, i.e. the test does not have adequate sensitivity in some cases. However, in this research it was hypothesized that this lack of sensitivity can be overcome by using more tortuous test variations.

With regards to the test variations, each test variation results in a different condition that triggers aggregate debonding. The comparison between these variations is important as typically the nylon brush specified in the ASTM D7000 is not tortuous enough to abrade specimens, particularly when the intended application is to evaluate adhesion for both emulsified (fully cured) and hot applied binders. Thus, it was decided to expand and include more tortuous conditions by using higher speed of brooming with the same nylon brush and two additional variations by replacing the brush with a PVC tube at two different brooming speeds. The results from these four variations were evaluated to select the most promising variation that was both sensitive and repeatable.

3.4.2 Specimen fabrication and testing

ASTM D7000 specifies aggregate application rates depending on their bulk specific gravity values and only one application rate of binder regardless of the aggregate type. For the Limestone and Sandstone used in this task, bulk specific gravity values were determined using the ASTM C127-15 as shown in Table 3.3. The two aggregates used in this study had similar bulk specific gravity. Consequently, according to ASTM D7000, the aggregate mass applied on the surface of the binder was 500 g for both types of aggregates. Binder application rate was set to 1.42 Kg/m^2; this amounts to a total binder mass of 83±5 g for each test specimen. In the case of emulsion, the amount of emulsion applied was increased by a factor of 1.3 such that the residual binder was 83±5 g for each test specimen. This factor was verified by separately boiling off the water from a small sample of the emulsions.

Table 3.3. Aggregate bulk specific gravity values for aggregates used in establishing test protocol

Material	Oven dry (OD),g	Saturated surface dry(SSD), g	Apparent mass in water, g	Sp. gravity(OD)	Sp. gravity (SSD)	Apparent sp. gravity
Limestone	2,095.5	2,123.7	1,304.2	2.56	2.50	2.65
Sandstone	2,094.5	2,137.4	1,311.9	2.54	2.59	2.68

In order to prepare samples consistently, it was determined that an aggregate spreader was necessary. To this end, the research team developed and fabricated an aggregate spreader that can be used to uniformly spread aggregates on the binder or emulsion surface. This aggregate spreader comprises a frame, a honeycomb mesh, and a holding plate immediately below the honeycomb mesh that can be retracted to allow the aggregate particles to drop on the binder coated surface. Figure 3.1 shows an image of this spreader developed specifically to facilitate this test method.

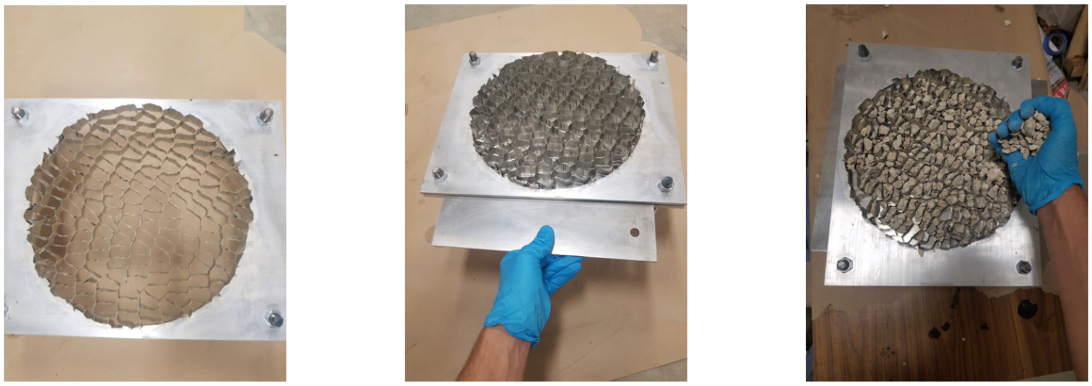


Figure 3.1. Photograph of the aggregate spreader showing aggregates before and after being dropped on to the testing surface

The required amount of aggregate for each specimen was weighed and set aside so the aggregate could be immediately applied to the asphalt binder or emulsion surface. The required amount of the asphalt binder or emulsion was poured in a metal can (with predetermined allowance for residual binder or emulsion in the container after emptying its contents). The asphalt binder or emulsion was then heated to the application temperature (approximately 150 to 160°C for hot applied binder and 60°C for the emulsion) and poured evenly on top of an asphalt felt disk of 11-inch diameter. The disk was tilted back and forth to ensure that a uniform film of the binder or emulsion was formed on the surface. The aggregate was immediately applied using the aggregate spreader on the binder (Figure 3.1).

A roller compactor with a rubber mat surface, similar to the one used for the Vialit test, was used to compact the aggregate and achieve an appropriate aggregate embedment. The roller was passed over the specimen three times (i.e. two forward passes and one backward pass) in one direction and another three times in a direction perpendicular to the previous direction. After compaction, the specimen was gently tilted towards the vertical direction and any loose aggregate particles were removed by hand sweeping. The specimen was cured at 35°C for 2 hours for both hot applied and emulsion-based specimens. At the end of curing period, the specimen was removed and allowed to come to equilibrium to room temperature (21°C). The surface temperature of the specimen was monitored using a thermocouple or IR gun. This usually took approximately 5 to 10 minutes. Note that the specimen was then subjected to the Sweep test after this time but no longer than four hours after sample preparation.

The specimen was weighed and the weight was recorded to the nearest 0.1 g and after hand sweeping. The specimen was then clamped to the Sweep test mixer which abrades the specimen using one of the two different fixtures selected for this test for a duration of one minute. When the test was complete, any loose aggregate particles were removed from the surface of the test specimen. The weight of the specimen was recorded after abrasion. Aggregate loss was calculated according to Equation 3.1. The factor 1.33 is an adjustment factor since the Sweep test fixture does not cover the entire area of the specimen.

$$\text{Aggregate Loss} = \frac{A-B}{A-C} \times 100 \times 1.33 \tag{3.1}$$

In Equation 3.1, A is the initial weight of the specimen, B is the final weight of the specimen, and C is the weight of the asphalt binder and the felt disk. Figure 3.2 and 3.3 shows a sample of specimen fabrication and the specimen attached to the Sweep test table using the tube variation, respectively.

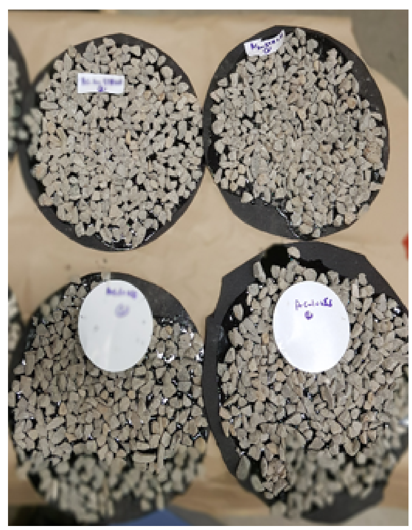


Figure 3.2. Specimen fabrication for the Sweep test (left: specimen before applying aggregates; right: after placing aggregates)

Figure 3.3. Specimen in the Sweep test

3.4.3 Results and discussion

Figure 3.4 and 3.5 present the results from the aforementioned tests. A few key observations are as follows:

- Other than AC-10, the brush at a low speed was not abrasive enough to create aggregate loss.
- The variability for each variation of the test in term of the average coefficient of variation is as follows:
  - Brush at low speed could not be determined
  - Brush at high speed from 16% to 63% and average = 55.2%
  - Tube at low speed from 2% to 52.5% and average = 39%
  - Tube at high speed from 6% to 46% and average = 30%

- In order to evaluate the sensitivity of the test, the coefficient of variation of the average for each variation from all the material combinations was computed is as follows:
    - Brush at low speed = 129%
    - Brush at high speed = 55.2%
    - Tube at low speed = 39.2%
    - Tube at high speed = 31.4 %
    - For all variations combined = 74%

  These results show that the

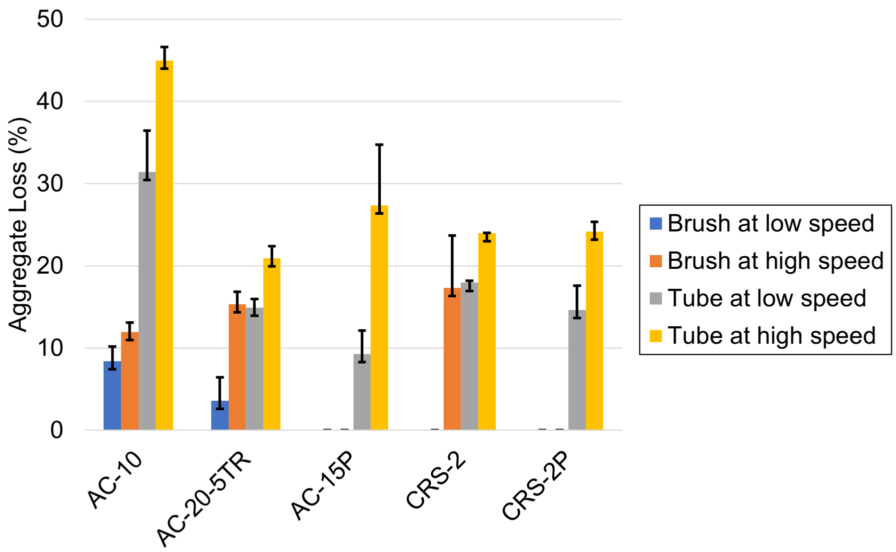


Figure 3.4. Aggregate loss using different Sweep abrasion; limestone

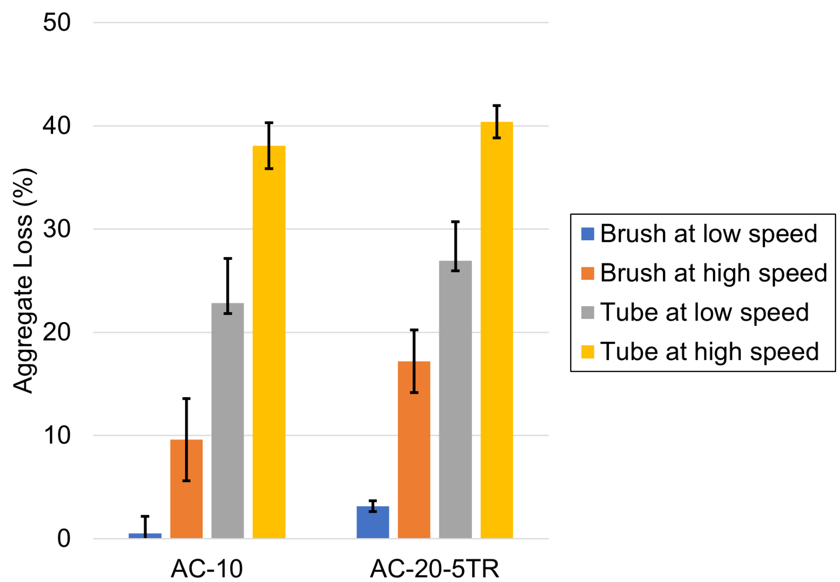


Figure 3.5. Aggregate loss using different Sweep abrasion; sandstone

3.5 VIALIT TEST

The Vialit test was identified as one of the candidate tests based on a review of the literature in Task 1. The European standard for this test involves conducting the test at low temperatures. An advantage of this method is that the loss of adhesion or ravelling is more pronounced at low temperatures and therefore the materials can be evaluated under these critical conditions. This test can be adapted for all types of asphalt binders, i.e. hot applied asphalt binders (e.g. AC-20-5TR, AC-15P, AC-10), emulsified asphalt binders (e.g. CRS-2, CRS-2P), and cutback asphalt binders (e.g. RC-250).

3.5.1 Material combinations and test variations

The experimental matrix for this test expands on the main program previously shown in Table 3.1. Table 3.4 presents the material combinations and conditions used to evaluate this test method. The rationale for the choice of materials and test conditions is discussed below.

The first set of tests evaluates the impact of factors such as test temperature and curing time of emulsion and cutbacks on aggregate loss. For example, it was of interest to explore whether the ravelling and aggregate debonding could be further exacerbated with the use of lower test temperatures compared to the current recommendation of 5°C. Also, it was of interest to explore the appropriate curing time and conditions required for testing emulsions and cutbacks. After these parameters were explored, the results from this first set of tests were used to inform the testing protocols for the subsequent sets.

The second set of tests were used to evaluate the sensitivity and repeatability of the test method using the protocols based on the findings from the first set. The third set of tests was conducted as a case study. A seal coat section in Bryan District that utilized cutback binder and a lightweight aggregate experienced premature ravelling. Although an extensive field evaluation was not a part of this task, this particular section was included as a means to evaluate both the efficacy of the test method and the materials used for the seal coat.

3.5.2 Specimen fabrication and testing

The starting point for the Vialit test was based on the standards developed in France and documented as EN 12272-3. The specimen fabrication comprises of a flat steel plate with a rim height of 2 mm and planar dimensions of 200 x 200 mm. The plate itself is 2 mm thick.

The application rate depends on the aggregate size and the type of asphalt binder or emulsion. Based on the aggregate grades used in Texas and the recommendations from the EN 12272-3 standard, it was decided to use a finite number of aggregate particles for each grade. Specifically, for all the tests conducted in this part of the study the number of particles were standardized to 100 particles for Grade 4 and 50 particles for Grade 3. For the asphalt binder, the application rate was standardized based on the aggregate grade to ensure consistent embedment depths. For Grade 4 aggregates the amount that was used was equivalent of 0.22 gallons/square yard (note that this is slightly lower than typical application rates because the metal plate does not present any binder absorption). This amounts to 40 g of the binder for this plate. For Grade 3 aggregates the amount that was used was equivalent of 0.29 gallons/square yard, although no Grade 3 aggregates were used in this part of the study. Note that similar to the Sweep test, these rates were adjusted when an emulsion or a cutback was used to ensure that the target residual binder rates were achieved.

Table 3.4. Expanded experimental matrix for the Vialit test

Binder Type	Limestone	Sandstone	Lightweight	Objective
		Set 1		
AC-10 AC-20-5TR AC-15P	See Table 3.5	– – –	– – –	Effect of test temperature on sensitivity at 5°C, -5°C, and -12°C
CRS-2 CRS-2P	2 2	– –	– –	Evaluate the effect of curing time on emulsions
RC-250	2	–	–	Evaluate the effect of curing time on cutbacks
		Set 2		
AC-10 AC-20-5TR AC-15P CRS-2 CRS-2P	3 3 3 3 3	3 3 – – –	– – – – –	Evaluate sensitivity and accuracy of method
		Set 3		
RC-250 (Source 1) RC-250 (Source 2)	3 3	– –	3 3	Case study

The required number of aggregate particles for each specimen were set aside so they can be immediately applied to the asphalt binder or emulsion surface. Similar to the Sweep test, the asphalt binder or emulsion or cutback was weighed and heated to the appropriate spraying temperature and applied on the steel plate (approximately 150 to 160°C for hot applied binder and 60°C for the emulsion and cutback to equilibrate). In this case, the steel plate was also heated to the same temperature as the binder to prevent immediate cooling of the binder after it was applied. The metal plate was tilted back and forth to ensure that a uniform film of the binder or emulsion was formed on the surface. The aggregate particles were immediately placed by hand on the binder. This was done as quickly as possible but in no more than two minutes to ensure that the binder did not cool down as the aggregates were being placed. The specimen was then compacted using a rubber wheel roller with a mass of 25 Kg and a rubber thickness of 15±2 mm and diameter of 250 mm. The compactor was passed three times in each of the transverse and longitudinal direction of the steel plate. In case of AC binders, the specimen, i.e. the plate with the binder and aggregate, was then placed in a refrigerator at 5°C to bring the specimen to test temperature. While, in the case of emulsions and cutbacks, the specimen was cured at 35°C then placed in a refrigerator to achieve test temperature. The temperature was monitored using a thermocouple.

After the temperature conditioning, the test was conducted by flipping the plate and placing it on 3-pointed supports. A steel ball of mass 510 g and diameter of 50 mm was dropped three times on the back of the plate. Aggregate loss was calculated by counting the number of aggregates that broke loose from the plate according to Equation 3.2.

$$\text{Aggregate loss} = \frac{A - B}{A} \times 100 \tag{3.2}$$

In Equation 3.2, A is the initial number of aggregate particles (100 or 50 depending on the grade of aggregate), and B is the number of aggregates that broke loose and fell off the plate after the third drop.

Figure 3.6 illustrates the key steps in preparing a Vialit test sample.

3.5.3 Results and discussion

3.5.3.1 Sensitivity to Test Temperature

As previously shown in Table 3.4, the first set of tests were conducted using (i) different test temperatures to evaluate whether the use of lower temperatures can exacerbate the impact of adhesion loss and (ii) different curing times with emulsions and cutbacks to assess the optimal time required to cure the samples before testing (in this case the specimens were only examined for curing and the Vialit test was not conducted on premature samples). For the purposes of evaluating the impact of test temperature, the test specimens were placed inside a chiller to achieve different testing temperatures of 5°C, - 5°C and -12°C. Further, to capture the sensitivity

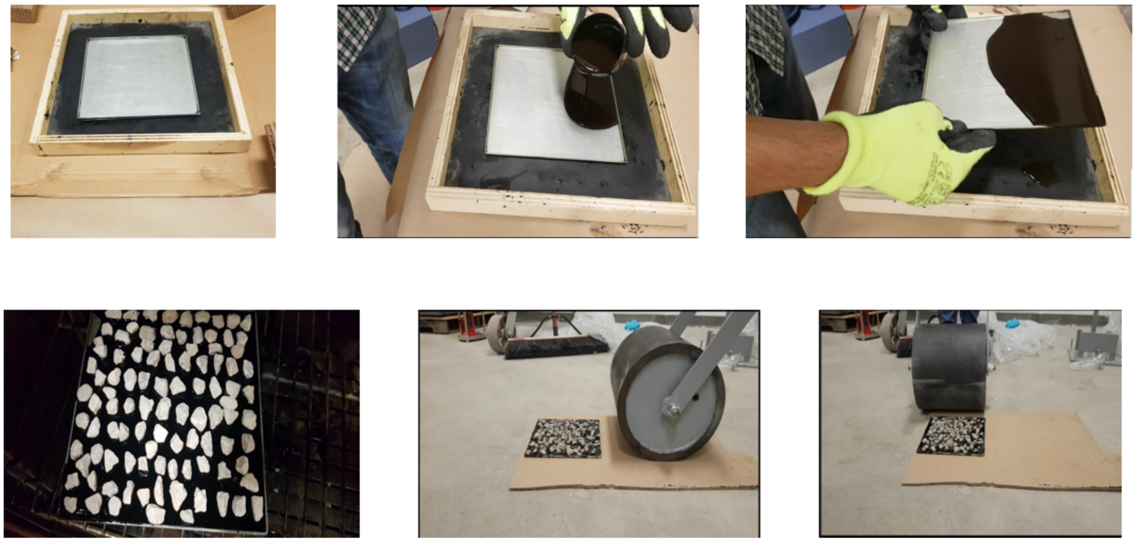


Figure 3.6. Vialit specimen fabrication

to test temperature, the aggregate count (loss) was recorded after each ball drop. Table 3.5 presents the results from these tests. These results clearly indicate that test temperatures of -12°C and -5°C are very harsh and compromise the sensitivity of the test method. At -12°C all material combinations showed 100% aggregate loss after the very first drop. Similarly at -5°C the aggregates showed 82% to 100% loss between the first and third drops. The sensitivity of the test method significantly improved at 5°C with results ranging from 20% to 98% aggregate loss after the third drop. Also, these results, were qualitatively consistent with expected performance. For example, AC-10, which is expected to perform poorly showed the highest loss of 98%, followed by AC-20-5TR with 46% loss, and AC-15P with 20% loss.

Another objective of these tests was to evaluate the optimal curing time in the case of emulsions and cutbacks. To this end, Vialit test specimens were prepared as described previously. The test specimens were then allowed to cure at 35°C. The surface of the emulsion or cutback was examined every two hours; the surface was gently probed to examine whether or not the emulsion or cutback had cured. It was found that it took at least six hours for the emulsion or cutback to break and stabilize (even if not fully cured). A curing time of six hours (prior to cooling at the test temperature) was adopted for the remainder of this portion of the study.

Table 3.5. Vialit sensitivity to test temperature

Temp.°C	Aggregate	Binder	Specimen No.	Aggregate Loss (%)
-12	Limestone	AC-20-5TR	R1	100% after first drop
-12	Limestone	AC-15P	R6	100% after first drop
-5	Limestone	AC-10	R4	98% after first drop 100% after second drop
-5	Limestone	AC-20-5TR	R2	100% after first drop
-5	Limestone	AC-15P	R7	82% after first drop
+5	Limestone	AC-20-5TR	R3	46% after first drop
+5	Limestone	AC-10	R5	90% after first drop 98% after second drop 98% after third drop
+5	Limestone	AC-15P	R7	20% after third drop

3.5.3.2 Sensitivity and repeatability of the test method

As shown in Table 3.4, the second set of tests were conducted using different material combinations to evaluate the sensitivity and repeatability of the test method. Based on the findings from the previous test, all tests in this set were conducted at 5°C and following the method described earlier. Figure 3.7 shows aggregate loss of the Vialit specimens prepared by using five types of binders and two types of aggregate mineralogy. These results show that this test protocol had good repeatability (coefficient of variation was between 0 and 29%), sensitivity (Coefficient of variation = 94%), and also demonstrated qualitative accuracy, e.g. the AC-10 showed the highest aggregate loss of all combinations, and the emulsions showed better performance than the hot applied binders (note that the hot applied binder was being used with uncoated aggregates, which is an extreme case and not typical in use).

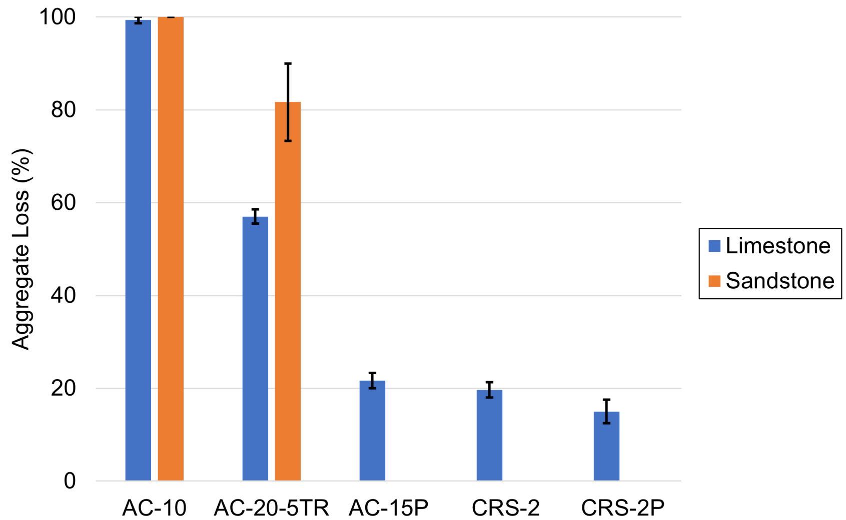


Figure 3.7. Results from Set 2 showing repeatability, sensitivity, and qualitative accuracy of the Vialit test method.

3.5.3.3 Evaluation of cutbacks from a field section

As described earlier, the third set of tests in this part of the study involved materials from a seal coat section in Bryan district. The seal coat section utilized a lightweight aggregate with a RC-250 cutback from a source marked as "Producer 1". This seal coat section experienced premature raveling and potential causes included: (i) contamination of the cutback, (ii) the specific cutback did not cure as expected in the field, and (iii) the materials were not compatible. This scenario was used as a means to evaluate the newly developed Vialit test. In order to examine and rule out or verify the aforementioned potential causes, an additional aggregate source (Limestone) and cutback source ("Producer 2") were added. This resulted in the testing of four different material combinations with three replicates each.

Figure 3.8 presents the results from this set. These results highlight that the RC-250 from the different producers performed similarly with each aggregate. Also, typically the limestone aggregate showed slightly lower adhesion compared to the sandstone for both cases. These results further speak to the sensitivity and repeatability of the test method.

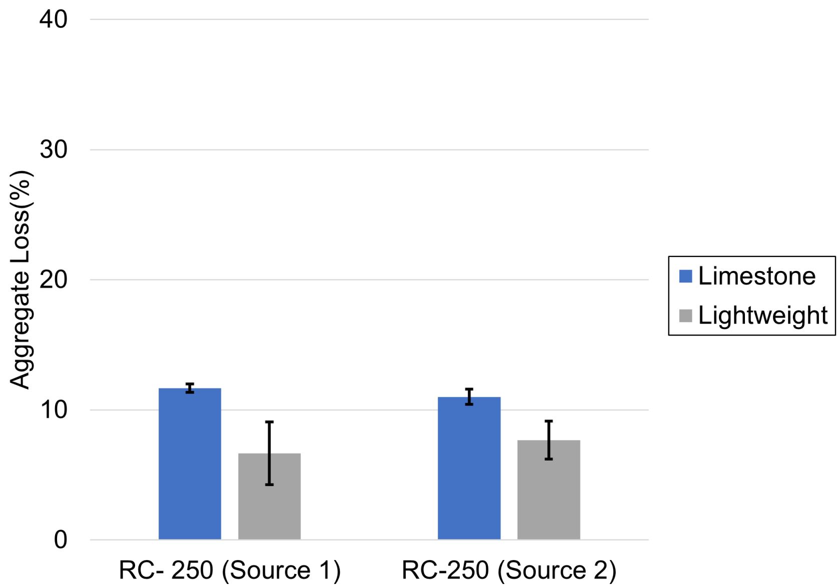


Figure 3.8. Vialit aggregate loss for RC-250 from two different sources with two different types of aggregates

3.6 CANTABRO TEST

The Cantabro test was identified as one of the candidate tests based on a literature review in Task 1. The existing standard for this test method is used to determine the abrasion loss in a hot-mix asphalt specimen. It was included in this project as a potential candidate to evaluate the susceptibility of seal coat materials to raveling. The Cantabro test is a torture test that subjects the test specimen to high impact and abrasive action, triggering debonding between the aggregate and the binder.

3.6.1 Material combination and test variations

The experimental matrix of this test expands on the overall test matrix shown in Table 3.1. Table 3.6 presents the material combinations used to evaluate this test method. Three replicates for each material combination were fabricated. A subset of these materials was used to evaluate the rate of specimen abrasion in the Cantabro machine as discussed later in results and analysis.

Table 3.6. Material combinations used to develop and evaluate the cantabro test method

	Limestone	Sandstone	Lightweight
AC-10	3	3	–
AC-20-5TR	3	3	–
AC-15P	3	–	–
CRS-2	3	–	–
CRS-2P	3	–	–
RC-250 (Source 1)	3	–	3
RC-250 (Source 2)	3	–	3

3.6.2 Specimen fabrication and testing

The starting point for the Cantabro test was the Texas standard Tex-245-F. However, since the aforementioned is intended for hot mix asphalt, certain modifications to the specimen fabrication procedure had to be developed. For this study, the test specimen was fabricated by mixing 900 g of Grade 4 seal coat aggregates and 5% of binder (by weight of aggregates) at 155°C in a silicone bowl using a silicone spatula. This binder content was selected because it is a typical value that is used to prepare asphalt mixes using a Marshall mold. Note that in case of emulsions and cutbacks, the amount of binder was adjusted to ensure that the target residual binder equals 5% by weight of aggregate.

A couple of points related to specimen fabrication are noteworthy. First, initially the test specimens were fabricated using a sample of the Grade 4 aggregates. However, there is a small percentage of finer particles that are typically allowed in Grade 4. Results from initial tests showed a very high variability. To overcome this, the Grade 4 aggregate was sieved and only aggregate particles retained on the No. 4 sieve and passing through 1/2-inch sieve were used for sample preparation. This step of sieving aggregates reduced the variability. Second, researchers recognize that the 5% binder content typically used in hot mix is intended for a dense graded mix and not for single sized aggregate, as is the case with the seal coat. However, this was considered as a good starting point to develop the test procedure.

For the binders, the mixing process was done in no more than 3 min and then placed in the oven at 155°C for 10 min to regain heat for compaction. After that the mixture was added immediately to a 101.6 mm Marshall mold and a straight spatula was used to spread the mix inside the mold. The compaction of the mold was carried out using Marshall drop hammer by applying 50 drops on each side of the specimen. In the case of emulsions and cutbacks, the specimen was treated as a cold mix and the loose mix was compacted using the drop hammer by applying 50 drops on each side of the specimen. The mixture inside the mold was allowed to cure in the oven at 35°C for 24 hours.

After compacting the specimen in the mold, it was allowed to cool down for two hours before extraction using the 101.6 mm Marshall extractor machine. Then the specimen was allowed to stand at room temperature for a minimum of 24 hours but no more than 48 hours. After this period, the weight of the specimen was recorded. The specimen was placed in the Los Angeles abrasion machine at a speed of 30-33 revolution per minute for 300 revolutions. Finally, the specimen was removed from the machine and the weight was recorded. Cantabro loss was calculated according to Equation 3.3.

$$\text{Cantabro loss} = \frac{A - B}{A} \times 100 \tag{3.3}$$

In Equation 3.3, A is the weight of specimen before abrasion, and B is the weight of specimen after abrasion. Figure 3.9 illustrates the key steps in preparing a Cantabro mix for seal coat applications.

3.6.3 Results and discussion

3.6.3.1 Sensitivity and repeatability of the test method

In order to assess the sensitivity of the test method, for two different material combinations, the Cantabro test was run and stopped intermittently to measure the Cantabro loss. These rate of loss measurements were used to assess at the optimal time required to run the test. Figures 3.10 and 3.11 show the results from these tests. These results show that after 10 minutes of test duration, the materials registered a loss of 15 to 60%, which was considered reasonable to be used for further testing. In addition, the three replicates from each material combination also showed consistent results over time.

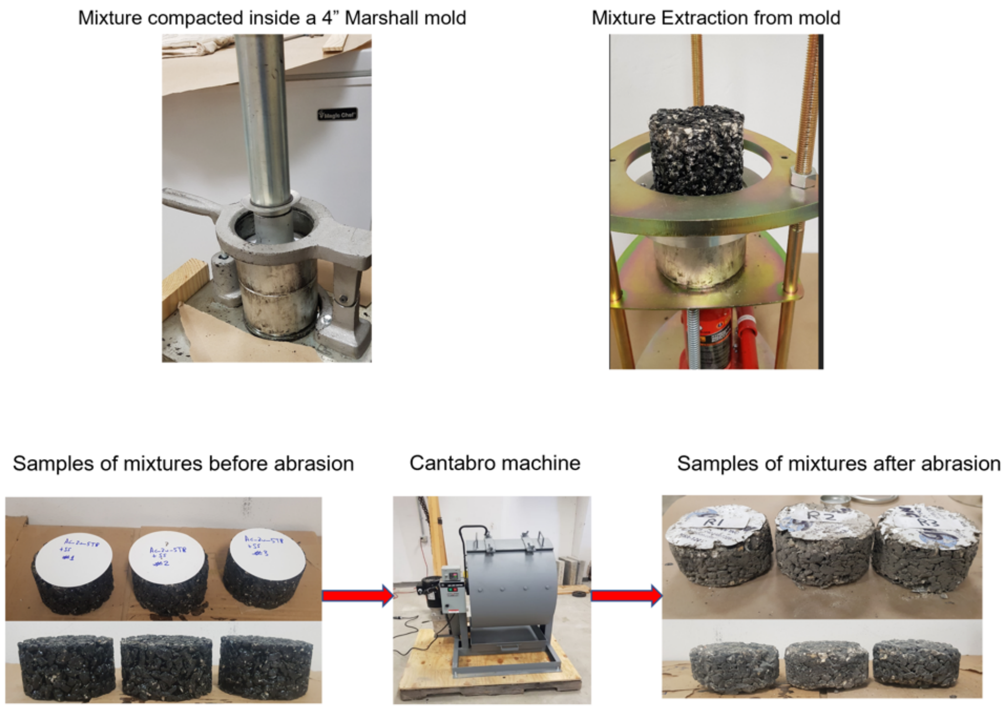


Figure 3.9. Specimen fabrication and testing using the Cantabro method

Figure 3.12 presents the results for all material combinations shown in Table 3.6. In terms of repeatability, the replicates resulted in a coefficient of variation that varied from 0% to 29.5%. This range is very reasonable considering the repeatability values for typical test methods used with asphalt materials. In terms of the sensitivity, the coefficient of variation for the averages of all material combinations was 51%. This high value of coefficient of variation indicates that the test method is also sensitive to different material types. Finally, in terms of accuracy, a qualitative assessment can be made by comparing the results from AC binders. As expected, for a given aggregate type, the AC-10 binder showed lowest adhesion compared to the other two binders. Another note from Figure 3.12 is that the emulsions and cutbacks showed much higher aggregate loss compared to the AC binders. It is suspected that this was potentially due to a combination of residual uncured emulsion or cutback and the tortuous nature of this test.

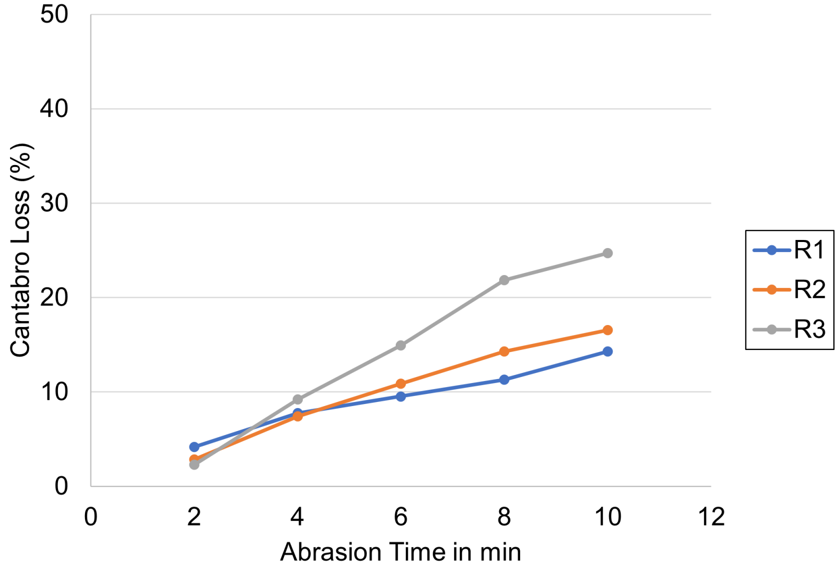


Figure 3.10. Cantabro loss for limestone + AC-20-5TR mixture.

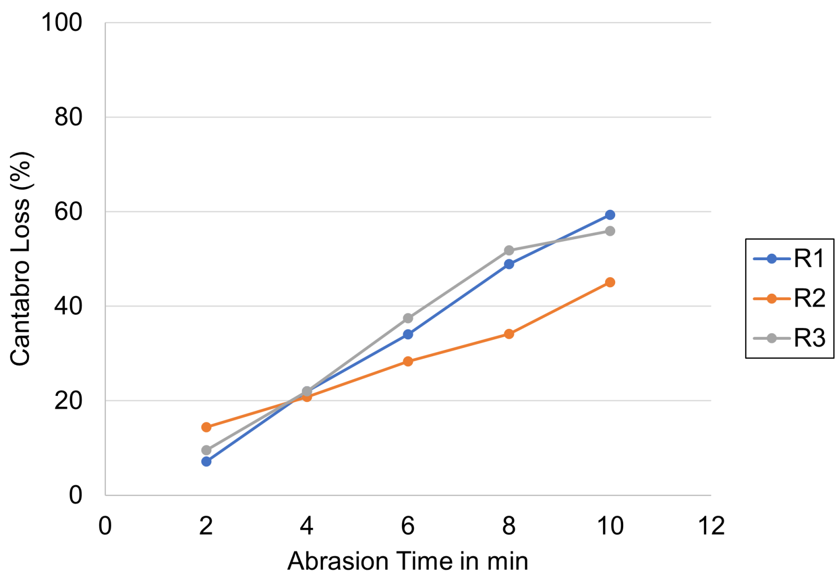


Figure 3.11. Cantabro loss for sandstone + AC-20-5TR mixture

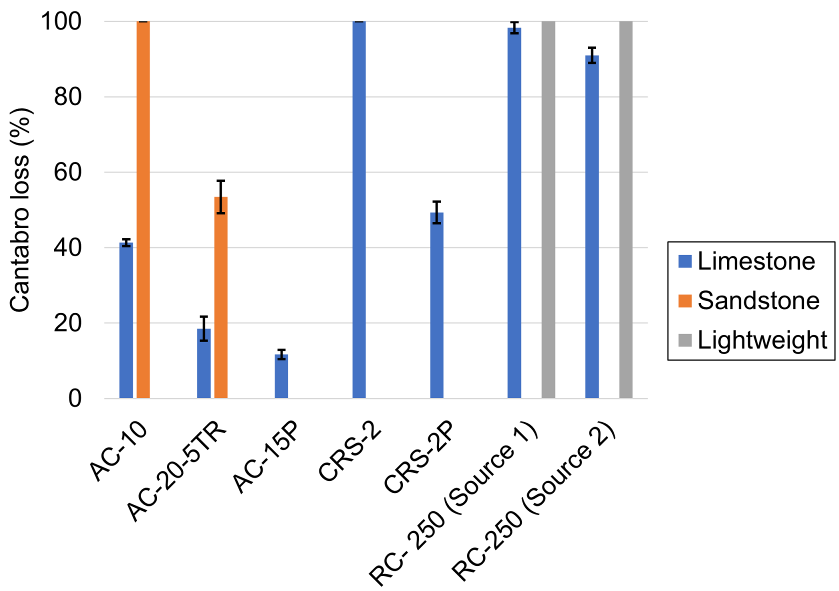


Figure 3.12. Cantabro loss for sealcoat mixtures to evaluate compatibility

3.7 PULL-OFF TEST

The research team examined the potential of using a pull-off test to measure the bond strength of the aggregate to the binder in a seal coat specimen. The specimen can be fabricated with project materials, conditioned in any way desired and then tested. This test method was closely based on another similar method that is being developed to evaluate tack coat adhesion in asphalt pavements.

3.7.1 Material combination and test variation

Table 3.7 presents the combination of different materials that were used to develop and evaluate the pull-off test method. Each material combination was intended to be evaluated using two different variations of the pull-off test: low tensile rate of loading (0.6 kN/second) and high tensile rate of loading (6 kN/second). As shown later in results and analysis, these tensile loading rates did not yield reaction loads that were large enough to be accurately recorded by the instrument. In order to overcome this limitation, significant changes to the device and loading configuration were required. Further, in light of the results from the previous methods, the development of this method was not pursued.

Table 3.7. Material combinations and test variations used to evaluate the pull-off test method

No.	Aggregate	Asphalt Binder	Tensile loading rate
1	Limestone	AC-10	Low pull-off rate
2	Limestone	AC-10	High pull-off rate
3	Limestone	AC-20-5TR	Low pull-off
4	Limestone	AC-20-5TR	High pull-off rate

3.7.2 Specimen fabrication

The specimen fabrication of this test consisted of two metal discs each 100 mm in diameter and with a rim of 2.5 mm height and a threaded hole on one side that was 15 mm deep. On the inside surface of one of the metal discs, a epoxy paste adhesive (gorilla glue paste) was applied and 7 to 8 aggregate particles were partially embedded into this adhesive paste. This disc was left to cure at room temperature for 24 hours so that the adhesive would cure and bond the metal with the aggregate particles. After the 24 hours, a sample of the asphalt binder was heated at 155°C and the second disk was placed in the oven at the same temperature for 10 min before pouring the binder. The binder was removed from the oven and poured to cover the entire area of the heated disc. Immediately after this, the disc that holds the aggregate was brought into contact with the asphalt binder and allowed to set for 30 min to develop adhesion. After the setting time, the bottom of fabricated specimen was fastened to the reaction plate using a bolt. The pulling stub of the automated pull-off device (Proceq Dy 206) was attached to the top of the fabricated specimen using a draw bolt and the legs of the device were adjusted to sit completely on the reaction plate. Finally, tensile loading was applied by the pulling stub of the device until the bond between the aggregate and the binder failed. The tensile loading used two different rates (low rate of loading and high rate of loading) as shown earlier in Table 3.7.

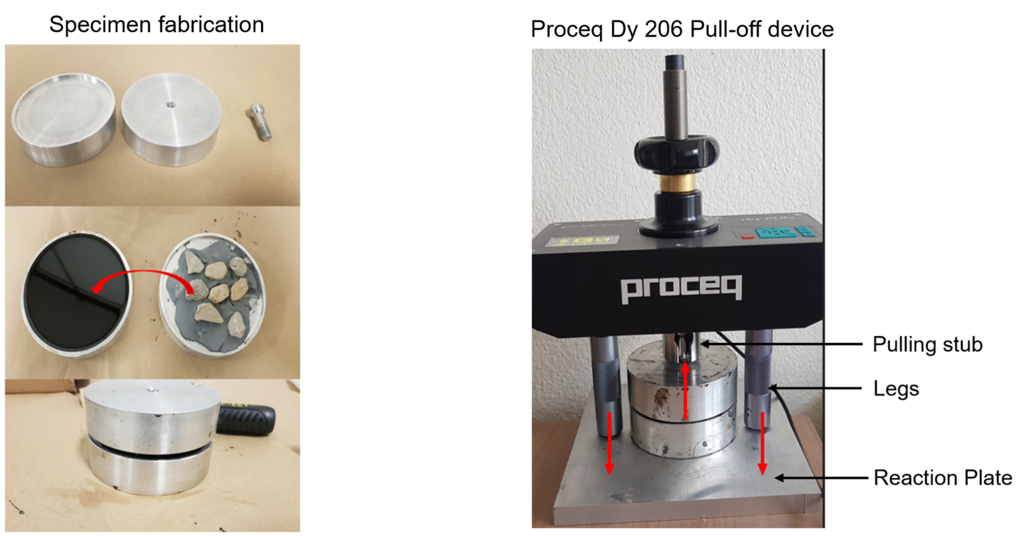


Figure 3.13. Specimen fabrication for the pull-off test.

3.7.3 Results and analysis

The preliminary results from this test showed that the total adhesive bonding between the aggregate particles and the binder was too low for the instrument to detect with adequate sensitivity. One means to mitigate this would be to configure the plate and increase the number of particles. However, this would require significant improvements to the set up and was not pursued any further.

3.8 SUMMARY

The main goal of this part of the study was to develop and compare different candidate test methods that can potentially be used to evaluate the quality of adhesion in seal coat materials. The candidate methods that included the Sweep test (with four different variations), Vialit test, Cantabro test, and the Pull-off test. A summary of the methods developed and evaluated in this portion of the study is provided below.

1. **Sweep test**
   - Overview: This method uses a planetary mixer that is retrofitted to abrade the surface of a laboratory prepared seal coat specimen. The test can be performed using different configurations in terms of the test speed and the fixture used to the abrade the surface. A sample preparation method was developed in this study and four different configurations were evaluated (low and high speed with a brush and PVC tube fixture at the end). The version with a rubber hose was found to be the most viable in terms of both repeatability and sensitivity.
   - Advantages: The sample preparation method and test itself are easy to conduct and interpret. The capital cost of the equipment is not too high and can be easily set up in any field or district laboratory or even at a contractors facility.
   - Limitations: The test requires some customization and fabrication of accessories to a commercial planetary mixer. There are commercial vendors who supply such accessories but such vendors are very few.
   - Summary: This approach is recommended for further evaluation in the remainder of this project as one of the two methods to evaluate the quality of adhesion between the aggregate and the binder.

2. **Vialit test**
    - Overview: This method uses a metal plate to prepare a sample of the seal coat. A controlled impact load is applied to the sample at low temperatures to assess the degree of debonding that occurs between the binder and the aggregate. A sample preparation method for hot applied binder was developed and the test was evaluated for its sensitivity under different test conditions.
    - Advantages: The sample preparation method and test itself are easy to conduct and interpret. The capital cost of the equipment is moderate and it is easy to setup in any district, field, or contractors laboratory. All components of this test are now commercially available. The test is conducted at low temperatures when the potential for raveling or debonding is high.
    - Limitations: The capital cost of the equipment and accessories (e.g. cooler to cool the sample to the test temperature and a heater to cure emulsion and cutback samples) is moderate (approximately <$10,000).
    - Summary: This approach is recommended for further evaluation in the remainder of this project as one of the two methods to evaluate the quality of adhesion between the aggregate and the binder.
3. **Cantabro test**
    - Overview: This method uses an LA Abrasion machine to evaluate the durability of a compacted specimen. A test method was developed to prepare and test durability of adhesion between the aggregate and binder used in seal coats.
    - Advantages: The sample preparation method and test itself are easy to conduct and interpret. The capital cost of the equipment is moderate and all equipment required to conduct the test are commercially available.
    - Limitations: The capital cost of the equipment is relatively higher compared to the other methods. From a technical standpoint a major limitation of this method is that the sample preparation procedure forces complete coating of the aggregate by the binder. In the case of precoated aggregates and hot applied seal coats, this method will not be sensitive to issues that may arise due to incomplete coating or improper coating. Also, sample preparation method using cutbacks and emulsions can take a lot of time to cure.

- Summary: This approach was not considered as appropriate to assess bonding for all seal coat applications and less advantageous compared to the two other methods.

4. **Pull-Off Test**

   The pull-off test proved not able to provide usable data, and while in theory may have merit, in reality cannot be performed in the procedure evaluated.

Based on these findings, the Sweep test and Vialit tests were considered as final candidates for further development and use with the remainder of the test matrix.

CHAPTER 4. MATERIAL SELECTION

This chapter summarizes seal coat materials selected for use in subsequent tasks for laboratory and field evaluation.

4.1 LABORATORY EVALUATION

The materials for laboratory evaluation were selected and obtained from various material producers or were synthesized in the laboratory to change the expected adhesive properties.

4.1.1 Materials from producers

For laboratory evaluation of different method to evaluate adhesion, the decision on material selection was based on results from surveys from Chapter-2. The materials included hot-applied binders (AC-10, AC-20-5TR, AC-15P), emulsions (CRS-2, CRS-2P); and aggregates representing four different mineralogy (limestone, sandstone, gravel, and rhyolite). In addition, asphalt binders with varying degrees of expected performance were also included. For example, AC-10 is typically not used for seal coat applications because it results in relatively poorer performance compared to AC-15P and AC-20-5TR. However, AC-10 was included to provide a relative qualitative baseline (i.e. expected to perform poorly) that could be used to evaluate the sensitivity of the test method. Similarly, CRS-2P is typically expected to perform better than CRS-2 on account of the polymer content. This relative, albeit qualitative difference in expected performance, will be used as a guide to assess the accuracy and sensitivity of the candidate test methods.

The materials identified above were obtained from different producers who supply seal coat materials to the state of Texas. The total number of producers were seven; three producers supplied seal coat binders and four producers supplied seal coat aggregates. For the latter, it was important to reach out to producers from different parts of the state of Texas to ensure a variety of aggregate mineralogy.

4.1.2 Synthesized binders produced in the laboratory

Another portion of material selection was to include synthesized binders that have been suspected to result in inferior performance. Specifically, one base binder was modified using a softening agent such as Recycled Engine Oil Bottom (REOB) and also separately using a stiffening agent such as Polyphosphoric Acid (PPA). It is worth iterating that the purpose of this modification is to artificially change the grade of the base binder to an AC grade binder that could be used for hot applied seal coat.

The modified binders were used with the selected test later in the study. However, before the step in which the test is performed, it is necessary to determine the optimal content at which each of these additives should be added to the base binder in order to achieve a target grade. In order to obtain an estimate of the amount of additive required to dose the base binder, two approximate values were found from the literature for each additive. Table 4.1 shows the starting points of these additives (Hajj.et al 2018, FHWA, 2012).

Table 4.1. Additives with starting points for modifications based on literature.

Additive	Lower Dose	Higher Dose
REOB	2%	10%
PPA	0.25%	1.2%

4.1.3 Summary

In summary, the materials selected for laboratory evaluation included a variety of combinations of binder and aggregate mineralogy. Table 4.2 below presents the materials selected for the experimental program that was carried out during the project.

Table 4.2. Aggregate and binder combinations for laboratory evaluation

Aggregate	Asphalt Binder
Limestone	AC-20-5TR
Limestone	AC-15P
Limestone	AC-10
Limestone	CRS-2P
Limestone	CRS-2
Limestone	xx (Modified with REOB)
Limestone	AC-10 (Modified with PPA)
Sandstone	AC-20-5TR
Sandstone	AC-15P
Sandstone	AC-10
Sandstone	CRS-2P
Sandstone	CRS-2
Sandstone	AC-10 (Modified with REOB)
Sandstone	AC-10 (Modified with PPA)
Gravel	AC-XX (Selected later in the study)
Gravel	CRS-XX (Selected later in the study)
Rhyolite	AC-XX (Selected later in the study)
Rhyolite	CRS-XX (Selected later in the study)

4.2 FIELD EVALUATION

One of the main goals of this project is to validate and refine the selected test method(s) using field materials. For this purpose, a multitude of field sections representing different geographical and climatic regions were identified. These sections were inspected before and after construction. Additional details on these sections are provided in the subsequent chapter. Materials from 34 of these field sections were sampled at the time of construction for further evaluation.

CHAPTER 5. RESULTS FROM LABORATORY TESTS

This chapter summarizes results from the materials evaluated in the laboratory testing program of this study.

5.1 TEST METHODS USED FOR LABORATORY EVALUATION

The Sweep and Vialit candidate test methods were selected in the previous tasks of this study as the potential candidate methods for use with laboratory and field materials. A detailed and standardized test procedure for use of these methods with both hot applied and emulsion-based seal coats was developed and is documented in an Appendix to this report. These included some modifications over the previously used procedures, made to accommodate ease of specimen fabrication, sample conditioning, and testing. These procedures were followed for all the testing reported in this chapter.

To summarize the Sweep test, the base binder was applied to a circular metal pan and a pre-specified amount of the aggregate was spread over the binder (Figure 5.1). A roller compactor was then used to compact and embed the aggregate into the binder. The sample was allowed to cool to room temperature as measured with an IR gun, then it was placed in the Sweep test machine, in which it was abraded with a rubber hose for one minute (Figure 5.2). Figure 5.3 shows a typical test specimen before and after testing. The percentage of aggregate loss was calculated by comparing the weight of the specimen before abrasion to the weight of the specimen after abrasion.

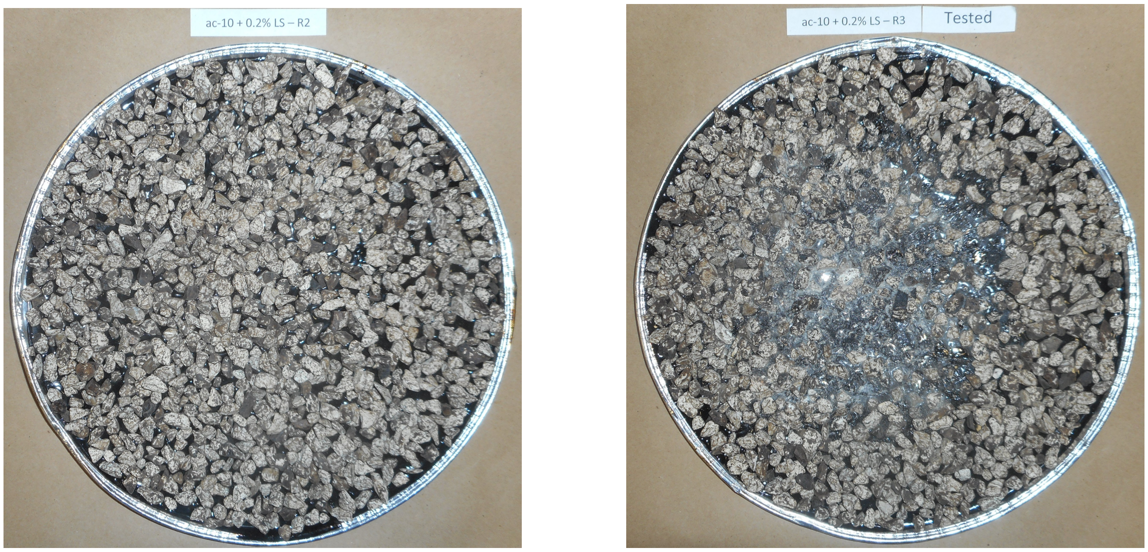
To summarize the Vialit test, the sample was created by heating and applying the base binder to a square metal tray. The aggregates were placed onto the binder and compacted using a roller compactor (Figure 5.4). The tray of binder and aggregate was placed in a refrigerator at 5°C for one hour to bring it to test temperature. Once the sample was temperature conditioned, it was removed from the refrigerator and placed upside down on metal supports. A 510 g steel ball was dropped three times on the back of the plate from a height of 50 cm (Figure 5.5). The percentage of aggregate loss was calculated by comparing the before and after weights of the specimen. Figure 5.6 shows a typical test specimen before and after testing. Since the Vialit test, unlike the Sweep test, is conducted at a low temperature, the Vialit results may be able to lend insight into the low-temperature adhesion behavior of seal

Figure 5.1. Specimen fabrication for the Sweep test.

Figure 5.2. Specimen in the testing setup for the Sweep test.

coats.

The above procedure summaries describe the procedure for hot applied binders. For both tests, curing procedures were added for using asphalt emulsion as binder. These are detailed in the test procedures attached in Appendix C.



(a) Before testing. **(b) After testing.**

Figure 5.3. Typical test specimen for the Sweep test.

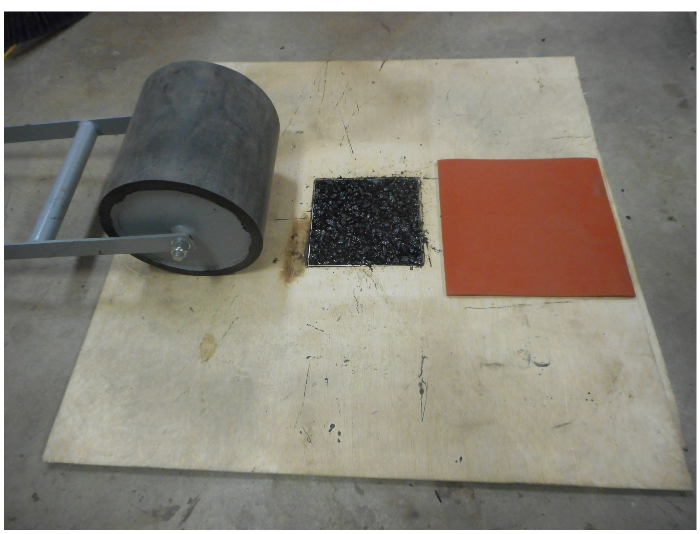


Figure 5.4. Specimen fabrication for the Vialit test.

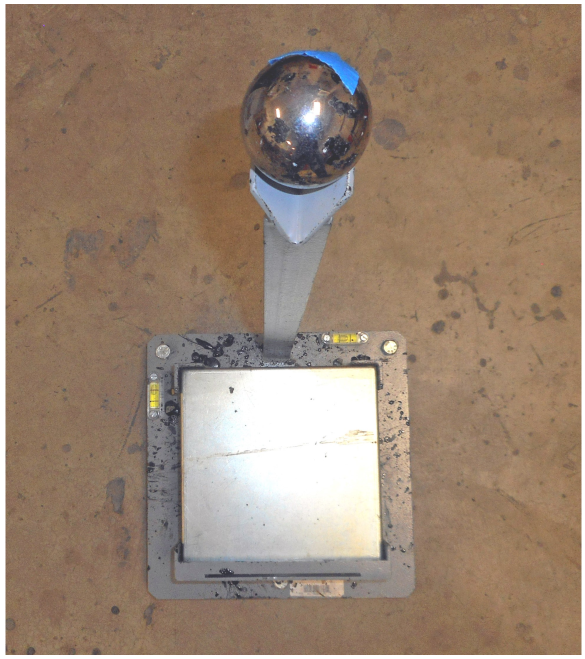


Figure 5.5. Specimen in the testing setup for the Vialit test.

(a) Before testing.

(b) After testing.

Figure 5.6. Typical test specimen for the Vialit test.

5.2 RESULTS

5.2.1 Impact of binder type

Figures 5.7 and 5.8 show the results from testing five different base binders using two different aggregates with the Vialit and Sweep tests, respectively. Note that in the case of AC-20-5TR and AC-10, the aggregates were precoated using 0.6% of PG 64-22 by weight of the aggregate. For the three emulsions, no precoating was applied to the aggregates. A few pertinent observations from these results are as follows.

Based on the results from the Vialit test, generally emulsions showed lower aggregate loss compared to hot applied, but this could also be an artifact of the test procedure itself (i.e. due to systematic biases in sample preparation). Overall CRS-2P emulsions showed the lowest loss closely followed by HFRS-2. AC-10 showed higher loss compared to AC 20-5TR, which is expected. Both aggregates showed similar performance and the results were more sensitive to the binder quality.

Results from Sweep test were different compared to the Vialit test. Based on the results from the Sweep test, overall CRS-2P and AC-20-5TR showed similar loss. To some extent, this is consistent with field experience.

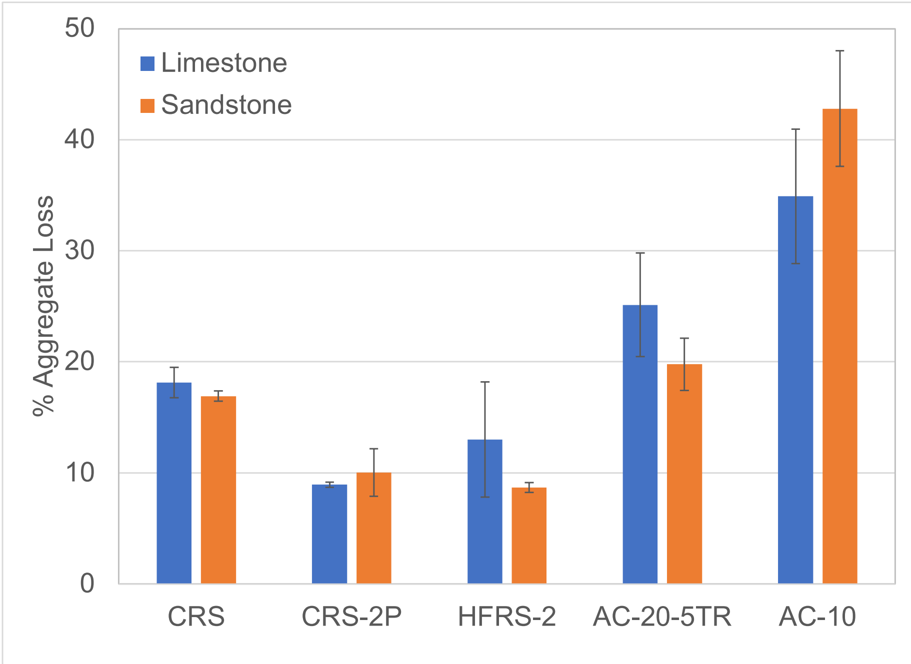


Figure 5.7. Results from the Vialit test showing the influence of five different base binder types on aggregate loss using two different aggregates.

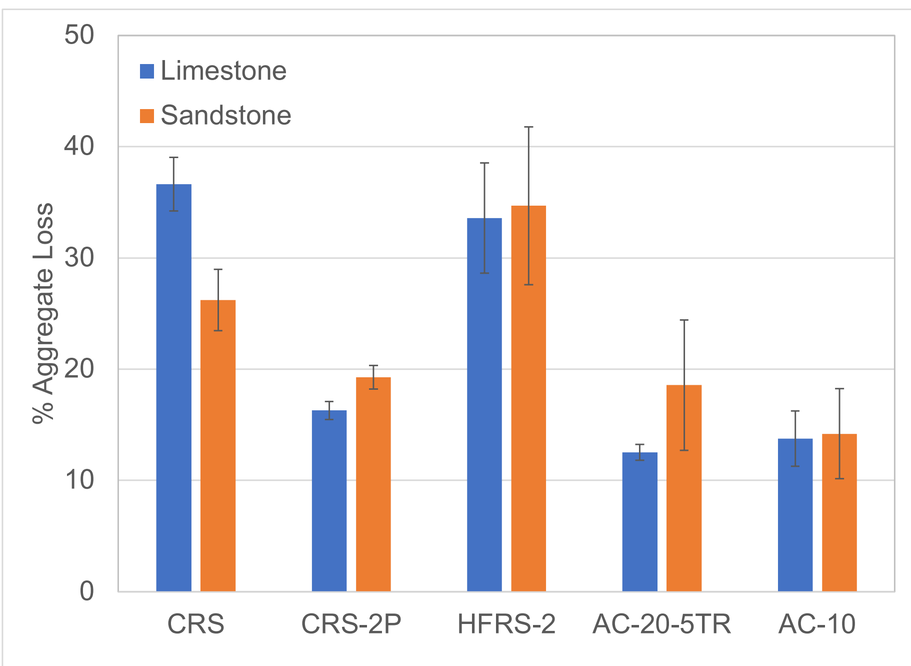


Figure 5.8. Results from the Sweep test showing the influence of five different base binder types on aggregate loss using two different aggregates.

5.2.2 Influence of aggregate type

Figures 5.9 and 5.10 show the results from testing four different aggregates using three different base binders (two hot applied and one emulsion) with the Vialit and Sweep tests, respectively. Note that in the case of AC-20-5TR and AC-10, the aggregates were precoated using 0.6% of PG 64-22 by weight of the aggregate. For the emulsion, no precoating was applied to the aggregates. A few pertinent observations from these results are as follows.

Based on the results from the Vialit test, all aggregates showed almost consistently that AC-10 had the highest loss followed by AC-20-5TR followed by CRS-2P (rhyolite was a slight exception). These results suggest that the Vialit test is more sensitive to binder quality rather than the aggregate binder adhesion.

Results from Sweep test were different compared to the Vialit test. Based on the results from the Sweep test, Limestone and Sandstone showed statistically similar results with all three binders. Gravel and Rhyolite showed slightly higher loss with CRS-2P compared to hot applied binders. However, these aggregates were precoated at a higher than optimal percentage as determined from another study.

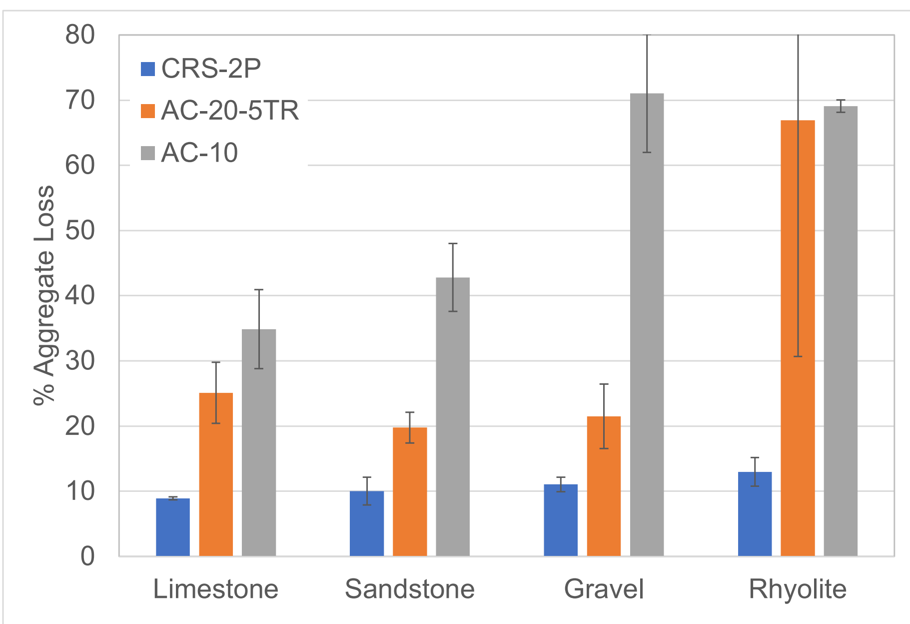


Figure 5.9. Results from the Vialit test showing the influence of four different aggregate types on aggregate loss using three different base binders.

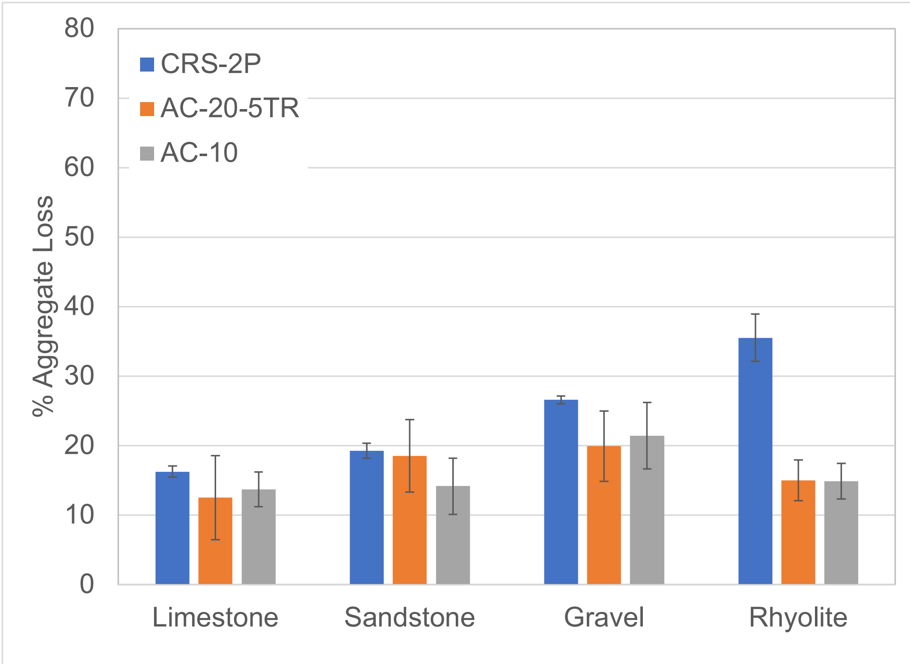


Figure 5.10. Results from the Sweep test showing the influence of four different aggregate types on aggregate loss using three different base binders.

5.2.3 Impact of dust

In order to evaluate the impact of dust on the quality of adhesion, limestone fines were sieved using the #200 sieve in the laboratory. These fines were added to the coarse aggregate (1% by weight of the aggregates) and thoroughly mixed to create "dusty aggregates". The dusty aggregates were then used with the CRS-2P emulsion and the Sweep and Vialit tests. These tests were conducted as before. Figures 5.11 and 5.12 consistently show the adverse impact of dust.

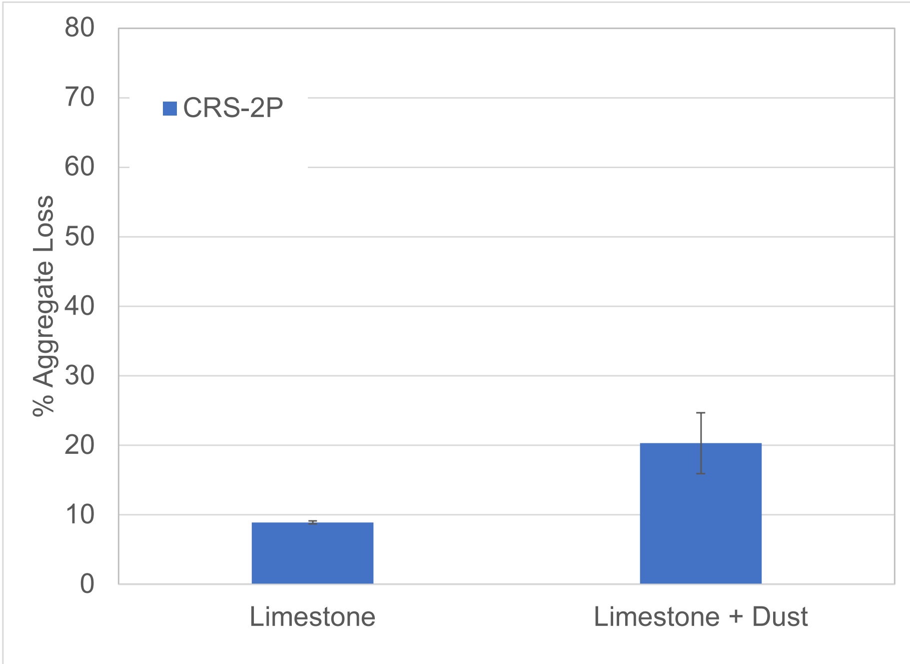


Figure 5.11. Results from the Vialit test showing the influence of dust on aggregate loss.

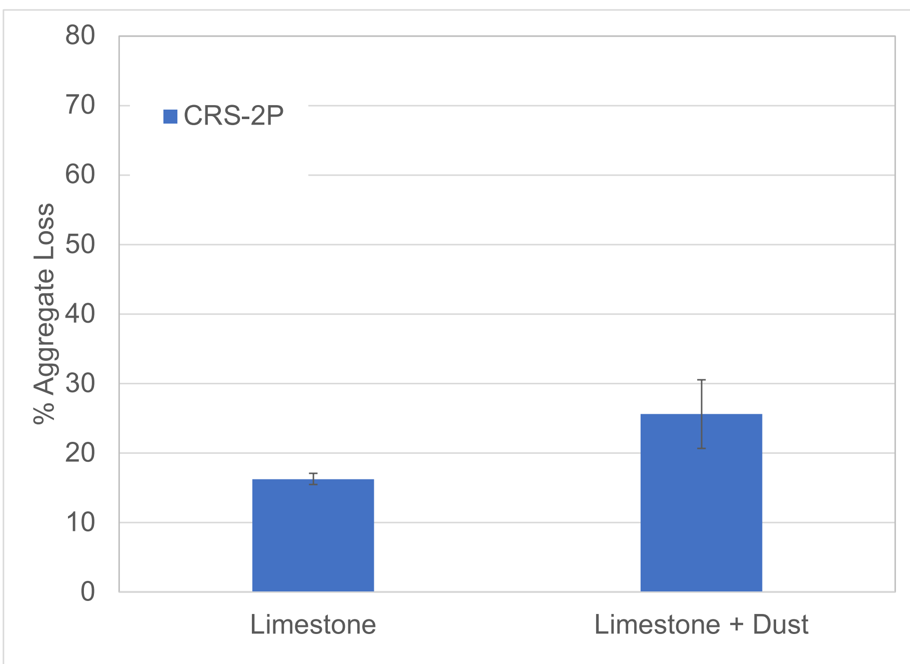


Figure 5.12. Results from the Sweep test showing the influence of dust on aggregate loss.

5.2.4 Influence of REOB and PPA

The influence of REOB and PPA was evaluated in two different ways on the quality of adhesion. A PG58-28 binder was blended with 1% PPA to produce close to a PG 64-22 binder in the lab, which was then used either for precoating the aggregates (at 0.6%) or as the base binder. Similarly, a PG 64-22 base binder was modified with 10% REOB to soften the binder, which was also used either for precoating the aggregates or as the base binder. All tests in this regimen were carried out using hot applied binders.

Aggregates precoated using PPA or REOB modified binders were evaluated using AC-20-5TR and AC-20XP as the base binder with the Vialit and the Sweep tests. Figures 5.13 through 5.16 show the results from these tests. These figures use the test results from the respective aggregates with PG 64-22 as the precoating binder and AC-20-5TR as the base binder as the baseline for comparison. The Vialit test results shows that the PPA and REOB modified binders used for precoating reduce the aggregate loss, although this reduction is not substantial. Interestingly, Sweep test results show that precoating with PPA and REOB modified binders had a negative impact on the adhesion quality with varying degrees depending on the type of binder and aggregate. However, when PPA or REOB modified binders were used as the base binders with aggregates precoated using a typical PG 64-22, both the Vialit and Sweep tests showed either no statistically significant change or an increase in the amount of aggregate loss (Figure 5.17 and Figure 5.18). All aforementioned results suggest a conservative position to disallow the use of PPA and REOB for either precoating or use as a base binder.

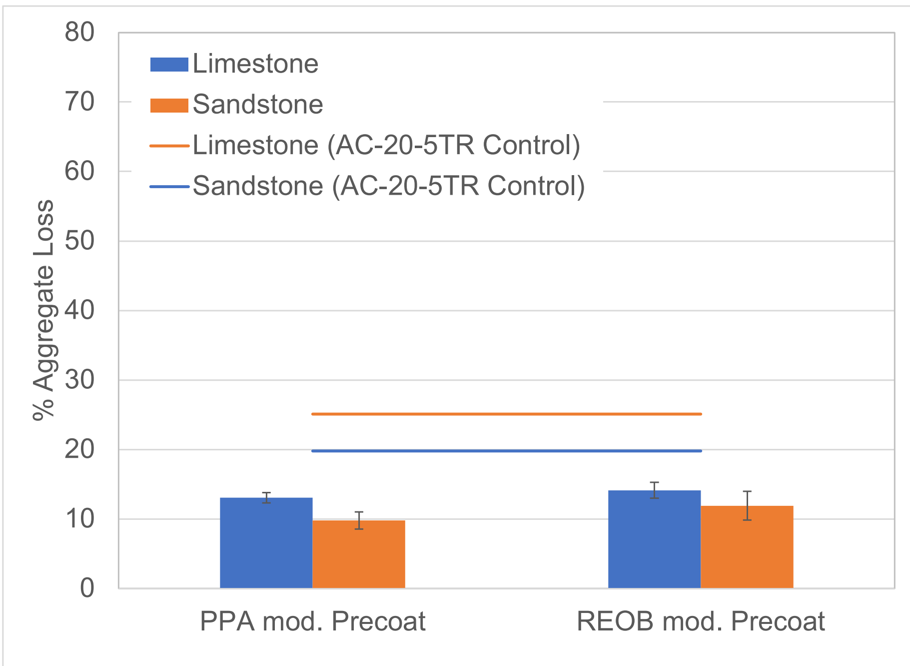


Figure 5.13. Results from the Vialit test showing the influence of PPA and REOB modified binders used for precoating with AC-20-5TR base binder on aggregate loss.

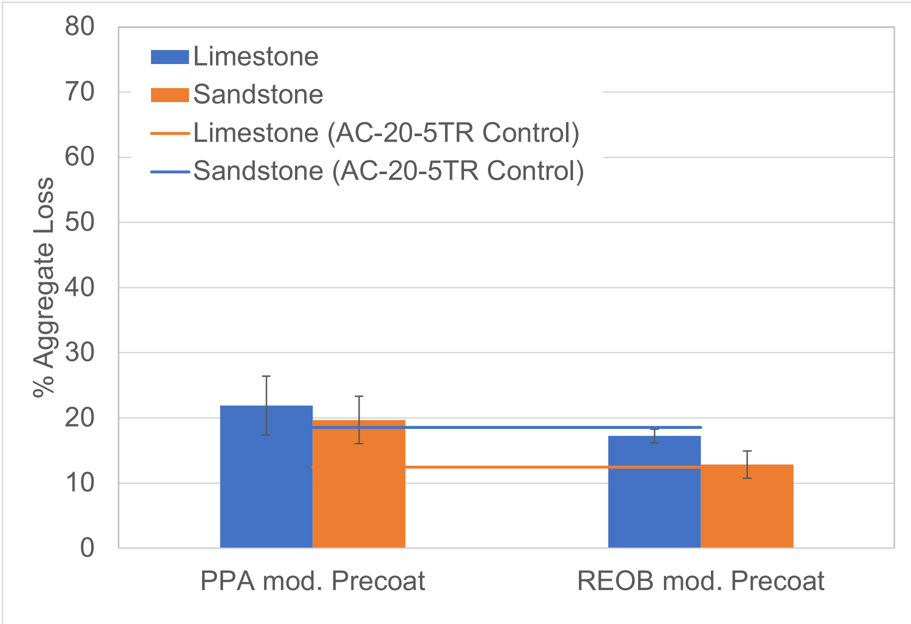


Figure 5.14. Results from the Sweep test showing the influence of PPA and REOB modified binders used for precoating with AC-20-5TR base binder on aggregate loss.

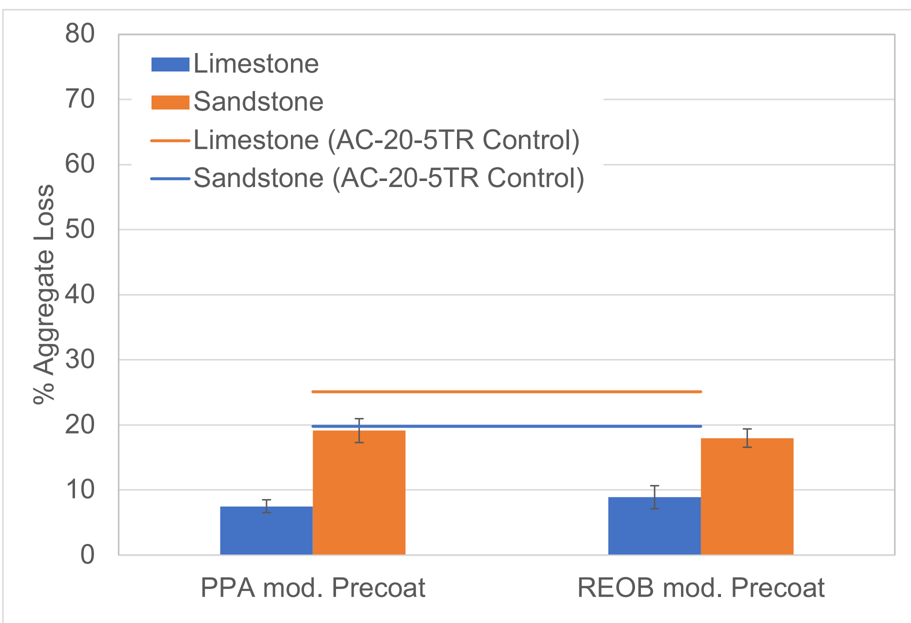


Figure 5.15. Results from the Vialit test showing the influence of PPA and REOB modified binders used for precoating with AC-20XP base binder on aggregate loss.

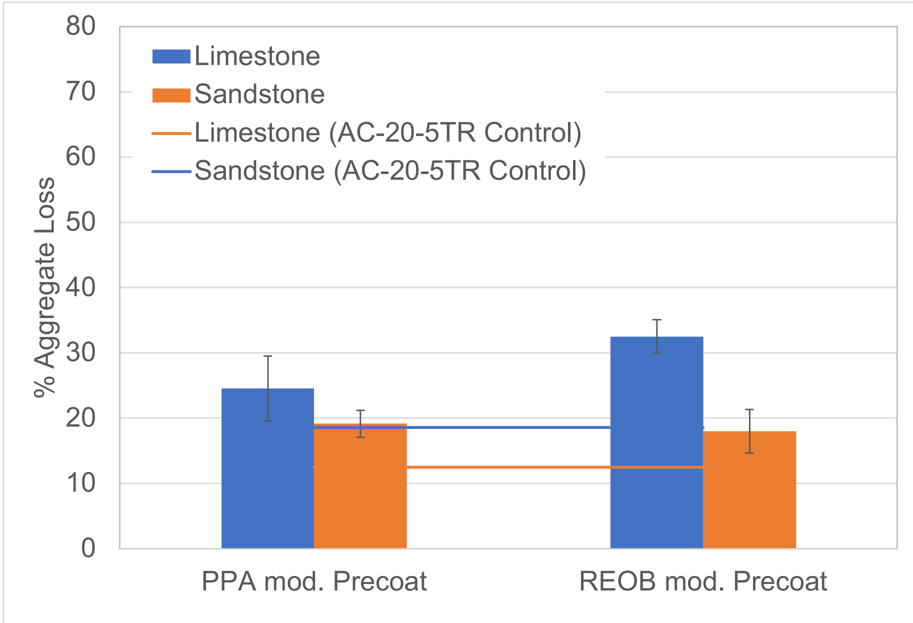


Figure 5.16. Results from the Sweep test showing the influence of PPA and REOB modified binders used for precoating with AC-20XP base binder on aggregate loss.

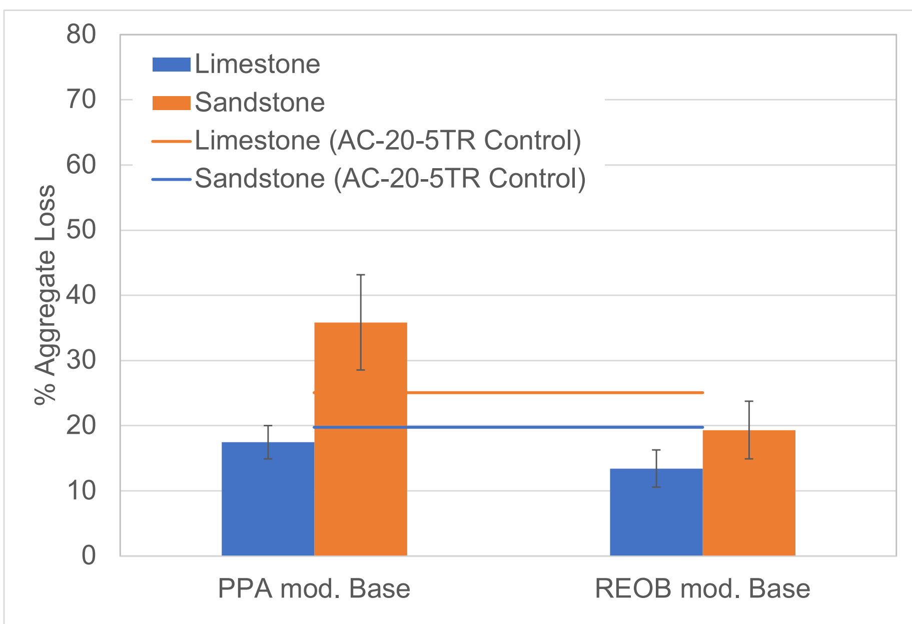


Figure 5.17. Results from the Vialit test showing the influence of PPA and REOB modified binders used for as the base binder on aggregate loss.

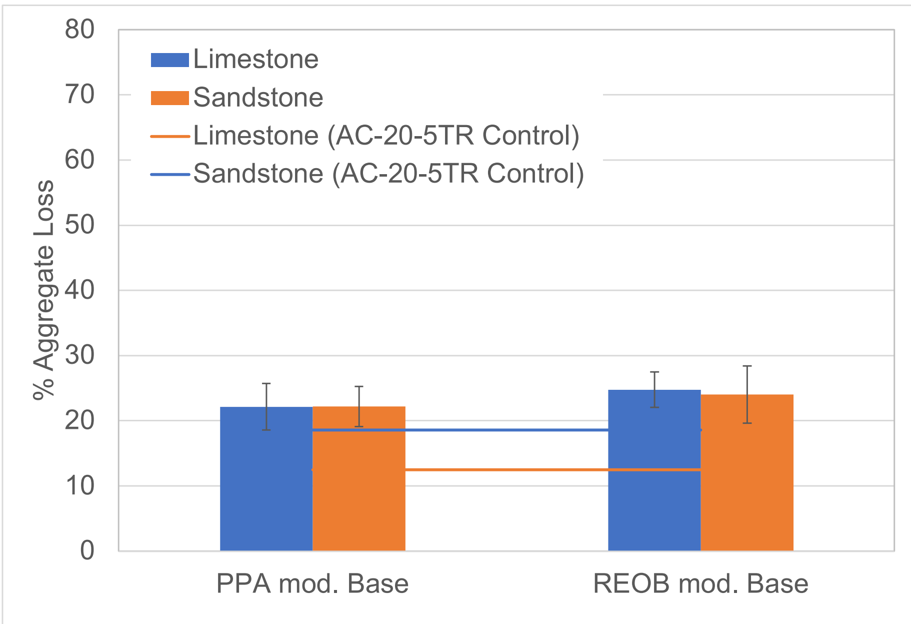


Figure 5.18. Results from the Sweep test showing the influence of PPA and REOB modified binders used for as the base binder on aggregate loss.

5.2.5 Influence of Liquid Anti-Strip Agent

One of the goals of this study was to evaluate whether or not a liquid anti-strip agent can improve the adhesion performance in a seal coat. This is particularly important in the context of aggregates that have inherently a very low surface texture or specific surface area such as gravels. To achieve this, samples for two commercial liquid anti-strip agents were obtained from a supplier typical to such applications. These two were referred to as Additive 1 and Additive 2. Based on producer recommendations, a PG 64-22 binder was blended using 1% of Additive 1 and 2% of Additive 2 at a temperature of 160°C. The blending was carried out using a heating mantle and a regular rotary blade (propeller type) blender at approximately 600 rpm for 30 minutes. The blended binder was used as the base of the seal coat with precoated gravel (conventional PG 64-22 was used as the precoating binder).

Figures 5.19 and 5.20 show the results from these tests. These results show that the use of these two liquid antistrip agents reduced aggregate loss based on the Sweep test. However, based on the Vialit test, only one of the liquid anti-strip agents showed some improvement with AC-20-5TR. In fact, with the Vialit test, the AC-10 binder showed similar or even worse performance with the liquid anti-strip additive. Another important point that must be noted here is that, although the Sweep test results show some improvement, the magnitude of this improvement may not be substantial to warrant the use of a liquid anti-strip agent. Nevertheless, these results show that the use of liquid anti-strip agents may be a potential solution when encountering problematic binder-aggregate pairs.

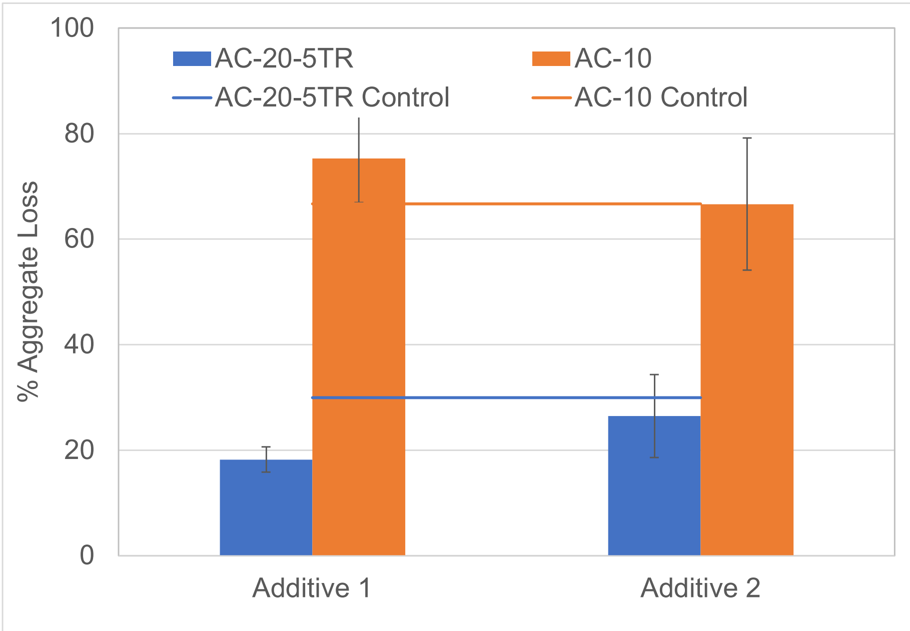


Figure 5.19. Results from the Vialit test showing the influence of liquid anti-strip agents on aggregate loss with gravel and AC-20-5TR and AC-10 binders.

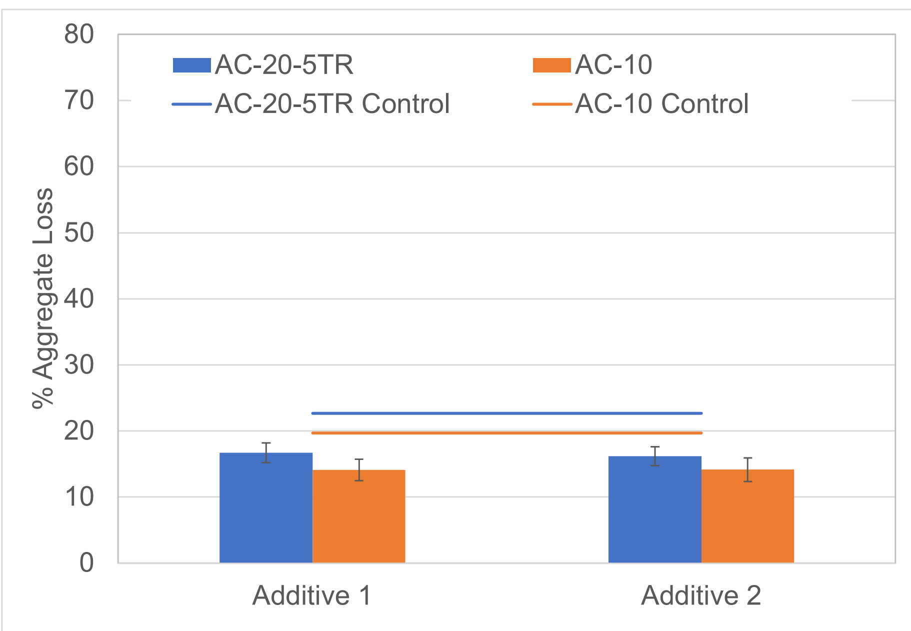


Figure 5.20. Results from the Sweep test showing the influence of liquid anti-strip agents on aggregate loss with gravel and AC-20-5TR and AC-10 binders.

CHAPTER 6. RESULTS FROM FIELD SECTIONS

6.1 FIELD EVALUATION

One of the main goals of this task was to validate and refine the selected test method(s) using field materials. To achieve this, a multitude of field sections representing different geographical and climatic regions were identified. These sections were inspected before and after construction. Figure 6.1 shows the location of these sections. The sections are grouped in this map based on the construction season and method of data collection (2018, 2020A, and 2020B). Note that the sections from 2018 construction season were from a different preceding study but the material samples and construction information were available for use to incorporate in this study. These sections were re-visited during the course of this study for performance evaluation. Details on material sampling and the protocols used for field inspection for these sections are described next.

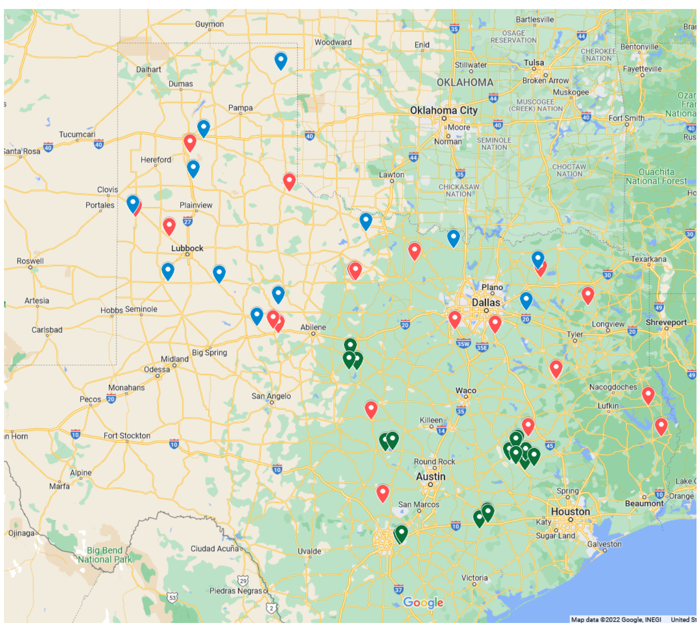


Figure 6.1. Seal coat sections monitored in this study; red pins indicate 2018 sections, green pins indicate 2020A sections, and blue pins indicate 2020B sections.

6.2 2018 SEAL COAT SECTIONS

The following process was used to document the performance of these sections.

- The research team reached out to the 25 Districts to identify seal coat jobs planned for the 2018 construction season. Based on the responses received, a total of 20 seal coat sections across the state were identified and included in a preceding study.
- For each section the research team documented the condition of the site immediately before construction. Representative areas of the existing pavement surface were imaged. A 3D laser profiler was used to obtain a point-cloud texture of the surface of the existing pavement. The location of sealed cracks were recorded via GPS and metallic nails were embedded on either side of the cracks at multiple locations. The research team tested the use of a metal detector to locate these metal nails after placing the chip seal. This was done to allow researchers to collect cores spanning across the crack at a future date if required.
- During construction, the research team used the carpet method to measure the amount of binder that was being placed on the surface at three different locations across the lane where the seal coat was being placed. A comparison of the measurements from the carpet method and the specified design application rate showed that the actual application rate met the design requirements in all cases and that the distributors were well calibrated.
- Immediately after construction, the 3D laser profiler was used again to obtain the texture of the newly constructed surface. The texture measurements were taken on and between wheel paths. The surface of the pavement was imaged at representative locations.
- Materials used during construction were sampled and taken to the research laboratory. Note that in some cases, it was not feasible to obtain a sample of the asphalt binder on site. In such cases, a sample was requested from the contractor.
- After approximately three years from construction, these sites were visited again. During this visit, the surface of the pavement was examined. The 3D laser profiler was used again to obtain a point cloud of the surface texture that could be used for quantitative analysis. Representative locations of the section were

imaged.

6.3 2020A SEAL COAT SECTIONS

The following process was used to document the performance of these sections.

- The research team reached out to the 25 Districts in the fall of 2019 to identify seal coat jobs planned for the 2020 construction season. Based on the responses received, a total of 30 seal coat sections across the five climatic zones of Texas were identified and included in the study.
- Field visits were conducted during and approximately one to two years after construction for 17 out of 30 of these sections. Another 12 sections were included in the "2020B" group discussed below.
- The process used to document the site condition before, immediately after, and approximately one to two years after construction was very similar to the 2018 sections listed above, with the exception that no verification of binder application with the carpet method was performed. Similar to the 2018 sections, materials were sampled for validation testing as needed (note that in some cases sample of the asphalt binder was not immediately available).

6.4 2020B SEAL COAT SECTIONS

- The sections in this group were 12 from the 30 identified from the 2020 construction season that were not from the "2020A" group discussed above. Due to logistical constraints and travel restrictions, it was not feasible to visit these sections during construction, although these sites were visited after construction.
- Regarding field inspection for these 12 sections, site engineers were asked to capture a set of 2D images (one set included 12 to 18 images) of representative areas of the sections before and immediately after placement of the seal coat. A field guide with illustrative visuals was developed for this task and shipped to site engineers. The shipment also included four plastic strips that are intended to be used as a calibration tool for the 3D model generated from these images. The purpose of these images was to explore whether it was feasible to obtain 3D texture measurements using photogrammetry with 2D images from the field. This is discussed in the subsequent sections.

- Site engineers were also asked for assistance to sample and ship materials to the research lab because of constraints in travel during the period of this study.
- Research team members visited these sections approximately one to two years after placement for a field assessment. Representative locations of the section were imaged and condition of the pavement was recorded.

6.5 ANALYSIS OF 2018 AND 2020A SECTIONS

The 3D point cloud data was available for these sections immediately after construction as well as one to three years after construction. These data were used to quantify the texture of the pavement immediately after construction as well as after a performance period. The texture from these two points in time was used to estimate the loss in texture over time. Figure 6.2 shows a typical example of the 3D mesh (along with a plane fitting the profile) using the point cloud measured at a section from the 2020 construction season on US 87. The seal coat binder was AC-20-5TR and the aggregates were precoated Grade 4 SAC B.

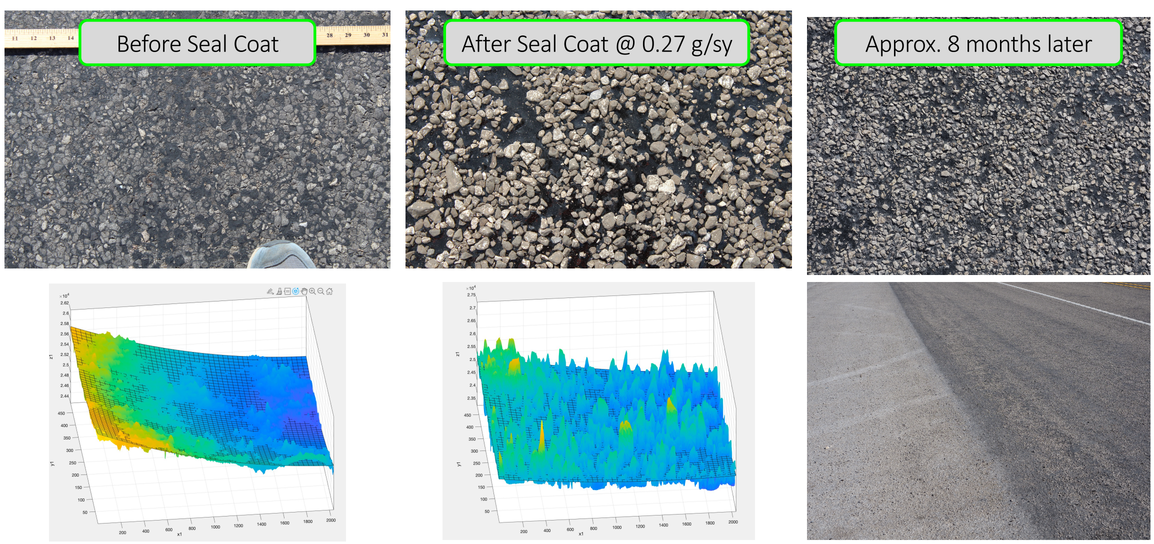
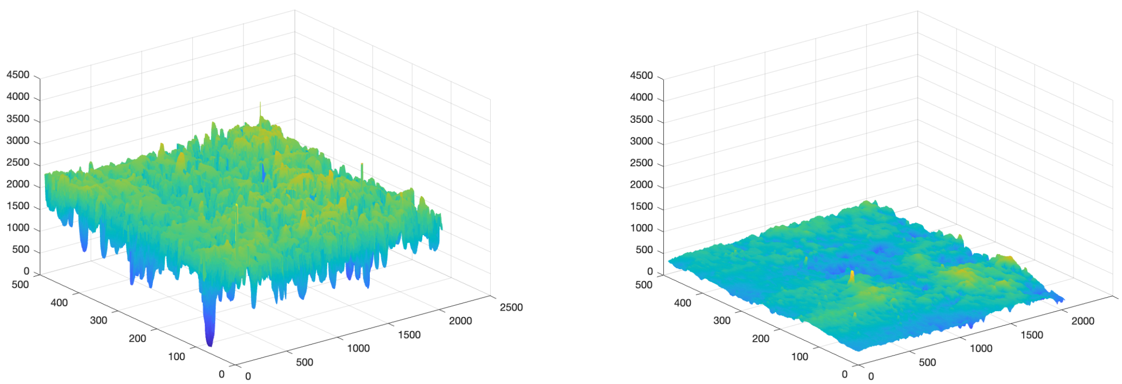


Figure 6.2. The 3D model generated using a point cloud (top left - image before seal coat, bottom left - 3D scanned image before seal coat, top middle - image after seal coat, bottom middle - 3D scanned image after seal coat, top and bottom right - images approximately 8 months later).

In terms of a quantitative measure of texture, the 3D point cloud data from the laser profiler was analyzed as follows. A second-degree polynomial surface was fit to the point cloud. Note that slight difference in pressure applied to scanner during measurement, geometry or camber of the pavement surface, and slight variations in the alignment of the profiler can cause the profile to drift from an ideal flat surface. However, the process of fitting a surface can compensate for these effects. The error from the actual points measured to the best fit surface was used as a quantitative measure of the texture. Simply put, higher error from the best fit surface indicates a coarser texture and vice-versa.

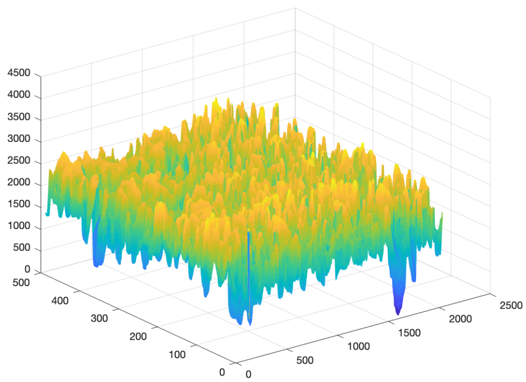


(a) Immediately after placement. **(b) Three years after placement.**

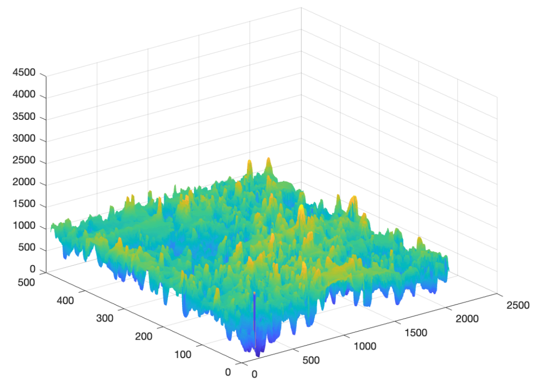
Figure 6.3. Texture from a typical section that has shown substantial loss in texture over period of observation.

The quantitative measurements of texture were used to calculate texture loss as shown in Equation 6.1. A summary of this parameter is presented in Table 6.4.

$$\text{Texture Loss (\%)} = \left(1 - \frac{\text{texture after period of performance}}{\text{texture immediately after construction}}\right) \times 100 \qquad (6.1)$$



(a) Immediately after placement.



(b) Three years after placement.

Figure 6.4. Texture from a typical section that has shown resistance to texture loss over period of observation.

6.6 ANALYSIS OF 2020B SECTIONS

These sections were not accessible for quantitative texture measurement using the profiler due to logistical constraints at the time of construction. Therefore, for these sections an alternative approach using photogrammetry was explored to measure the texture of the seal coat surface. To achieve this, the site engineers were asked to take images of the seal coat surface before and after construction using their smartphone camera. The engineers were provided with plastic strips to create a 12-inch x 12-inch box on a representative area to use as a subject for the images. The engineers were asked to take the images by going around the strips. For example, they were asked to start from the middle of one of the strips (say 12 o'clock position) and then take an image as they moved around the square (e.g. from approximately 1 o'clock, 2 o'clock, 3 o'clock and so on). In addition to the 12 photos above, they were asked to take another 6 to 8 images from random locations around the square so that there are a total of at least 18 to 20 images per set. Figure 6.5 shows some of the typical images acquired using this process.

The images collected from this process were used with a commercial photogrammetry software to obtain a 3D point cloud of the surface with adequate resolution that can be used to quantify the surface texture. Figure 6.6 shows the images being converted to a 3D point cloud matrix. Figure 6.7 shows the final 3D point cloud distribution from the set of images. Note that the purpose of this exercise was only to explore the feasibility of this approach for future use, if needed. Only a subset of these sections were imaged immediately after construction but were not imaged after the performance period due to limitations in the access to the photogrammetry software.

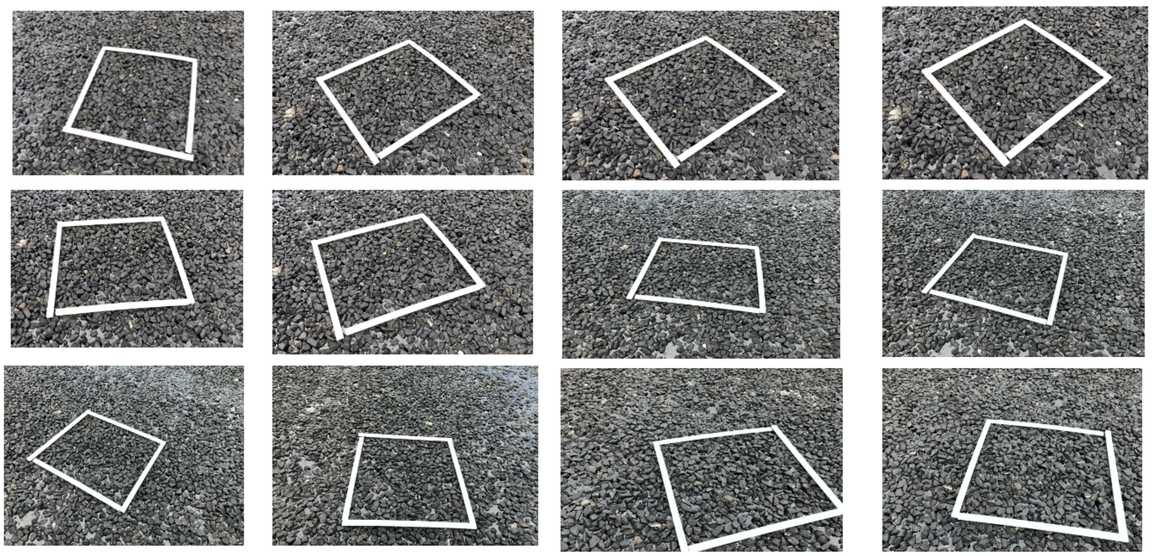


Figure 6.5. A set of 2D images of US84 after the placement of seal coat at the wheel path (courtesy: Mr.Stewart Chapman from Abilene district).

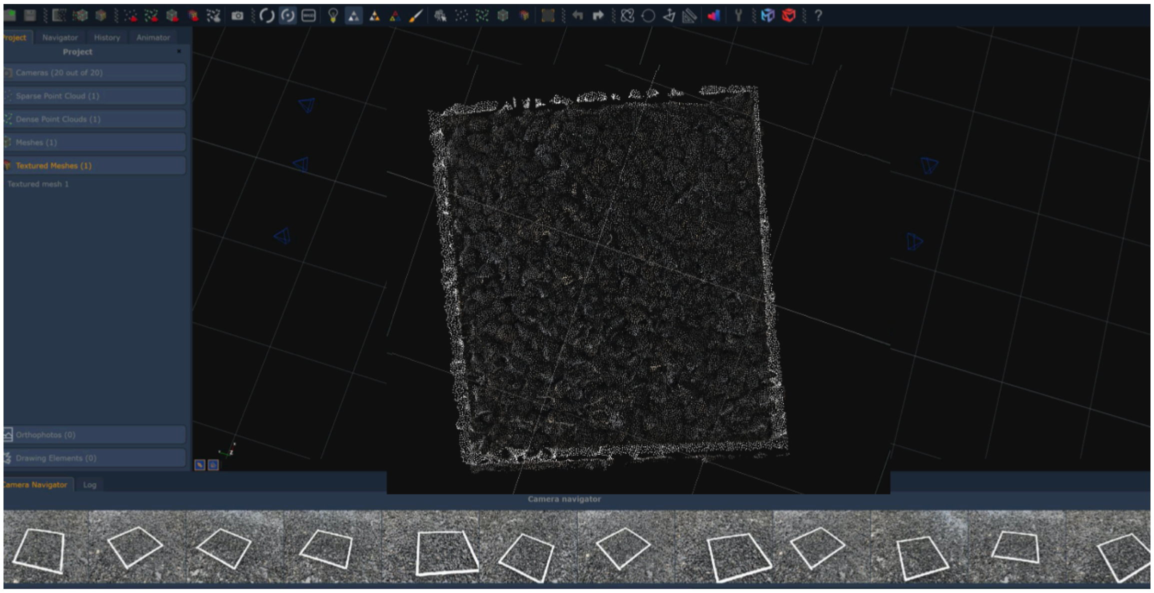


Figure 6.6. A 3D model of the US 84 seal coat section generated from 2D images using photogrammetry algorithms.

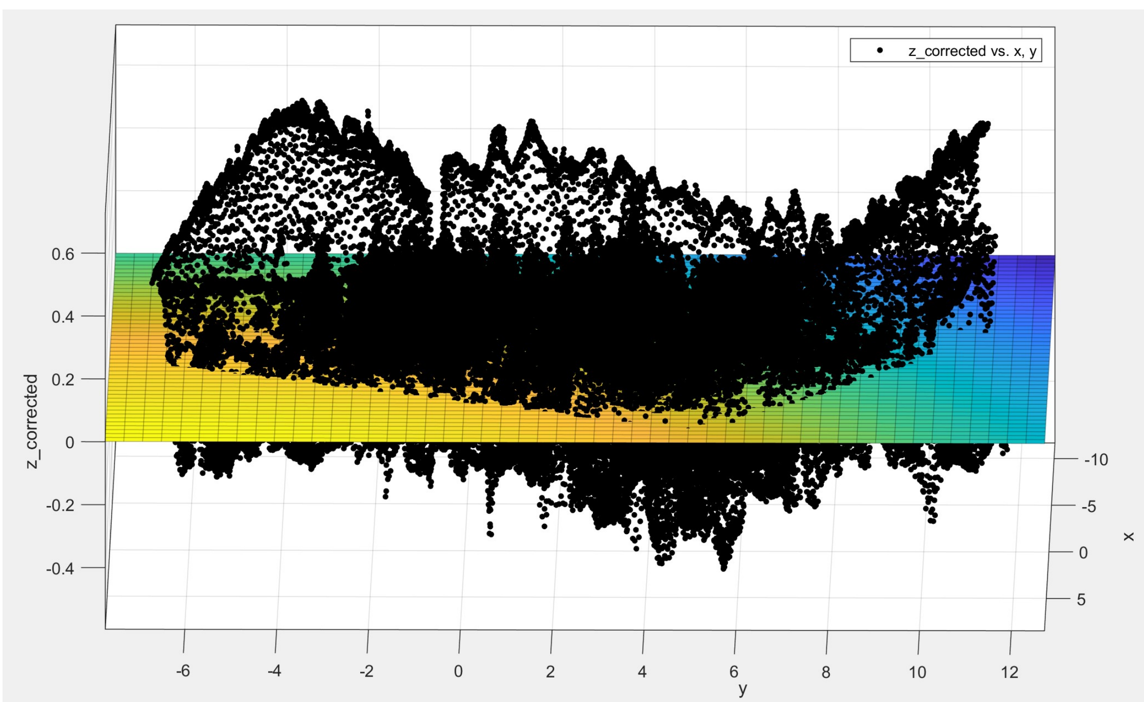


Figure 6.7. Point cloud showing aggregate distribution on a sample image of the US 84 seal coat section generated from 2D images using photogrammetry algorithms.

6.7 PERFORMANCE OF FIELD SECTIONS

Texture measurements were available for the 2018 and 2020A sections and were used to calculate the texture loss over the observation period of the pavement using Equation 6.1. In addition, a qualitative assessment was made for all the 49 sections evaluated in this study. Table 6.4 presents a summary from the visual assessment as well the texture loss measured. The qualitative assessment was based on a scale of 1 to 5 with 1 being the poorest performance and 5 being the best performance. An appendix to this report also presents images and a summary of the qualitative (all sections) as well as the quantitative texture loss (2018 and 2020A sections).

Figure 6.8 illustrates a distribution of the sections based on the qualitative ranking and Figure 6.9 illustrates a distribution of the sections based on the quantitative texture loss. It is very important to emphasize that both the qualitative and quantitative rankings are based on the overall condition of the seal coat after one to three years of performance. The overall condition of the pavement is a function of ravelling or adhesion loss as well as aggregate embedment into the substrate of the seal coat. Although the focus of the present study is adhesion loss, it must be pointed out that very few sections showed aggregate loss due to raveling and even in such cases, the aggregate loss was very low. In almost all cases, aggregate loss was due to the "punching in" or embedment of the aggregate particles into the surface of the pavement.

Table 6.1. Qualitative and quantitative rating of field sections (Part 1 of 4)

Section No.	Comments	Qualitative Rating	% Texture Loss
1	Slight aggregate loss in wheel path.	4	56%
2	Slight loss of aggregate but appears to be sparse coverage at the time of application	4	68%
3	Slight loss of aggregate along the wheel path.	3	56%
4	Significant bleeding. Some aggregate loss and lots of submerged aggregate. Wheel path is worst.	2	83%
5	Aggregate loss. No apparent bleeding. Aggregate loss even higher in between wheel paths.	2	40%
6	Significant Bleeding in wheel path. Looks more like submerged than raveled.	2	81%
7	Some aggregate loss and/or punched into underlying layer. This is more in the wheel paths.	3	42%
8	Combination of aggregate loss and punchdown in wheel paths.	2	82%
9	Some aggregate loss, but no bleeding. This may have been a low aggregate rate.	3	38%
10	Slight aggregate loss in wheel path.	4	49%
11	Some aggregate loss in wheel path. Looks more like loss than embedment.	3	52%
12	Some aggregate punched into underlying layer producing higher embedment in wheel path. Some aggregate loss between wheelpaths. Still very functional.	3	69%
13	Bleeding in wheel path. Not much rock loss.	3	84%
14	Slight bleeding in wheel path. Rock is more submerged than lost.	4	54%
15	Some aggregate loss and/or punched into underlying layer. This is especially evident in the wheel paths.	3	66%

Table 6.2. **Qualitative and quantitative rating of field sections (Part 2 of 4)**

Section No.	Comments	Qualitative Rating	% Texture Loss
16	Either slight loss of aggregate or not complete coverage initially. But aggregate appears to be submerged either by too much asphalt or being punched into the underlying layer.	3	56%
17	Flushing, especially in the wheel path. Does not appear to have significant aggregate loss.	3	72%
18	Significant Bleeding and Aggregate loss. Wheel path may be worse, but bleeding is on most of road.	1	85%
19	Looks good. Lanes including wheel paths look as good as shoulders.	5	NA
20	Significant aggregate loss, especially in the wheel path.	2	NA
21	Aggregate loss. More outside wheel path.	2	57%
22	Slight aggregate loss in outside wheel path.	4	40%
23	Some aggregate loss more noticeable in wheel path.	3	56%
24	Bleeding in wheel path. Looks to be aggregate submersion from too much asphalt or punch in. Road is rutted also.	2	59%
25	Slight aggregate loss or higher embedment on outside wheel path.	4	45%
26	Bleeding in wheel path. Looks to be aggregate submersion from too much asphalt or punch in.	3	62%
27	Some aggregate loss and some high embedment.	3	49%
28	Some aggregate loss and/or punched into underlying layer. This is especially evident in the wheel paths.	3	63%
29	Bleeding in wheel path. Looks to be aggregate submersion from too much asphalt or punch in. There is rutting apparent too.	2	68%

Table 6.3. Qualitative and quantitative rating of field sections (Part 3 of 4)

Section No.	Comments	Qualitative Rating	% Texture Loss
30	Bleeding in wheel path. Looks to be aggregate submersion from too much asphalt or punch in.	2	82%
31	Slight filling of voids in wheel paths. Not bleeding at least yet.	4	50%
32	Bleeding in wheel path. Looks to be aggregate submersion from too much asphalt or punch in.	2	78%
33	Slight higher embedment in wheel paths. Generally looks good.	4	63%
34	Some punch-in in wheel paths. Some streaking evident. I would have rated as 2, but it is better than others rated as 2.	3	62%
35	Some aggregate loss and/or punched into underlying layer. This is especially evident in the wheel paths.	3	60%
36	Slight aggregate loss or outside wheel path. Higher embedment in wheel path.	4	65%
37	Some aggregate loss and/or punched into underlying layer. This is especially evident in the wheel paths.	3	62%
38	Some aggregate loss and/or punched into underlying layer. This is especially evident in the wheel paths.	3	NA
39	Looks like minor aggregate loss. Most aggregate is above the surface that continues to give texture to the seal coat even though embedment is on the high side.	4	NA
40	Looks like good embedment. Some minor aggregate loss in some areas of wheel path. Wide view looks good.	4	NA
41	Still functional, but aggregate looks very embedded. Some higher embedment still in wheel paths or minor rutting.	2	NA

Table 6.4. Qualitative and quantitative rating of field sections (Part 4 of 4)

Section No.	Comments	Qualitative Rating	% Texture Loss
42	Minor aggregate loss between wheel paths. Aggregate has enough embedment. Functional.	3	NA
43	Looks like minor aggregate loss. Most aggregate is above the surface that continues to give texture to the seal coat even though embedment is on the high side.	4	NA
44	Bleeding in wheel path. Looks to be aggregate submersion from too much asphalt or punch in. There is rutting apparent too.	2	NA
45	Rate 2 because of high embedment, especially in wheel paths. No aggregate loss. Wide shot does not look as bad as close up.	2	NA
46	At this location, appears to have aggregate loss in wheel path and submersion of that is left.	1	NA
47	Severe aggregate loss or punch-in in the wheel paths. Shoulders look good in wide shot. Cannot have good skid. You are riding on asphalt in the wheel paths.	1	NA
48	Still functional, but aggregate looks very embedded. Some higher embedment still in wheel paths or minor rutting. Just not embedded as much as #47.	2	NA
49	Aggregate is not punched in like others, but there are some local areas of aggregate loss. Functional for texture.	3	NA

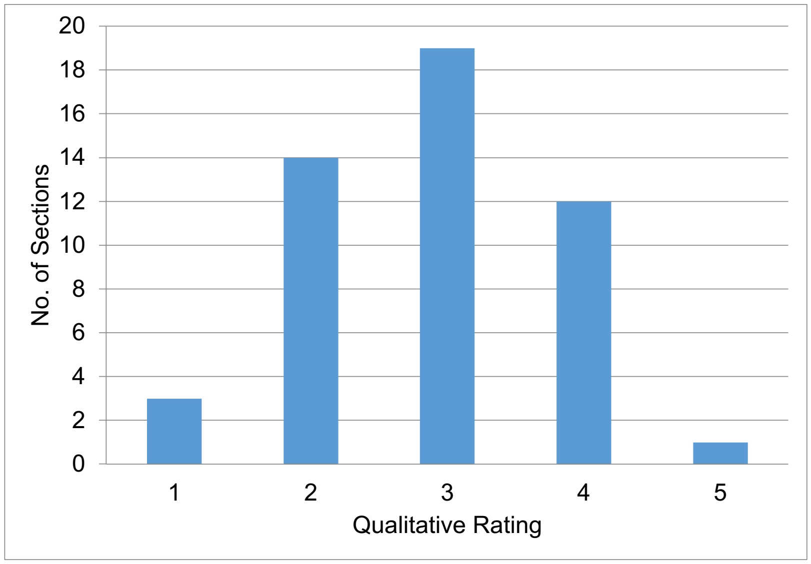


Figure 6.8. Distribution of sections based on qualitative ratings showing worst (left) to best (right) performance (NOTE: aggregate loss in most sections was due to embedment and not adhesion loss).

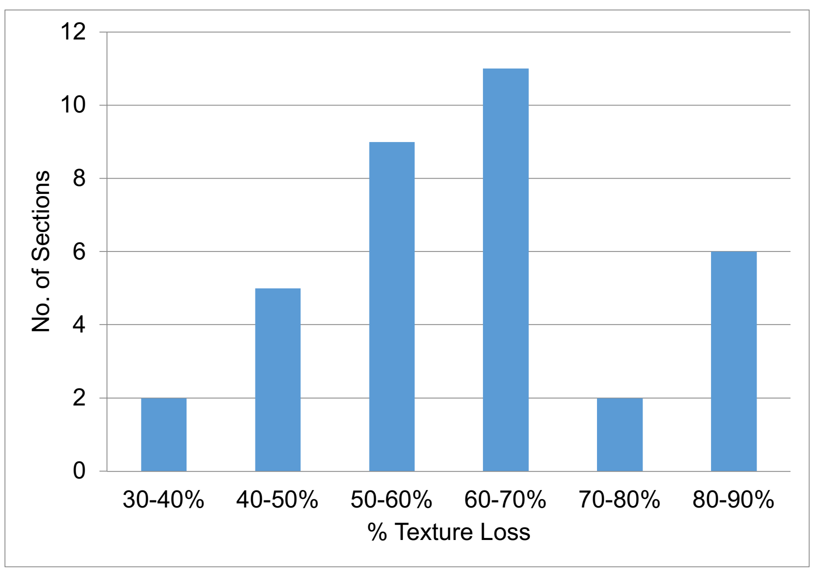


Figure 6.9. Distribution of sections based on percentage texture loss showing best (left) to worst (right) performance (NOTE: aggregate loss in most sections was due to embedment and not adhesion loss).

6.8 LABORATORY ADHESION TESTS USING FIELD MATERIALS

A subset of the field sections were selected to evaluate the quality of adhesion between the binder and aggregate using the materials sampled from the different field sections. These materials were used with the Sweep and the Vialit tests following procedures that were described in the previous chapters. It is important to emphasize that none of the field sections showed any substantial amounts of aggregate loss due to adhesion. Not withstanding the above, laboratory tests on field materials were performed to assess the typical range of aggregate loss from the laboratory on field materials as well as a threshold that is acceptable for materials intended to be used in the field.

Since the Vialit test, unlike the Sweep test, is conducted at a low temperature, the Vialit results may be able to lend insight into the low-temperature adhesion behavior of seal coats.

Figures 6.10 and 6.11 present the distribution of results from the Sweep and the Vialit tests. Figures 6.12 and 6.13 compare the texture loss measured in the field to the aggregate loss measured using the Sweep test and the Vialit test, respectively. In reviewing these figures it must be emphasized that although the texture loss in the field is a reflection of multiple mechanisms, i.e. embedment and adhesion loss, of which the former is the dominant mechanism based on field observations, the aggregate loss measured in the laboratory tests is exclusively due to adhesion loss.

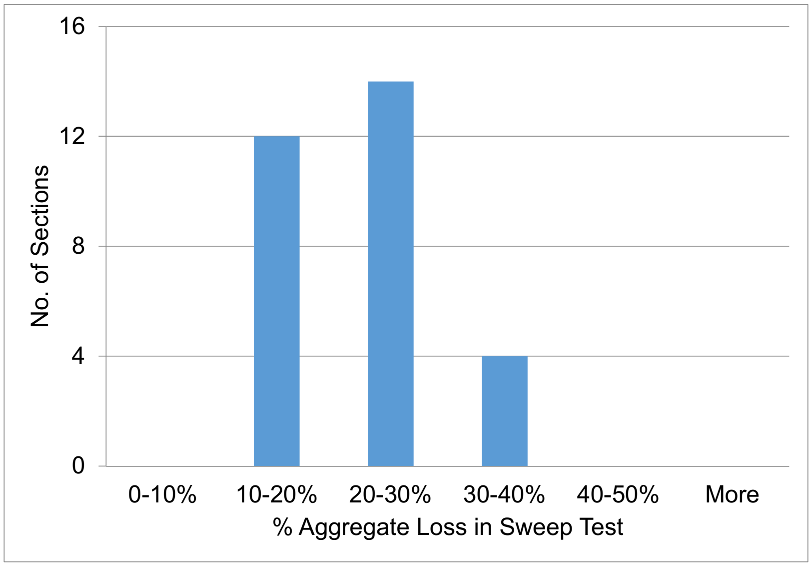


Figure 6.10. Distribution of results from Sweep test using field materials.

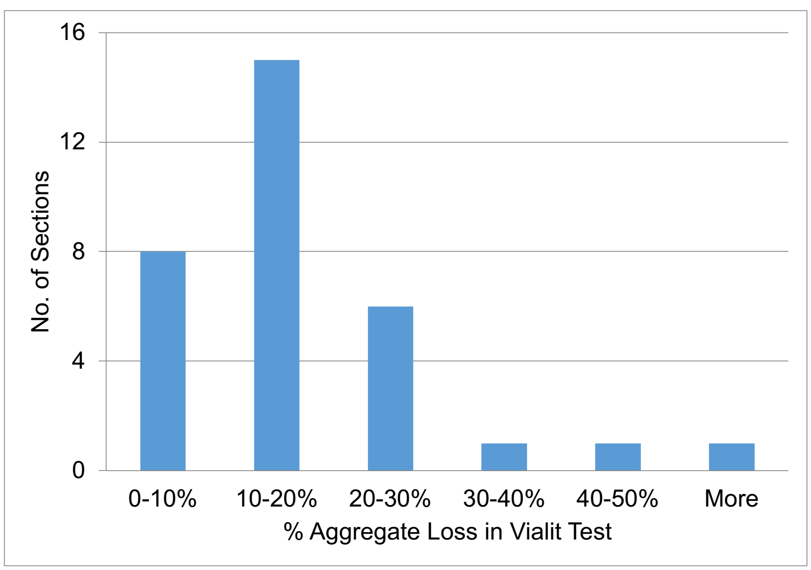


Figure 6.11. Distribution of results from Vialit test using field materials.

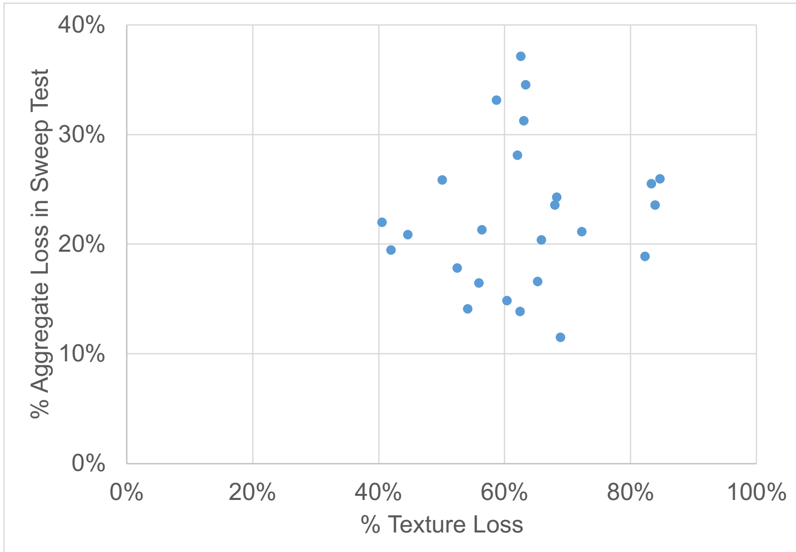


Figure 6.12. Comparison of texture loss measured in the field with aggregate loss from the Sweep test.

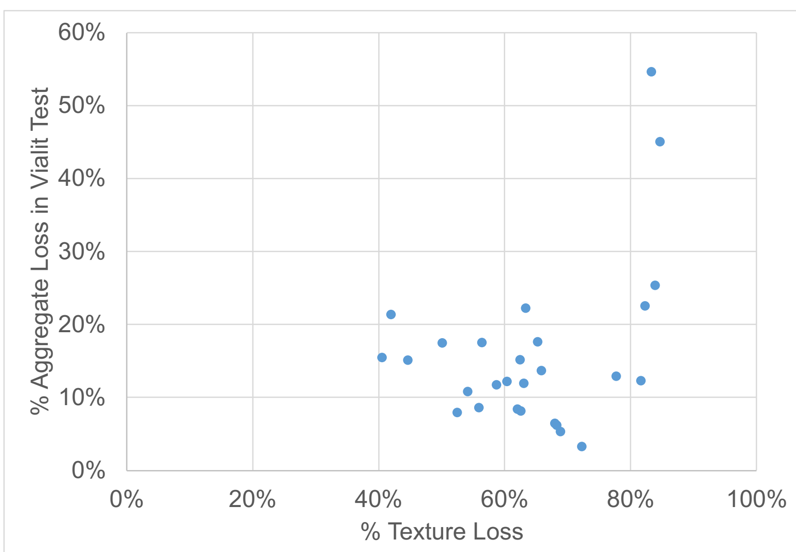


Figure 6.13. Comparison of texture loss measured in the field with aggregate loss from the Vialit test.

6.9 CONCLUDING REMARKS

The following key conclusions can be made based on the observation of field performance and measurement of adhesion loss using field materials with the laboratory tests.

- Approximately 30% of the field sections had a qualitative rating of 1 or 2 (on a scale of 1 to 5 where 1 is the poorest condition and 5 is the best condition). Approximately 25% of the field sections also showed a quantitative texture loss of 70% or more based on the texture condition of a newly placed seal coat. This loss was observed over a period of one to three years.
- In almost all cases texture loss in the pavement was due to aggregate embedment into the substrate layers. Loss due to adhesion was only very limited both in terms of the extent of adhesion loss as well as in terms of number of sections that showed adhesion loss.
- Only about 25% of sections had a high qualitative rating (4 or higher) and a texture loss less than 50%.
- Loss from the Sweep test was typically between 10 to 30% and only one of the 15 sections selected for laboratory testing had a Sweep test loss of greater than 30%. These numbers were consistent with the Sweep test loss measured under controlled conditions using binder-aggregate combinations that typically yield a good performance. These results also suggest a Sweep test loss criteria to be set at 25%.
- Results from the Vialit test showed more variability and sensitivity. This was consistent with the results from this test using controlled binder-aggregate combinations in the laboratory environment. Figure 6.13 may show an apparent correlation between texture loss in the field with the aggregate loss measured using the Vialit test, but this is not statistically significant. Moreover, the texture loss from the field is due to a combination of embedment and adhesion loss, with the former mechanism being the most dominant based on field observations.

CHAPTER 7. SUMMARY, CONCLUSIONS AND RECOMMENDED GUIDELINES

TxDOT's seal coat program is critical to preserve its existing roadway infrastructure and ensuring roadways retain adequate skid resistance. However, sometimes seal coats fail prematurely either due to factors such as incompatibility between aggregate and binder and/or binder that has poor durability while meeting other specification requirements. The overall goal of this project is to identify and develop a laboratory test(s) that can be used to evaluate the expected performance in terms of binder-aggregate adhesion and used as a screening tool for any given seal coat project using materials (aggregate and asphalt binder or emulsion) from that specific project.

7.1 SUMMARY

A summary of the complete study is outlined by the following.

7.1.1 Literature Review and Survey

In this project, a survey of TxDOT districts and other DOTs was conducted. The results show that seal coats are a mainstay for pavement maintenance. TxDOT and many other DOTs use seal coats as a tool to maintain their roadway network. TxDOT is unique in that it is one of only a few that construct a majority of seal coats with hot-applied binders. Many other DOTs use only asphalt emulsions. Many TxDOT districts and other DOTS use historical knowledge in setting asphalt and aggregate rates and a minority stated they use a seal coat design process. The survey informed some of the decisions in this study, particularly on materials to be included in a number of experiments. The survey results are in Appendix A.

A review of literature was conducted in the context of the main goals of this study. Most design methods related to seal coats focus on the application rates and volumetric approaches to ensure the optimal application rate. These methods implicitly assume that the aggregate-binder adhesion is durable and will last the intended service life of the seal coat. However, for a state as large as Texas, there is no guarantee that the chemical composition of the asphalt binder being procured from the same source and for the same grade will remain consistent year after year. As a result, despite using optimal application rate, there are instances of failure resulting from poor binder-aggregate adhesion. Such potentially expensive failures can be avoided by incorporating a simple binder-aggregate adhesion screening tool in the material selection and qualification process. The literature review also identified a few test methods that can potentially be used for this purpose.

7.1.2 Method Development and Establishment of Test Protocols

The main goal of this part of the study was to develop and compare different candidate test methods that can potentially be used to evaluate the quality of adhesion in seal coat materials. The candidate methods were, the Sweep test (with different variations), Vialit test, Cantabro test, and a Pull-Off test. A summary of the methods developed and evaluated in this portion of the study is provided below.

1. Sweep Test

   This method uses a planetary mixer that is retrofitted to abrade the surface of a laboratory prepared seal coat specimen. The test can be performed using different configurations in terms of the test speed and the fixture used to the abrade the surface. A sample preparation method was developed in this study and four different configurations were evaluated (low and high speed with a brush and PVC tube fixture at the end). The version with a rubber hose was found to be the most viable in terms of both repeatability and sensitivity.

2. Vialit Test

   This method uses a metal plate to prepare a sample of the seal coat. A controlled impact load is applied to the sample at low temperatures to assess the degree of debonding that occurs between the binder and the aggregate. A sample preparation method for hot applied binder was developed and the test was evaluated for its sensitivity under different test conditions.

3. Cantabro Test

   This method uses an LA Abrasion machine to evaluate the durability of a compacted specimen. A test method was developed to prepare and assess durability of adhesion between the aggregate and binder used in seal coats. From a technical standpoint a major limitation of this method is that the sample preparation procedure forces complete coating of the aggregate by the binder. In the case of precoated aggregates and hot applied seal coats, this method will not be sensitive to issues that may arise due to incomplete coating or improper coating. Also, sample preparation method using cutbacks and emulsions can take a lot of time to cure.

4. Pull-Off Test

   The pull-off test proved not able to provide usable data, and while in theory it may have merit, in reality cannot be performed in the procedure evaluated.

Based on these findings, the Sweep test and Vialit tests were considered as final candidates for further development and use with the remainder of the test matrix.

7.2 MATERIAL SELECTION

The materials selected for laboratory evaluation included a variety of combinations of binder (commercially available and synthesized), including hot applied asphalt cements and asphalt emulsions, and four aggregate mineralogies (limestone, sandstone, gravel, and rhyolite). Binders in particular were chosen based in information acquired from the survey of TxDOT Districts. Also, materials for evaluation of field materials obtained from over 30 field sections were available for testing from previous projects.

7.2.1 Results from Laboratory Tests

A set of experiments was conducted using the Sweep and Vialit tests and several combinations of base binders and aggregate types. For hot applied binders, all aggregates were precoated, and for emulsified asphalt all aggregates were uncoated, as they would be in the field. A summary of the experimental findings include the following.

7.2.1.1 Impact of Binder Type

Experiment #1 with limestone, sandstone, CRS-2, CRS-2P, HFRS-2, AC-20-5TR, and AC-10:

- Vialit tests showed emulsions had less aggregate loss than hot applied binders.
- Sweep tests showed hot applied binders with less loss than emulsions, but polymer modified emulsions were closer to hot applied binders.

Experiment #2 with limestone, sandstone, gravel, rhyolite, CRS-2P, AC-20-5TR, and AC-10:

- Vialit tests showed CRS-2P with the least loss for all four aggregate types and that gravel and especially rhyolite showed significantly more loss than other aggregate types with all binders.

- Sweep tests showed gravel and rhyolite with more losses in general and the CRS-2P showed more loss on all aggregate types.

7.2.1.2 Impact of Dust

Experiment #3 with limestone, limestone with added dust, and CRS-2P:

- Vialit tests showed more aggregate loss with added dust.
- Sweep tests also showed more aggregate loss with added dust.
- This is evidence that dust should be minimized on seal coat aggregate.

7.2.1.3 Influence of Recycled Engine Oil Bottoms (REOB) and Polyphosphoric Acid (PPA)

Experiment #4 with synthesized binders modified with PPA and REOB as both base binders and precoat binders:

- Vialit tests showed slightly less aggregate loss when both PPA and REOB modified binders were used as precoat materials.
- Sweep tests showed slightly higher aggregate loss when both PPA and REOB modified binders were used as precoat materials.
- When PPA and REOB modified binders were used as base binders, both Vialit and Sweep tests showed no statistically significant change in aggregate loss.
- When evaluated in total in a conservative stance, a slight increase in loss or no significant change in loss would continue to support limitations on PPA and REOB used in seal coat binders.

7.2.1.4 Influence of Liquid Antistrip Agent

Experiment #5 with antistrip treatment of base binder (two antistrip agents with one PG 64-22 base binder and standard precoated gravel aggregate (compared to the base binder with no antistrip treatment):

- The Vialit test showed one antistrip agent reduced aggregate loss.
- The Sweep test showed both antistrip agents reduced aggregate loss.

- This provides support for using antistrip agents for problematic binder aggregate combinations.

7.2.2 Results from Field Sections

For a number of TxDOT seal coat field test sections, texture measurements after construction and one to two years after construction were made with a 3-D laser or an imaging photogrammetry method to generate texture measurements. The change (loss) of texture over time could be quantified.

Additionally, all test sections were visited in this study for visual assessment. Images were acquired and a 1-5 rating was made along with comments on the general condition of each section.

In all measured sections, texture decreased substantially. The visual assessment found that for most sections the reduction in texture was not due to aggregate loss, but to aggregate "punching in" or embedment of the aggregate particles into the surface of the pavement.

For many of the field test sections, binder and aggregate had been collected when the sections were constructed. This allowed laboratory testing of these materials with the Vialit and Sweep tests. Most sections showed less than 30% aggregate loss on both tests. The following key conclusions can be made based on the observation of field performance and measurement of adhesion loss using field materials with the laboratory tests.

- Approximately 30% of the field sections had a qualitative rating of 1 or 2 (on a scale of 1 to 5 where 1 is the poorest condition and 5 is the best condition). Approximately 25% of the field sections also showed a quantitative texture loss of 70% or more based on the texture condition of a newly placed seal coat. This loss was observed over a period of one to three years.
- In almost all cases texture loss in the pavement was due to aggregate embedment into the substrate layers. Loss due to adhesion was only very limited both in terms of the extent of adhesion loss as well as in terms of number of sections that showed adhesion loss.
- Only about 25% of sections had a high qualitative rating (4 or higher) and a texture loss less than 50%.
- Loss from the Sweep test was typically between 10 to 30% and only one of the

15 sections selected for laboratory testing had a Sweep test loss of greater than 30%. These numbers were consistent with the Sweep test loss measured under controlled conditions using binder-aggregate combinations that typically yield a good performance. These results also suggest a Sweep test loss criterion to be set at 25%.

- Results from the Vialit test showed more variability and sensitivity. This was consistent with the results from this test using controlled binder-aggregate combinations in the laboratory environment. Figure 6.13 may show an apparent correlation between texture loss in the field with the aggregate loss measured using the Vialit test, but this is not statistically significant. Moreover, the texture loss from the field is due to a combination of embedment and adhesion loss, with the former mechanism being the most dominant based on field observations.

7.3 CONCLUSIONS

This study supports the following conclusions for performance of seal coats and selecting a test(s) that can be used to indicate aggregate adhesion as part of performance.

- The Vialit test and Sweep test were selected from several candidates as possibly indicative of seal coat adhesion performance. Test procedures of the final procedures, in TxDOT format are included in Appendix C.
- Vialit tests performed using lab and field materials seem to be more variable and indicative of binder fracture than adhesion. This phenomenon might best be managed in a binder specification, especially one that contains low temperature testing, similar to the PG binder specification. The specification for AC-20-5TR, for instance, contains some of these tests.
- The Sweep Test seems more indicative of early age aggregate loss, which is of immediate concern to TxDOT district personnel.
- Field evaluations indicate that aggregate “punch-in” to the pavement is more of a problem than aggregate loss.
- Sweep testing of field section materials, where aggregate loss was not a significant problem (punch-in was the major problem) when informed by laboratory testing suggest a Sweep test loss criterion to be set at 25%.

7.4 RECOMMENDED GUIDELINES

TxDOT specifications for seal coat are more directed to the work of applying a seal coat rather than assuring its performance. TxDOT Districts build the plans for seal coats with only generic aggregate types specified that can include multiple mineralogies, and binder selection based on available binder specifications. Districts must include tentative application rates to give estimates of material quantities to enable contractors to bid, while not knowing the binder supplier or the aggregate supplier. In the bidding process, contractors will usually settle on their suppliers to assure availability and cost. The winning bidder will usually know their material suppliers at this time.

Based on this study, it is recommended to:

- Include a Sweep Test in the specification for seal coats as a check on the compatibility of the project material with a 25% loss of aggregate as the maximum allowed. This test could be performed by TxDOT, but a more efficient way may be to require the contractor to secure a commercial lab certified to perform this test.
- Vialit testing should be reserved for use in a forensic analysis and not implemented on a routine basis.

7.4.1 Suggestion for implementation

Since the specifications for seal coat are more application oriented and less performance oriented, one possible implementation of this recommendation is to:

- Reiterate that the rates in seal coat plans are for bidding purpose only.
- Require the contractor to conduct a seal coat design procedure according to a TxDOT procedure to set a base rate that can be modified on the road according to pavement conditions. Deliver this design to TxDOT.
- Require the contractor to conduct a Sweep Test according to TxDOT test procedures to ensure adhesion compatibility of the binder aggregate proposed for use by the contractor. Deliver this test report to TxDOT.
- Both the design and Sweep testing could be performed by a commercial laboratory (or could be required to be performed by a commercial laboratory).

References

Adams, J., Castorena, C., and Kim, Y. R. (2019). Construction quality acceptance performance-related specifications for chip seals. *Journal of Traffic and Transportation Engineering (English Edition)*, 6(4):337–348.

ASTM International (2015). Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique. *American Society for Testing and Material*, E965.

ASTM International (2019). Standard Test Method for Sweep Test of Emulsified Asphalt Surface Treatment Samples. *American Society for Testing and Material*, D7000.

Beatty, T. L., Jackson, D. C., Dawood, A. D., Ford, A. R., Moulthrop, S. J., Taylor, D. G., Danchetz, L. F., Blanck, A. D., Fay, M. J., Keough, S. D., Rodriguez, M. L., Voth, D. M., and Webb, L. Z. (2002). *Pavement Preservation Technology in France, South Africa, and Australia*, volume 02.

Benson, F.A., and Gallaway, B. (1953). Retention of Cover Stone by Asphalt Surface Treatments, Bulletin 133, Texas Engineering Experiment Station, Texas A&M University System, College Station, 1953, 58 pp.

British Standards International (2003). Determination Of Binder Aggregate Adhesivity By The Vialit Plate Shock Test Method. *British Standards International*, EN 12272-3.

Colwill, N., John, M., and Clifford, N. (1995). U.K. Design Procedure for Surface Dressing, Transportation Research Record, 1507. Washington DC: Transportation Research Board, pp. 13-22. *Colwill, N, John, M. and J. Clifford, N.*

Cox, B. C., Smith, B. T., Howard, I. L., and James, R. S. (2017). State of Knowledge for Cantabro Testing of Dense Graded Asphalt. *Journal of Materials in Civil Engineering*, 29(10):1–15.

Epps, J. A. and Finn, F. N. (1980). Pavement Failure Analysis Example Problems.

Epps, J.A., and Gallaway, B. (1974). Synthetic Aggregate Seal Coats- Current Texas Highway Department Practices, Texas Transportation Institute, College Station.

Gransberg, D. (2007). Using A New Zealand Performance Specification to Evaluate U.S. Chip Seal Performance. *Journal of Transportation Engineering*, 133(12):688–695.

Gransberg, D. and James, D. M. (2005). *Chip Seal Best Practices, NCHRP Synthesis 342*. National Cooperative Highway Research Program, National Research Council, Washington, DC.

Gransberg, D. D. and Zaman, M. (2005). Analysis of emulsion and hot asphalt cement chip seal performance. *Journal of Transportation Engineering*, 131(3):229–238.

Halil, S., Nicholas, F., and Patrick, L. (2008). Validation of odot's laser macrotexture system. *Federal Highway Administration*, pages 93–99.

Hanson, F. (1934). Bituminuos Surface Treatment of Rural Highways. In *Proceedings of the New Zealand Society of Civil Engineers*, pages pp. 189–220.

Hinkle, A. (1928). Maintenance of Gravel and Stone Roads, Especially Surface Treatments. Highway Research Board Proceedings 7, Part II, pp. 270-273.

Hong, F. and Huang, Y. R. (2014). Measurement and characterization of asphalt pavement surface macrotexture using three dimensional laser scanning technology. *Journal of Testing and Evaluation*, 42(4):881–890.

Howard, I. L., Shuler, S., Jordan, W. S., Hemsley, J. M., and McGlumphy, K. (2011). Correlation of Moisture Loss And Strength Gain in Chip Seals. *Transportation Research Record*, (2207):49–57.

Hoyt, D. (2012). *Chip Seals For Asphalt Concrete Pavements: A Proposed Emulsion Residue Specification and Existing Pavement Texture Evaluation*. PhD thesis, Texas A&M University.

Huang, Y., Copenhaver, T., and Hempel, P. (2013a). Texas department of transportation 3d transverse profiling system for high-speed rut measurement. *Journal of Infrastructure Systems*, 19(2):221–230.

Huang, Y., Copenhaver, T., Hempel, P., and Mikhail, M. (2013b). Development of texture measurement system based on continuous profiles from three-dimensional scanning system. *Transportation research record*, 2367(1):13–22.

Im, J. H. (2013). *Performance evaluation of chip seals for high volume roads using polymer-modified emulsions and optimized construction procedures*. North Carolina State University.

Islam, S. and Hossain, M. (2011). Chip Seal with Lightweight Aggregates for Low-Volume Roads. *Transportation Research Record*, (2205):58–66.

Johannes, P. T., Mahmoud, E., and Bahia, H. (2011). Sensitivity of ASTM D7000 Sweep Test to Emulsion Application Rate and Aggregate Gradation. *Transportation Research Record*, (2235):95–102.

Jordan, W. S. and Howard, I. L. (2011). Applicability of Modified Vialit Adhesion Test for Seal Treatment Specifications.

Karki, P., Meng, L., Im, S., Estakhri, C. K., and Zhou, F. (2019). Re-refined Engine Oil Bottom: Detection and Upper Limits in Asphalt Binders and Seal Coat Binders. Technical report, Report No. FHWA/TX-18/0-6881-R1, Texas A&M Transrportation Institute, College Station, TX.

Kearby, J. P. (1953). Tests and Theories on Penetration Surfaces. *Highway Research Board Proceedings*, Vol. 32.

King, G. and Johnston, J. (2012). Polymer Modified Asphalt Emulsions Composition, Uses, and Specifications for Surface Treatments. (December).

Lee, J., Lee, J., Kim, Y. R., and Mun, S. (2012). A Comparison Study of Friction Measurements for Chip Seal. *Journal of Testing and Evaluation*, 40(4):103863.

McLeod, N. (1969). A General Method of Design for Seal Coats and Surface Treatments. *ssociation of Asphalt Paving Technologists*.

Oregon DOT (2016). Chip Seal Design and Specifications Final Report. Technical report.

Roberts, C., and Nicholls, J. C. (2008). Design Guide For Road Surface Dressing. IHS, Berkshire, UK.

Roque, R., Anderson, D., and Thompson, M. (1991). Effect of Material, Design, and Construction Variables on Seal Coat Performance. *Transportation Research Record: Journal of the Transportation Research Board*, 1300:108–115.

Seneviratne, P. and Bergener, J. (1994). Effect of Aggregate Seal Coats on Skid Index Numbers and Low Volume Roads in Utah, Utah Transportation Center, Utah State University, Logan, 1994, 39 pp.

Shuler, S. (2011). When to Broom or Remove Traffic Control Safely on Fresh Emulsified Asphalt Chip Seals. *Transportation Research Record*, (2235):82–87.

Shuler, S., Epps-Martin, A., Lord, A., and Hoyt, D. (2011). *Manual for Emulsion-Based Chip Seals for Pavement Preservation*.

Sprayed Seal Design Project Group (2001). Austroads Provisional Sprayed Seal Design Method Revision 2000, Austroads Project No. N.T.&E.9902, Austroads Incorporated Level 9. Technical report.

TEX-245-F (2019). Texas Department of Transportation. 200-F Bituminous Test Procedures Manual. Austin, TX, 2005.

The South African National Roads Agency (2007). Technical Recommendations for Highways.Technical Recommendations of Highways, Pretoria, South Africa.

Transit New Zealand (2005). Chipsealing in New Zealand. Transit New Zealand, Wellington, New Zealand.

TxDOT (2017). Seal Coat and Surface Treatment Manual.

Vilaça, J. L., Fonseca, J. C., Pinho, A., and Freitas, E. (2010). 3d surface profile equipment for the characterization of the pavement texture–texscan. *Mechatronics*, 20(6):674–685.

Walker, R. S. (2001). Development of a laser based texture measuring system.

Wasiuddin, N. M., Marshall, A., Saltibus, N. E., Saber, A., Abadie, C., and Mohammad, L. N. (2013). Use of Sweep Test for Emulsion and Hot Asphalt Chip Seals: Laboratory and Field Evaluation. *Journal of Testing and Evaluation*, 41(2):20120051.

APPENDIX A. SURVEY OF DISTRICTS WITHIN TXDOT AND OTHER STATE DOTS

A.1 SURVEY PROCESS

This Appendix covers the method and findings from a survey of personnel involved with seal coat construction from different state DOTs and different districts within TxDOT. The objective of this survey was to supplement findings from the literature review with current practices and experiences of different state DOTs as well different districts from within TxDOT to meet the goals of two different concurrent projects related to seal coats. The goal of the first project is to develop a tool that can be used to screen aggregate-binder combinations that result in poor adhesion and potentially premature failure of the seal coat. The goal of the second project is to develop a tool or best practices to ensure that aggregates are precoated adequately prior to being used in hot applied seal coats. The questions on this survey were designed to address practices related to each one of the key stages in selection of materials, selection of application rates, and construction of seal coats (Figure A.1).

In order to deliver the survey to different districts within TxDOT, the research team worked with the Materials and Test Division (MTD) of TxDOT. With help from Dr. Enad Mahmoud and Mr. Miles Garrison, Dy. Director of MTD, the survey was distributed to personnel responsible for seal coats in each of the 25 districts. All 25 districts responded to the survey. A second survey was targeted at representatives from different state DOTs. To this end, researchers reached out to the AASHTO Committee on Materials and Pavements to disseminate the survey to personnel responsible for seal coats in each state DOT. A total of 32 responses were received, three out of 32, namely District DOT (Washington DC), Florida DOT, and Hawaii DOT responded that seal coats are not a common practice in their pavement preservation programs. The summary presented in this document is based on the responses from the remaining 29 state DOTs. The respondents to the survey were maintenance managers and engineers, bituminous engineers, and surface treatment specialists.

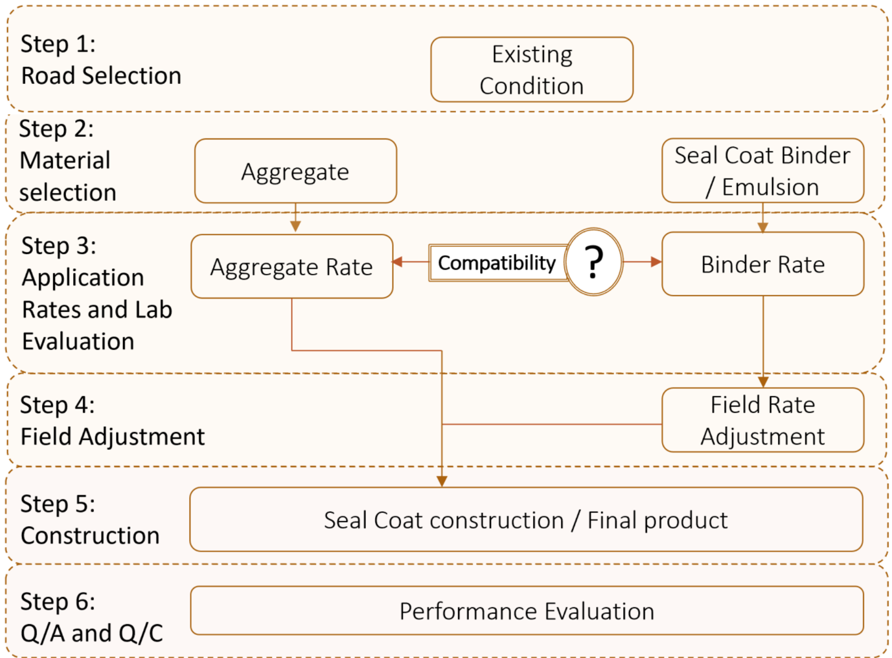


Figure A.1. Key stages in seal coat design and construction

A.2 SUMMARY OF FINDINGS

A summary of findings relevant to this project is presented below. Figures A.2 through A.43 present the detailed breakdown of responses from the statewide and nationwide surveys on practices related to each one of the six steps of design and construction.

- A vast majority of respondents use seal coats as a final riding surface or as a pavement preservation tool and in most cases the volume of seal coat applied is either stable from year-to-year or growing. This clearly demonstrates the significance of the scope of this project.
- About six states (including Texas) use hot applied seal coats exclusively or predominantly with Texas in the latter category. In fact, 23 out of 25 districts in Texas use hot applied seal coats 75% or more of the time. This suggests the scope and significant impact of addressing the quality of precoating, which is one of the key variables that impacts the overall quality of the chip seal. These data also suggest that this issue is unique to a handful of states.
- Interestingly, states that used emulsions and hot applied processes each claimed better performance for their choice. The proposed project will evaluate compat-

ibility of both hot applied and emulsion-based systems with different aggregates that can potentially provide some objective data in this regard.

- In the context of materials and application rate, a majority of districts within Texas use experience to determine the application rate. Such a process is potentially vulnerable to premature failure due to unwarranted changes in binder chemistry and concomitant aggregate-binder adhesion. This also highlights the need to have a screening process in place for material compatibility.
- In the context of precoating, 15 districts specify a binder content and use extraction to examine the adequacy of precoating, whereas 9 other districts use visual inspection or other means. In the context of this study, a validated guideline for specified amount of precoating combined with the use of extraction can be most easily implemented. Alternatively, a method to evaluate precoating should be easier and more accurate than the process of extraction and verification.
- Districts and states also indicate that in most cases a performance issue with a seal coat is detected within one year after construction. This is also important because it substantiates the basis used by the researchers to evaluate field performance of seal coats.

Although the following figures present responses to most survey questions, an important piece of information that was collected from these surveys pertained to the types of materials typically used for precoating and chip seal application. Tables A.1 and A.2 present the design process used by different states and districts. Table A.3 and A.4 presents this same information for districts within Texas. Tables A.5 and A.6 presents the materials typically used by different state DOTs for seal coats. The information presented in the aforementioned tables is extremely valuable in selecting candidate materials that will be used in different partial factorial test matrices for the two projects.

Table A.1. Design procedure used by different districts within TxDOT

District	Application Rates in Plans and Bid Document	Application Rates Upon Seal Coat Construction
Abilene	Historical knowledge	Same experts year after year
Amarillo	Historical knowledge	Same experts year after year
Atlanta	Historical knowledge	Same experts year after year
Austin	Historical knowledge design procedure	Modified Kearby Design Method Same experts year after year
Beaumont	Historical knowledge	Same experts year after year
Brownwood	Design procedure	Modified Kearby Design Method
Bryan	Historical knowledge	Same experts year after year
Childress	Historical knowledge	Same experts year after year
Corpus Christi	Historical knowledge	Same experts year after year
Dallas	District SOP	Same experts year after year
El Paso	Historical knowledge design procedure	Historical knowledge
Fort Worth	Inspector evaluation	Modified Kearby Design Method
Houston	Design procedure	Modified Kearby Design Method
Laredo	Historical knowledge	Modified Kearby Design Method
Lubbock	Historical knowledge	Same experts year after year
Lufkin	Historical knowledge	Same experts year after year
Odessa	Same as last year	Same experts year after year
Paris	Historical knowledge	Same experts year after year
Pharr	Historical knowledge	Same experts year after year rates in plans
San Angelo	Historical knowledge	Same experts year after year
San Antonio	Historical knowledge	Historical knowledge same experts year after year
Tyler	Historical knowledge	Same experts year after year
Waco	Design procedure	Modified Kearby Design Method
Wichita Falls	Historical knowledge	Rates based on field condition
Yoakum	Historical knowledge	Same experts year after year

Table A.2. Design procedure used by different states

State	Application Rates in Plans and Bid Document	Application Rates Upon Seal Coat Construction
Alaska	Historical knowledge	According to specs
Arkansas	Historical knowledge	Rates in plans
Arizona	Design Procedure	Design Procedure
Caltrans	Historical knowledge	Rates in plans
Connecticut	According to specs	Rates in plans
Delaware	Historical knowledge	Rates in plans
Indiana	Historical knowledge	Design procedure
Maryland	Design procedure	Design procedure
Massachusetts	Same as last year	Rates in plans
Michigan	Design procedure	Rates in plans
Mississippi	According to specs	According to specs
Missouri	Historical knowledge and design procedure	Design procedure
Montana	Historical knowledge	Warranty based and rates in plans
North Carolina	Ideal range of rates for both aggregates and emulsion	Rates in plans
Nevada	Historical knowledge	Rates in plans
New Jersey	Historical knowledge	Design procedure
North Dakota	Historical knowledge	Rates in plans
Oklahoma	Historical knowledge	Same experts year after year
Ontario	According to specs	Rates in plans
Oregon	Historical knowledge	Same experts
Pennsylvania	Historical knowledge	Design procedure
South Carolina	Historical knowledge	Same experts year after year
South Dakota	Historical knowledge	Design procedure
Tennessee	Historical knowledge	Field specific rates
Texas	Historical knowledge	Design procedure
Utah	Historical knowledge	Based on t unit weight of aggregate
Vermont Agency	Design Procedure	Design procedure
Virginia	Historical knowledge	Design procedure
Washington	Historical knowledge, same as last year and specifications	According to specs

Table A.3. Commonly used material types in different districts

District	Common Binder	Common Aggregate	Precoating binder if applicable
Abilene	AC-20-5TR		PG 64-16
Amarillo	No predominate binder	PB Gr 4, GR 4S, GR3 SAC B	AC-5
Atlanta	AC-20-5TR	Sandstone GR 3 SAC A, GR4 SAC A	N/A
Austin	AX-15P, AC-35TR and AC-20XP, (CRS-2P in house)	PD GR 4 SAC B, (D GR 4 SAC B in house)	N/A
Beaumont	AC-20-5TR	PL GR 4 SAC A, PL GR 3 SAC B	CSS-1H
Brownwood	AC-20-5TR	PB GR 4 SAC B	PG 64-22
Bryan	AC-20-5TR, AR II	PB or PL GR 4 SAC A, PB or PL GR 3 SAC A	SS-1
Childress	AC-20-5TR, (CHFRS-2P in house)	Volcanic GR 4	
Corpus Christi	AC-15P, AC 20-5TR	PB GR 4 4 SAC B, PB GR 3 SAC B	Contractor preference
Dallas		PB GR (3 or 4) SAC B, PL GR (3 or 4) Sac B	PG 64-22
El Paso	AC-20-5TR, (CHFRS-2P in house)	TY 3 GR (3 or 4) SAC A	PG 64-22
Fort Worth	AC-20 XP	PB GR (3, 4,5) SAC B	PG 64-22
Houston	No predominate binder	PB GR 4 SAC B, PL GR 4 SAC B	PG 64-22
Laredo	AC-15P (HFRS-2P (in house)	PB GR (3, 3s or 4S) SACB, PD GR (3. 3S or 4S) SAC B	AC-15P
Lubbock	AC-20-5TR	PB GR 4 SAC B, PB GR SAC A (High traffic)	PG 64-22
Lufkin	AC-20-5TR, CHFRS-2P	PL GR (4 or 5) SAC (A or B), L GR (4 or 5) SAC (A or B)	According to item 302.2.2.1

Table A.4. Commonly used material types in different districts (contd.)

District	Common Binder	Common Aggregate	Precoating binder if applicable
Odessa	AC-20-5TR	GR 3 SAC A, GR 4 SAC A	N/A
Paris	AC-20-5TR, AC 20 XP	PB GR 3 SAC A, PB GR 4 SAC A	
Pharr	SPG 70-13	PD GR (3, 4 or 5) SAC B	Contractor preference
San Angelo	No predominate binder	PD GR (3 or 4) SAC A (High traffic), PD GR 3 SAC B	PG 64-22, AC-0.6
San Antonio	AC-20- 5TR, AC 20 XP	GR 4 SAC A, GR (3 or 4) SAC B	PG 64-22
Tyler	AC-20-5TR	PD GR (3 or 4) SAC A, PL GR 3	PG 64-22
Waco	AC-20-5TR, AC 20 XP	PD (GR 3 or 4 or 5) SAC B	CSS-1H
Wichita Falls	AC-20-5TR	PB GR (3 or 4) SAC B, PE GR 4 SAC B	PG 64-22
Yoakum	AC-15P	PE GR (3 or 4) SAC B	AC 3, AC 0.6

Table A.5. Commonly used material types in different states

State	Common Binder	Common Aggregate	Precoating binder if applicable
Alaska	CRS-2P	According to Specs	PG 58-28
Arkansas	CRS-2	Crushed Stone	
Arizona	Terminal binder	Crushed Quarry Stone	Asphalt Cement
Caltrans	No predominate binder	No standard aggregate	
Connecticut	PG 58-22 with 20% rubber		
Delaware	CRS-2hl	AASHTO #8 Stone	
Indiana	CRS-2P,AE-90S	According to specs	
Maryland	CRS-2P	Grade 7 or Grade 8	
Mas-sachusetts	PG 58-28 rubber modified	Crushed stone	PG 58-28, PG 64-28
Michigan	CSEA	Natural, blast furnace slag	
Mississippi	No predominate binder	Limestone	
Missouri	CRS-2P	Lightweight	
Montana	CRS-2P, CHFRRS-2P	Size 1/2" or size 3/8"	
North Carolina	CRS-2L	Granite	
Nevada	LMCRS-2h, CRS-2nv	Size 3/8" or 1/2"	PG 64-22
New Jersey	PG 58-22 fuel resistant	According to specs	PG 64-22
North Dakota	CRS-2P	One size aggregate	
Oklahoma	CFHRS (High float)	Limestone	
Ontario	CRS-2P, HF-150 SP	According to specs	
Oregon	HFRS-P2 or CRS-2P	Gravel or Basal	PG 64-22

Table A.6. Commonly used material types in different states (contd.)

State	Common Binder	Common Aggregate	Precoating binder if applicable
Pennsylvania	CRS-2PM or CRS-2	AASHTO # 8	
South Carolina	CRS-2P	Lightweight (Stalite expanded shale)	
South Dakota	CRS-2P	Limestone, Granite, quartzite quarries	
Tennessee	Scrub seal emulsion	Crushed limestone and crushed gravel	
Texas	AC-20-5TR	Various by district	Varies
Utah	CRS-2P	According to specs	
Vermont Agency	No predominate binder	According to specs	
Virginia	CRS-2, 2M, 2h	According to specs	
Washington	CRS-2P, AC-15P	Gravel and quarry sources	PG 58-22, PG 64-28, and PG 64 H-22

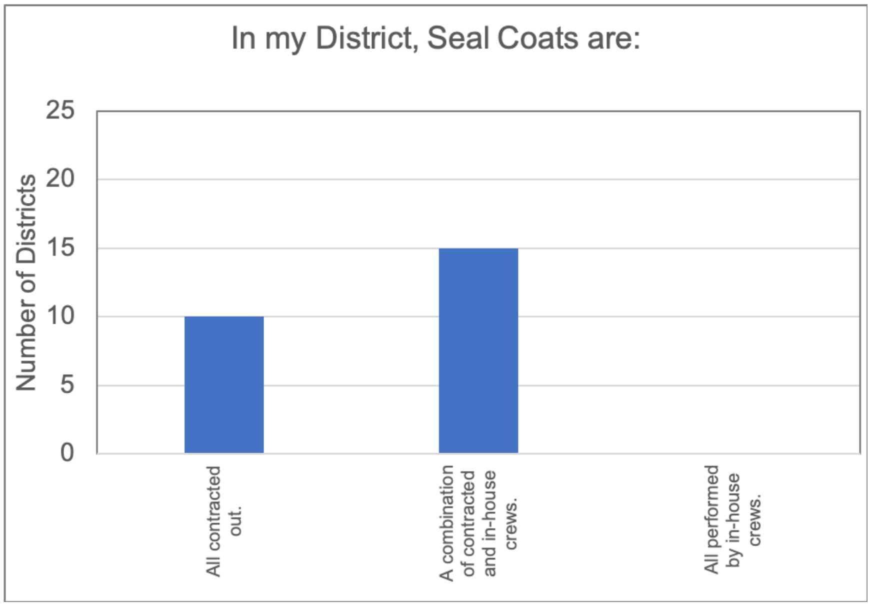


Figure A.2. Breakdown of contract type for seal coat construction among 25 districts within Texas

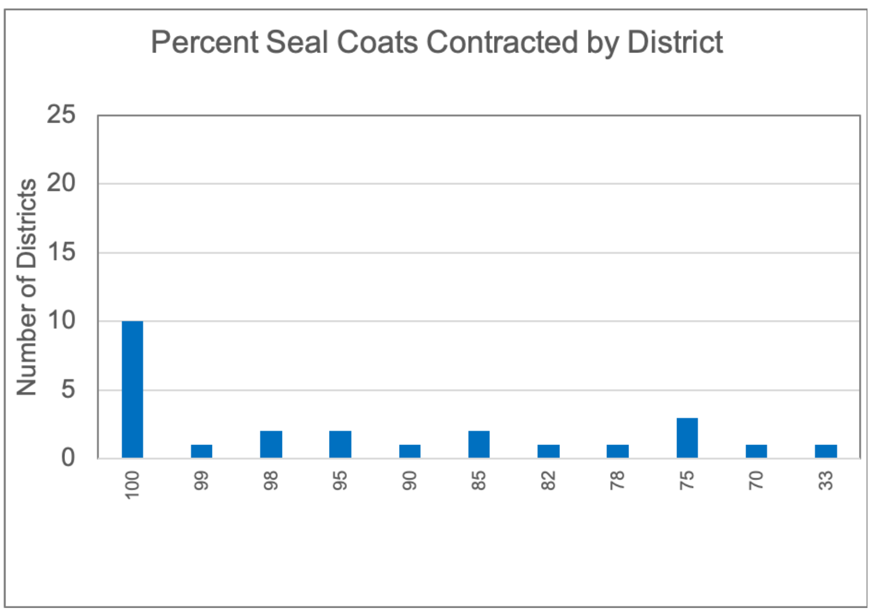


Figure A.3. Percentage of seal coat contracted among 25 districts within Texas

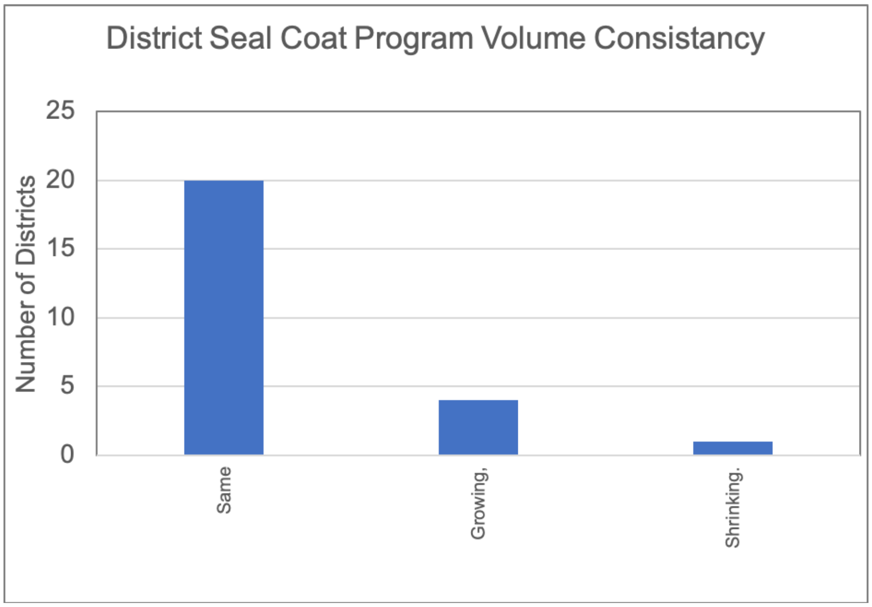


Figure A.4. Change in volume of seal coat construction among 25 districts within Texas

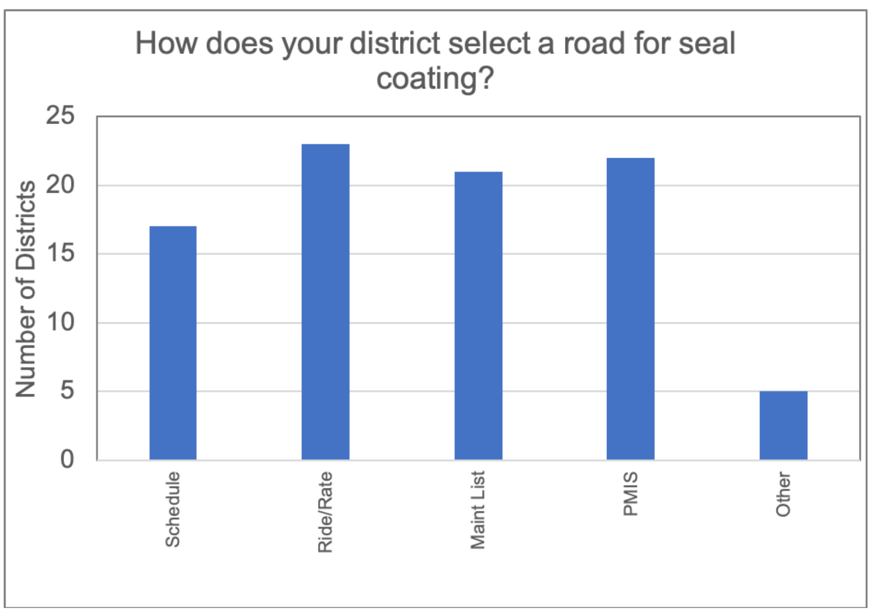


Figure A.5. Process used to select a roadway for seal coat application among 25 districts within Texas

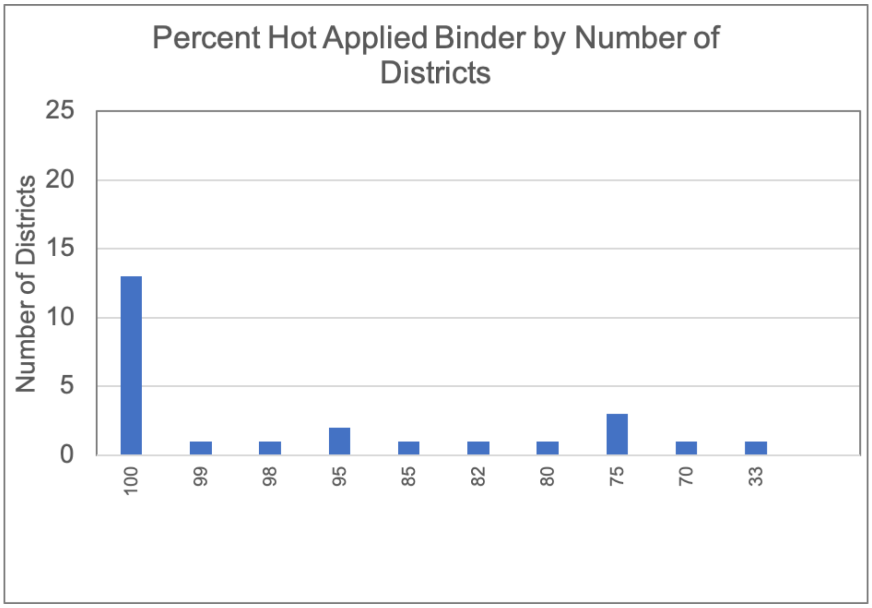


Figure A.6. Percent of hot applied binder among 25 districts within Texas

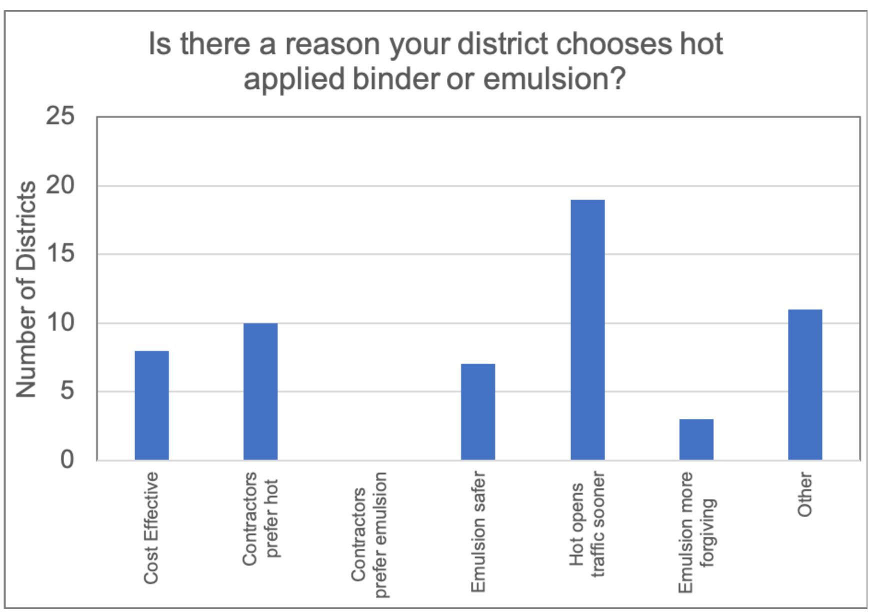


Figure A.7. Choice of emulsion versus hot applied binder among 25 districts within Texas

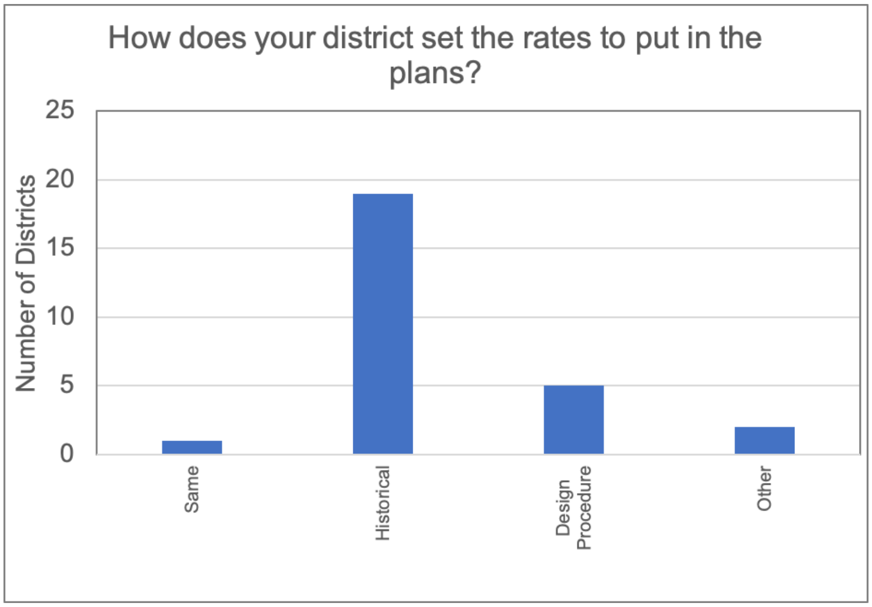


Figure A.8. Process for selecting application rate among 25 districts within Texas

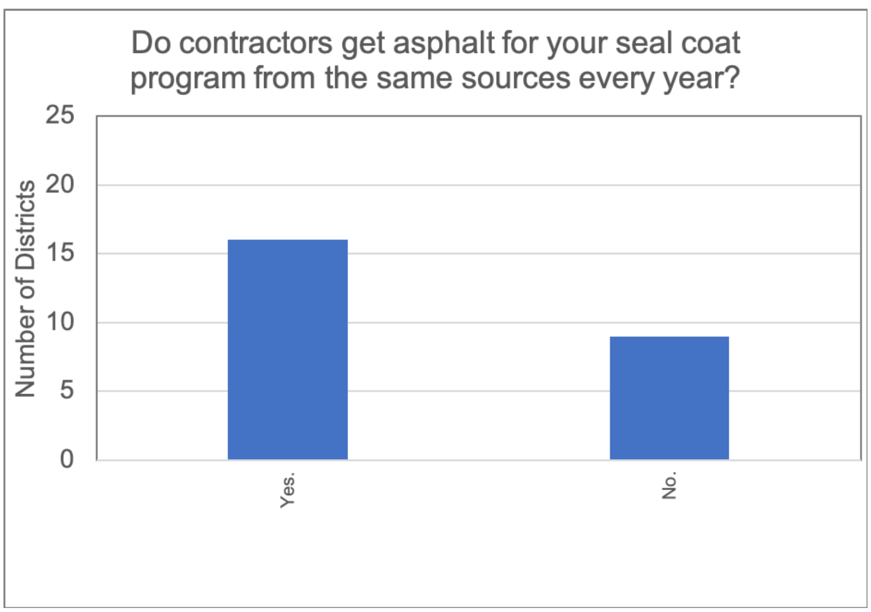


Figure A.9. Sourcing of seal coat binder among 25 districts within Texas

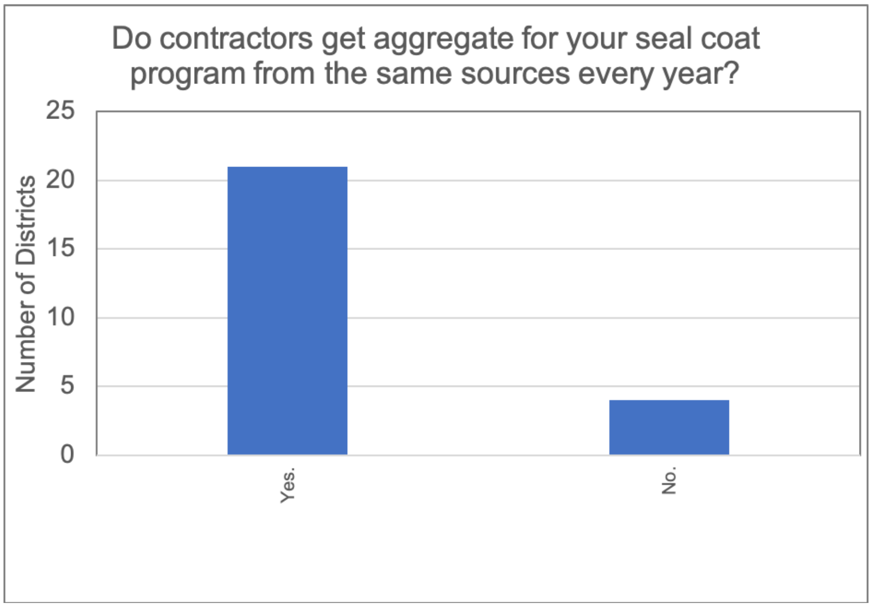


Figure A.10. Sourcing of seal coat aggregates among 25 districts within Texas

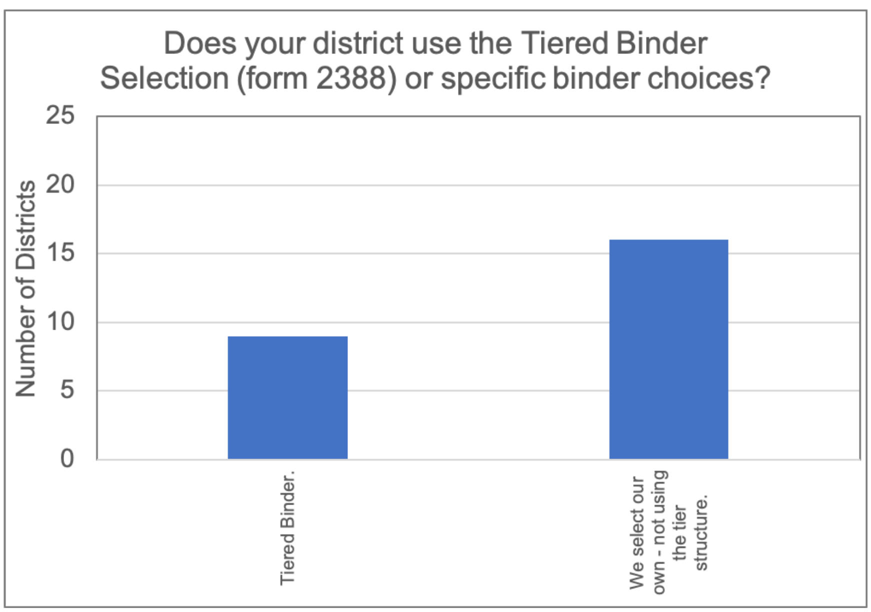


Figure A.11. Process for selecting binder grade among 25 districts within Texas

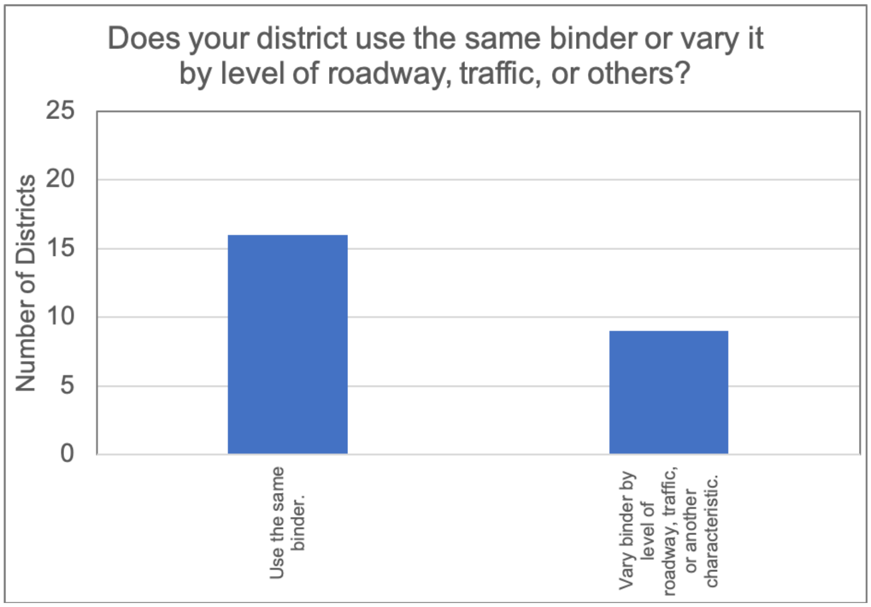


Figure A.12. Variation of binder type within the district among 25 districts within Texas

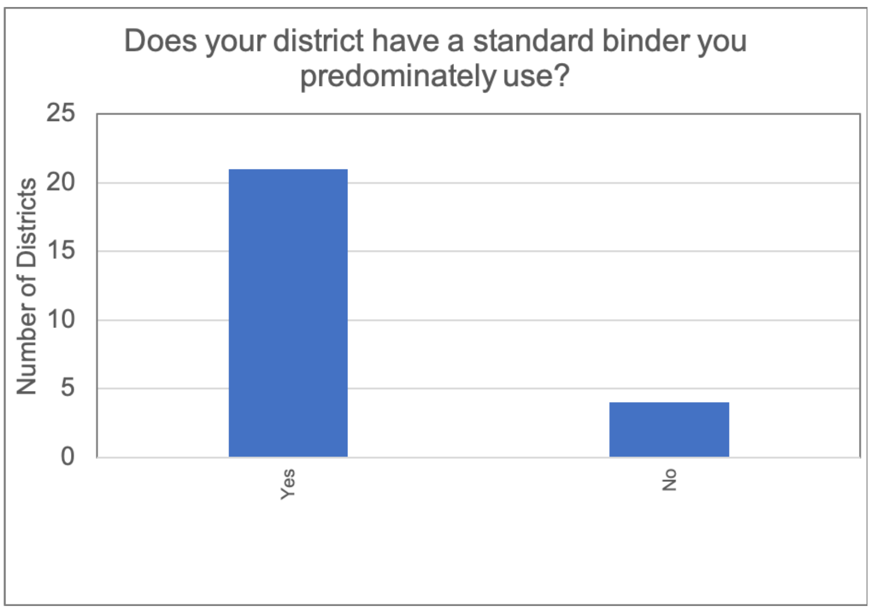


Figure A.13. Use of a standard binder among 25 districts within Texas

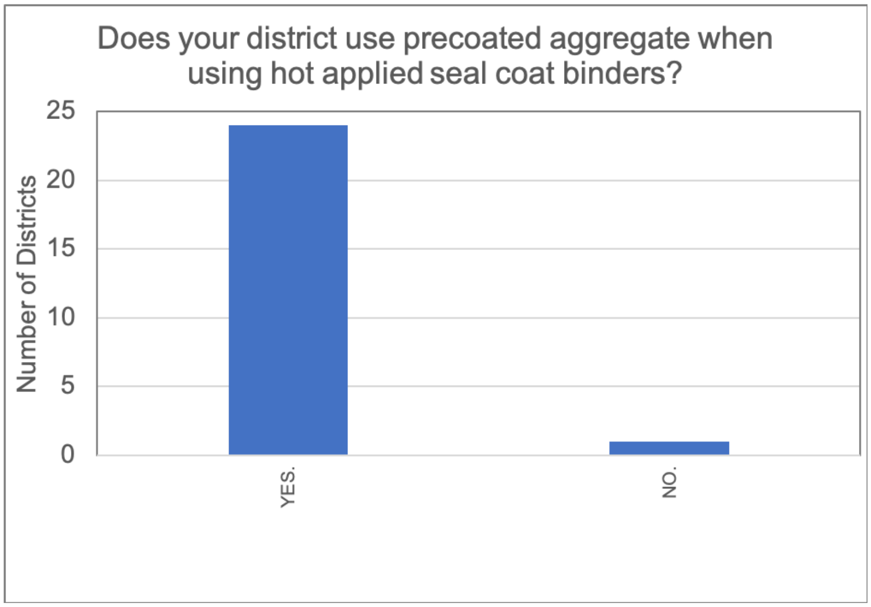


Figure A.14. Use of precoated aggregates for seal coats among 25 districts within Texas

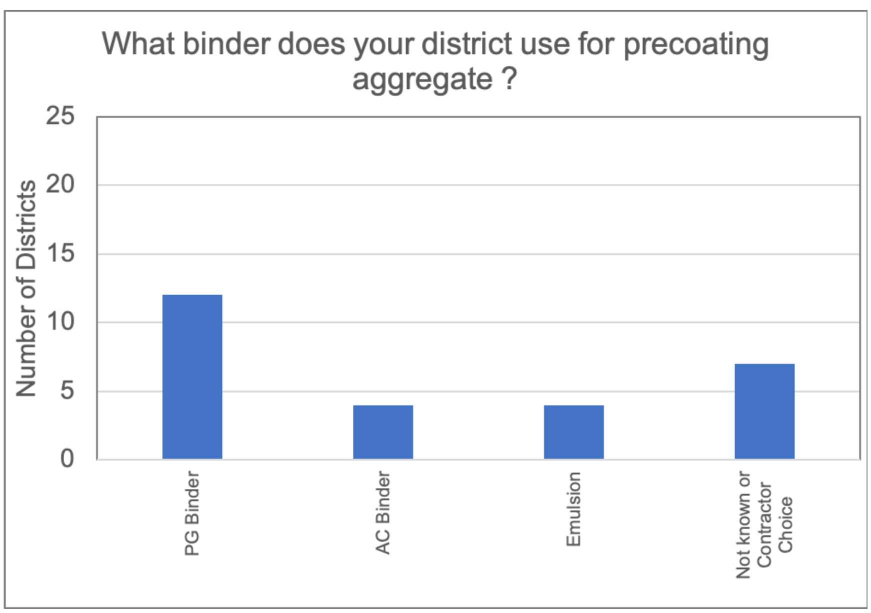


Figure A.15. Typical binder used for seal coating among 25 districts within Texas

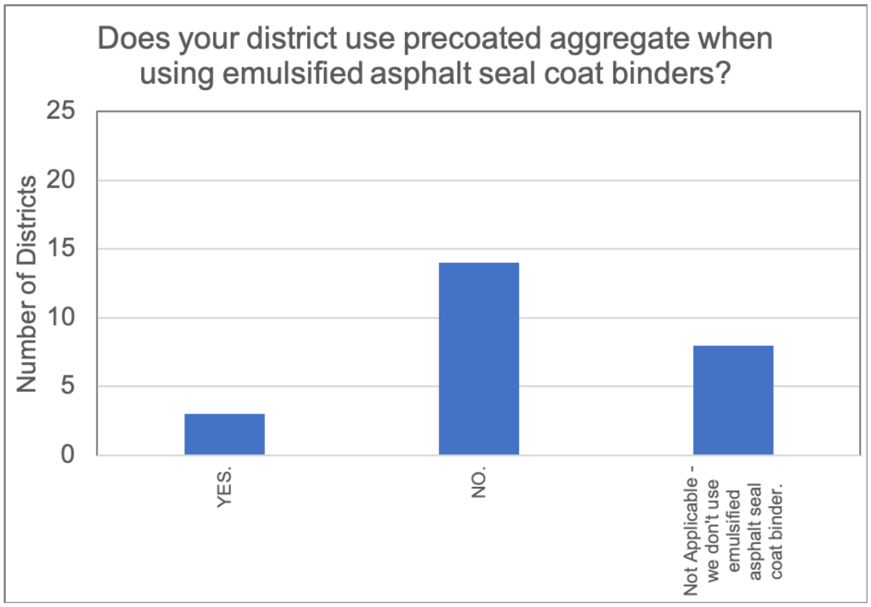


Figure A.16. Use of precoated aggregated with emulsified binder among 25 districts within Texas

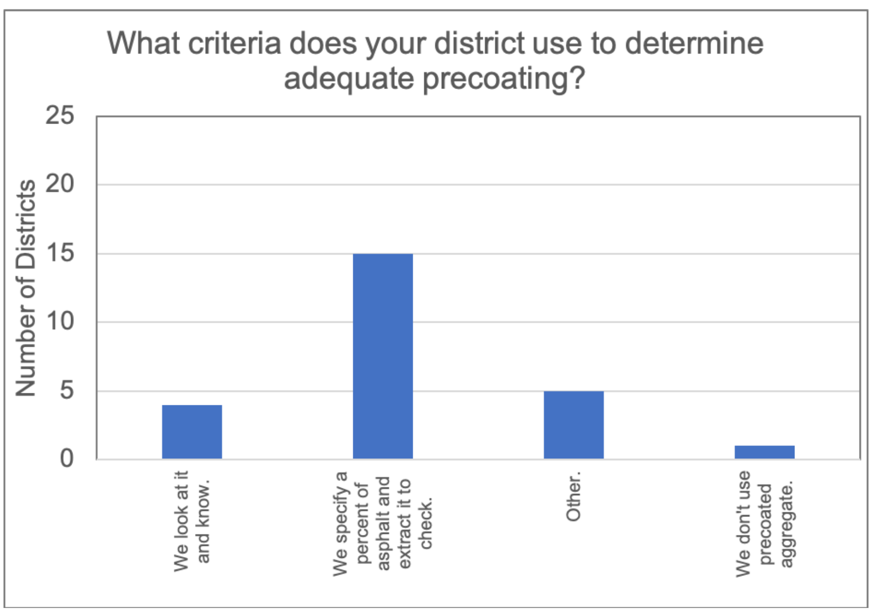


Figure A.17. Process for ensuring precoating of binders among 25 districts within Texas

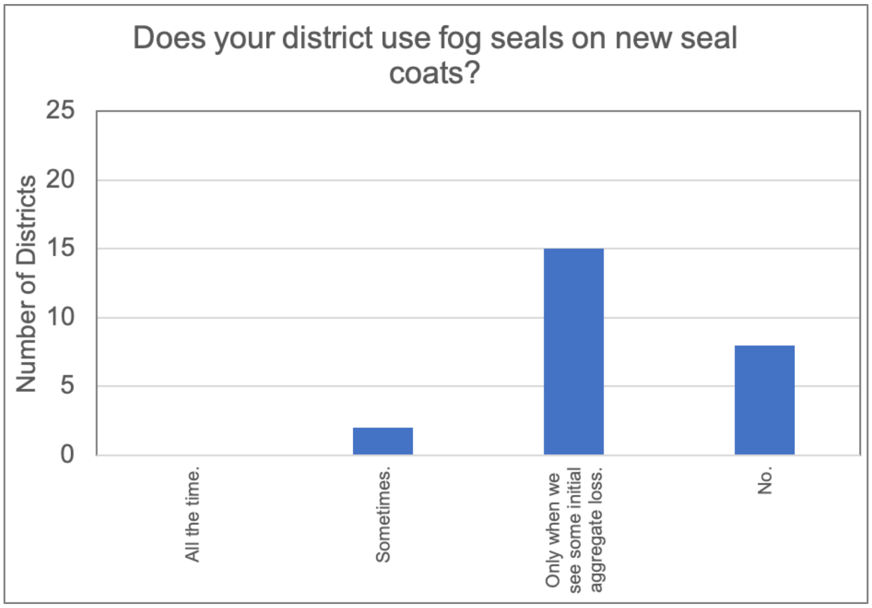


Figure A.18. Use of fog seals over seal coats among 25 districts within Texas

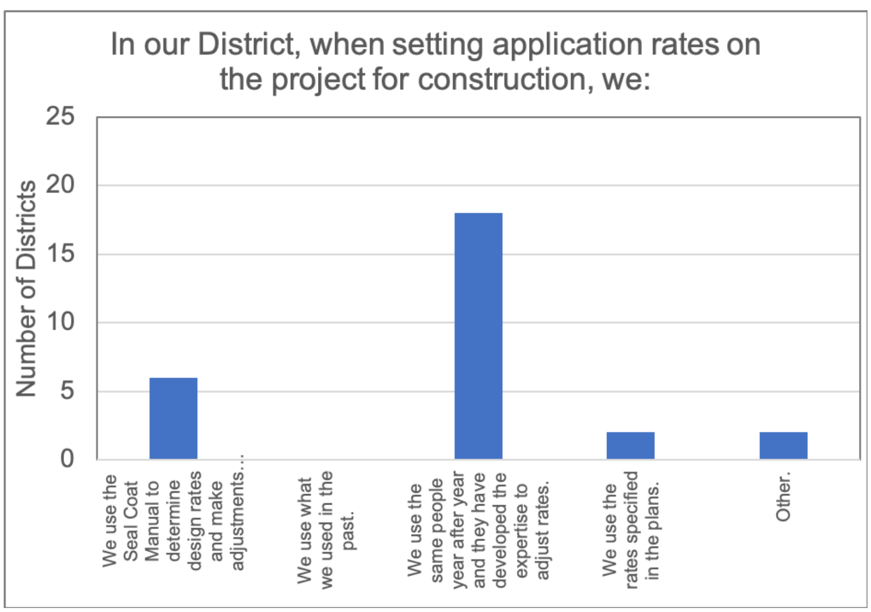


Figure A.19. Method used to establish application rate among 25 districts within Texas

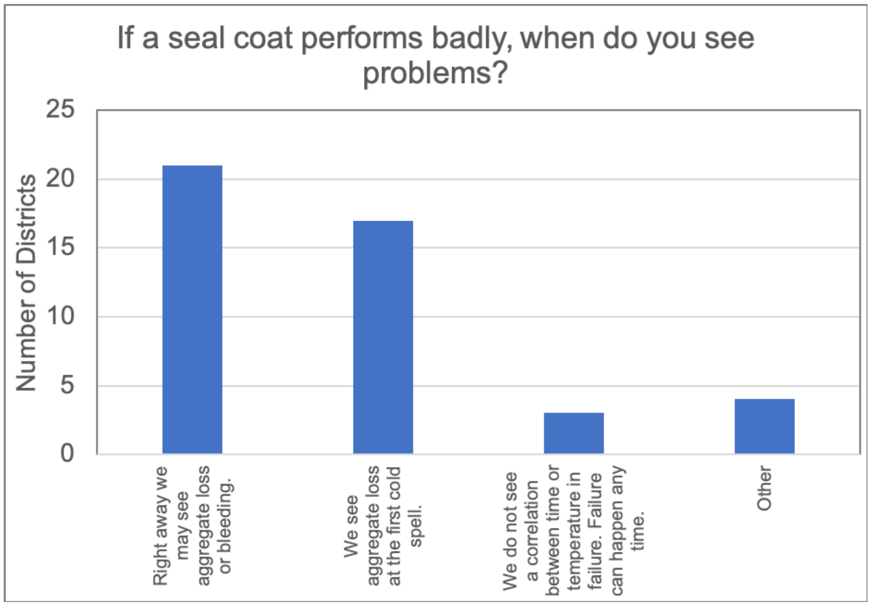


Figure A.20. Earliest failure detection among 25 districts within Texas

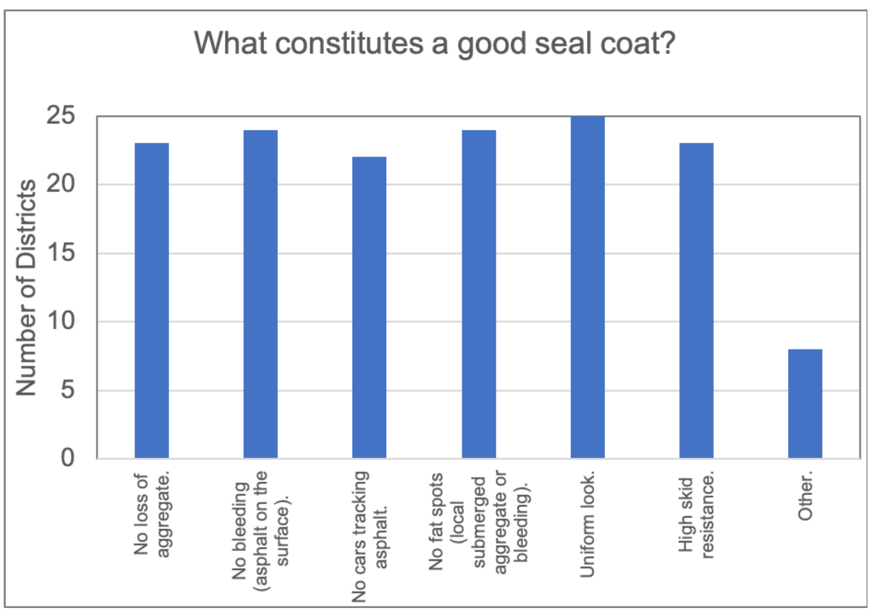


Figure A.21. Desirable performance characteristics for seal coats as described by the 25 districts within Texas

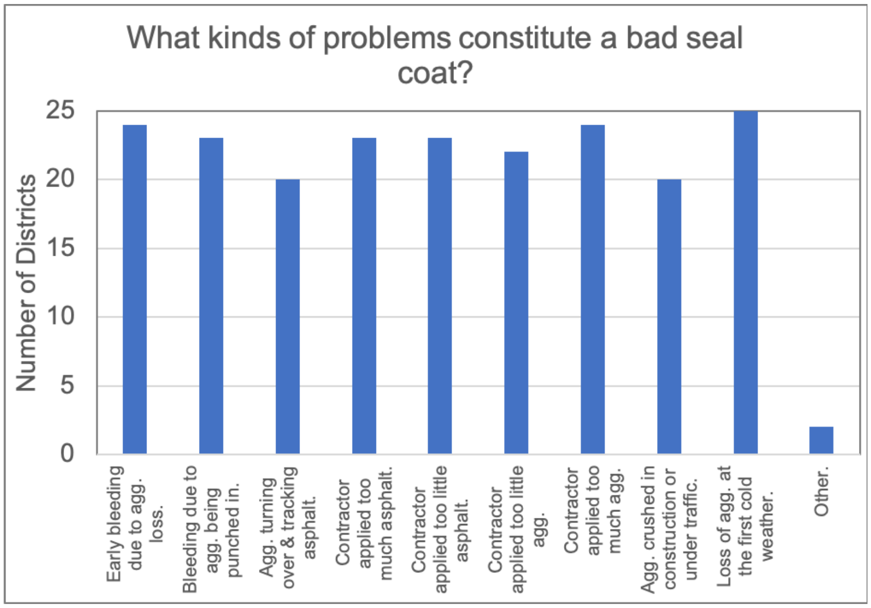


Figure A.22. Typical distresses in seal coats as described by the 25 districts within Texas

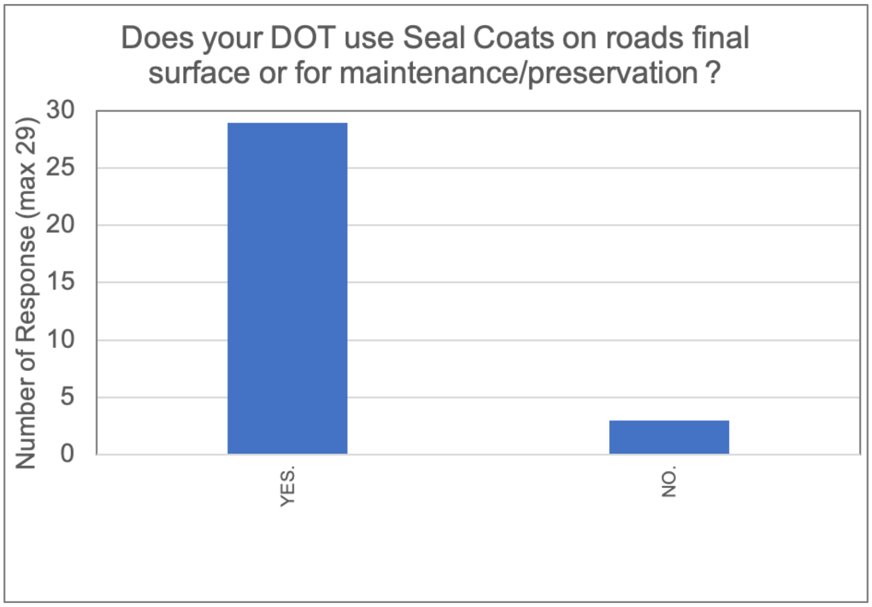


Figure A.23. Use of seal coat by different states (limited to survey respondents)

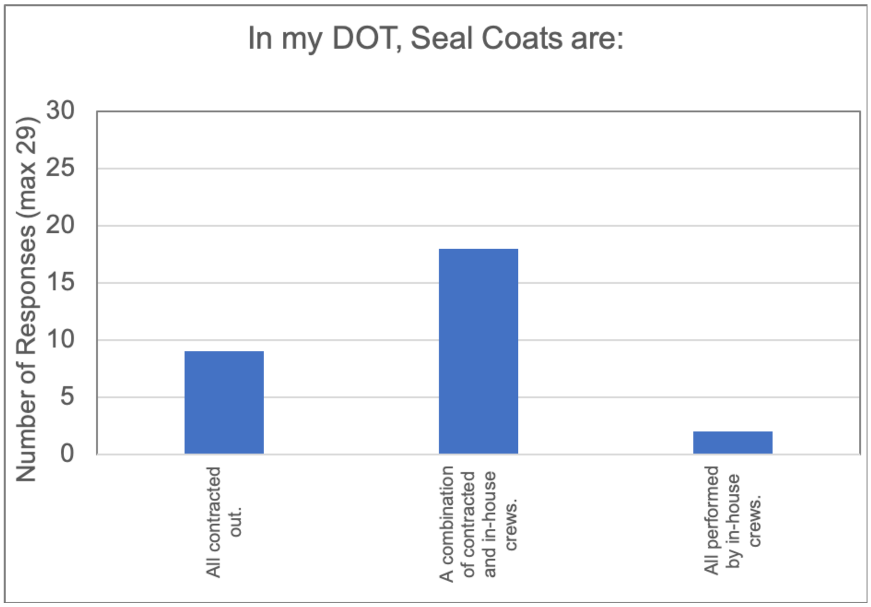


Figure A.24. Portion of states performing seal coats in-house versus contracting out by different states (limited to survey respondents)

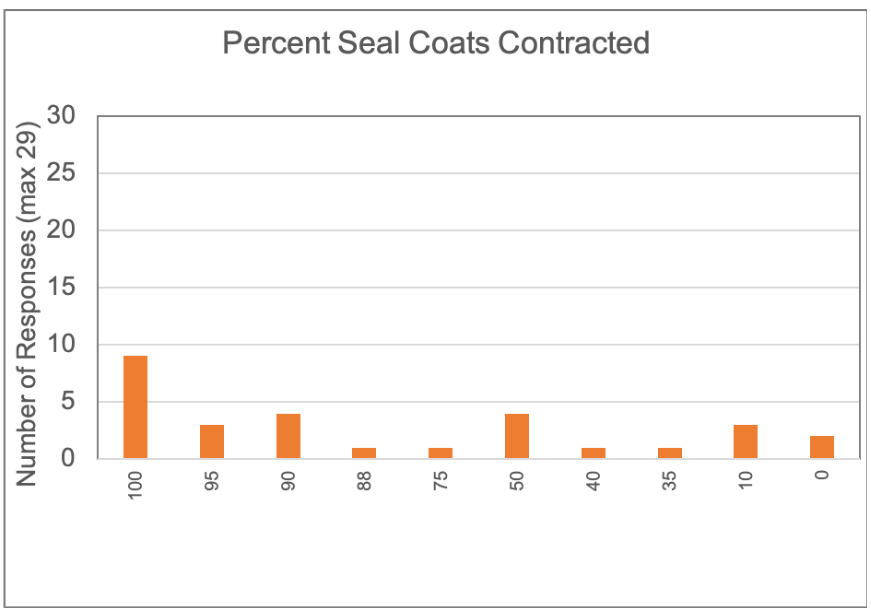


Figure A.25. Percentage of seal coat construction contracted out in different states (limited to survey respondents)

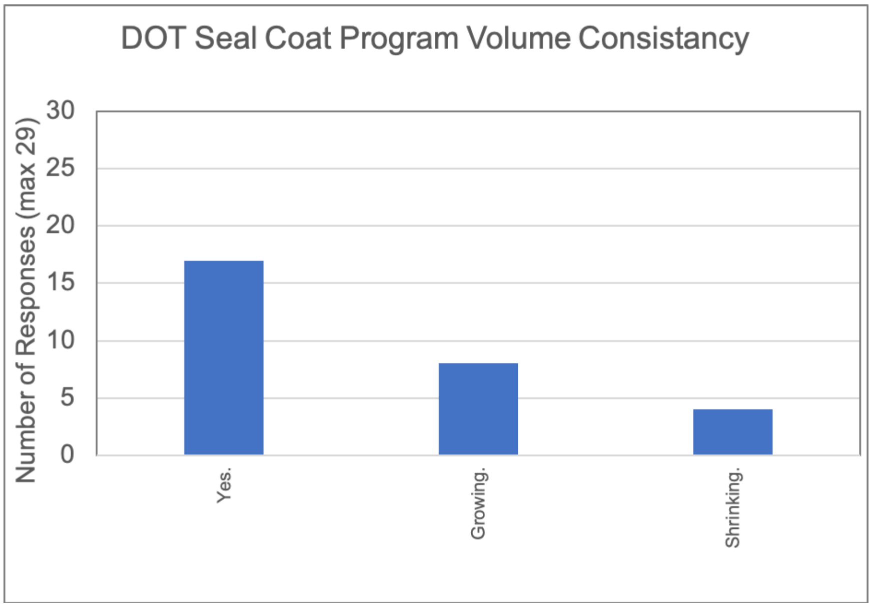


Figure A.26. Change in volume of seal coat construction by different states (limited to survey respondents)

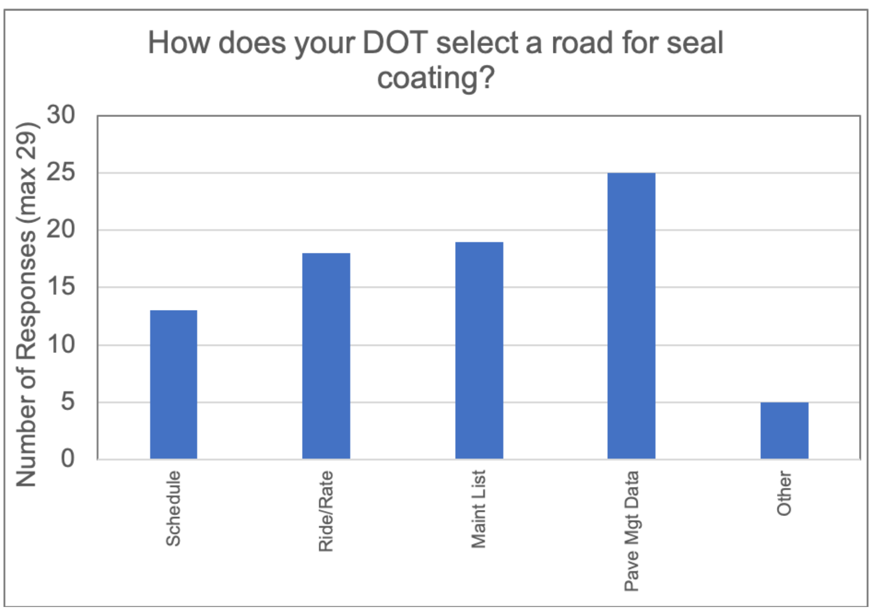


Figure A.27. Process for selecting seal coat construction by different states (limited to survey respondents)

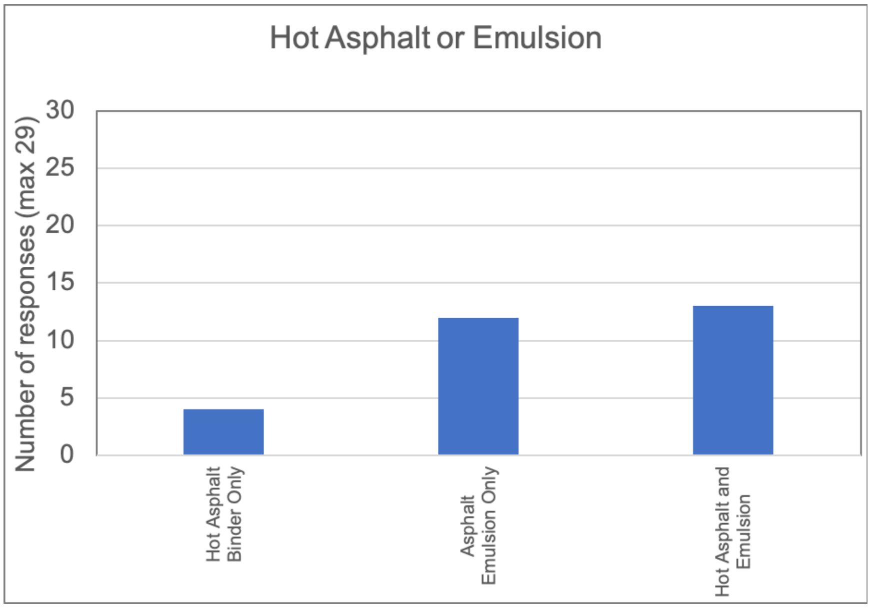


Figure A.28. Use of hot applied versus emulsion in seal coat construction by different states (limited to survey respondents)

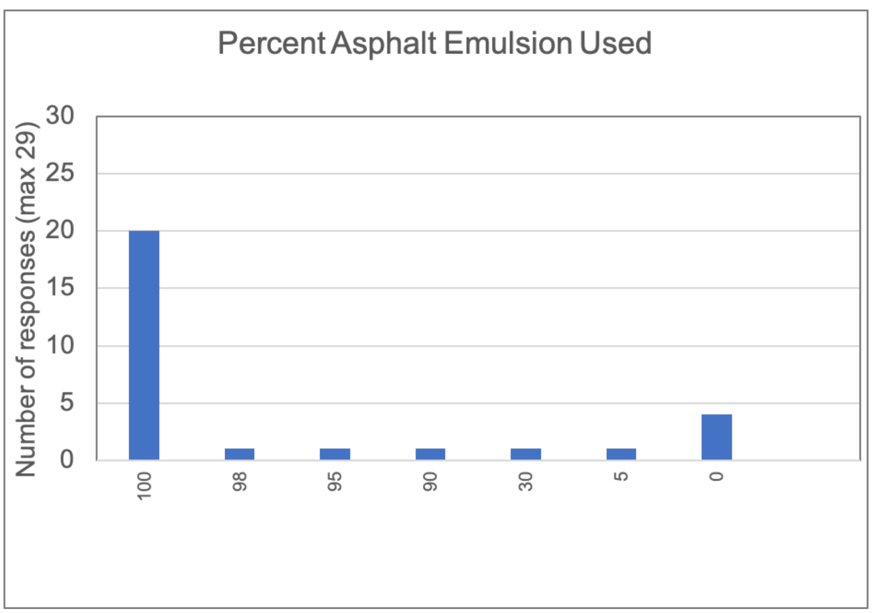


Figure A.29. Percentage of emulsion use for seal coat construction in different states (limited to survey respondents)

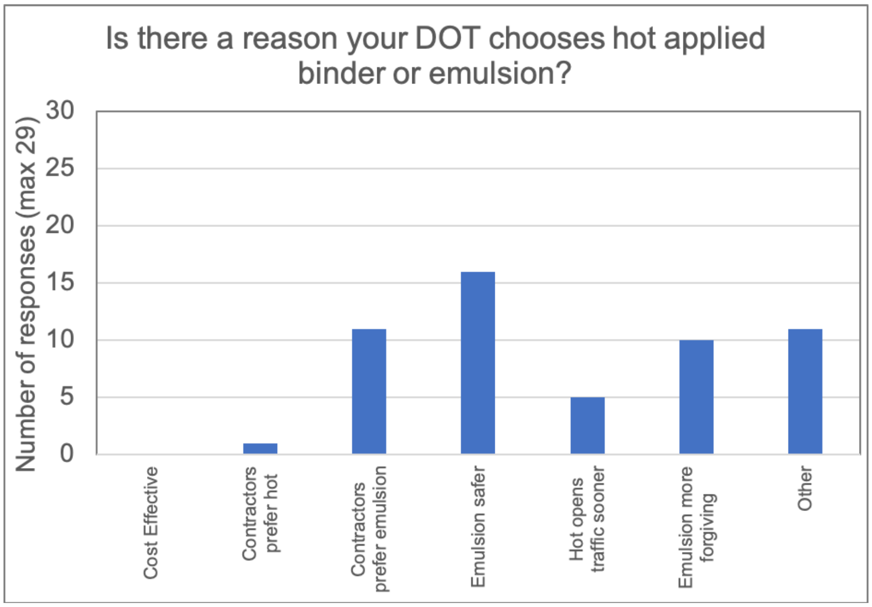


Figure A.30. Basis for selecting hot applied versus emulsion in seal coat construction by different states (limited to survey respondents)

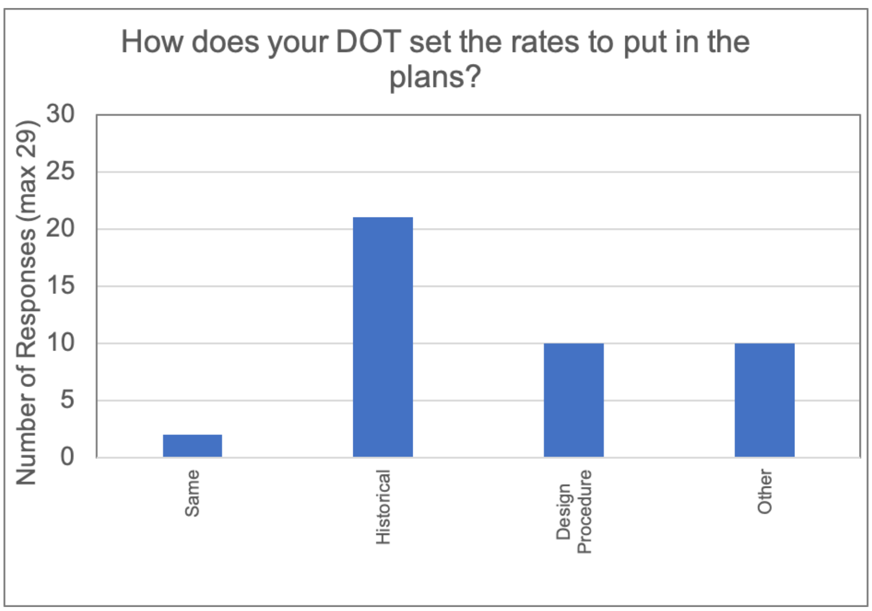


Figure A.31. Basis for selecting application rate in seal coat construction by different states (limited to survey respondents)

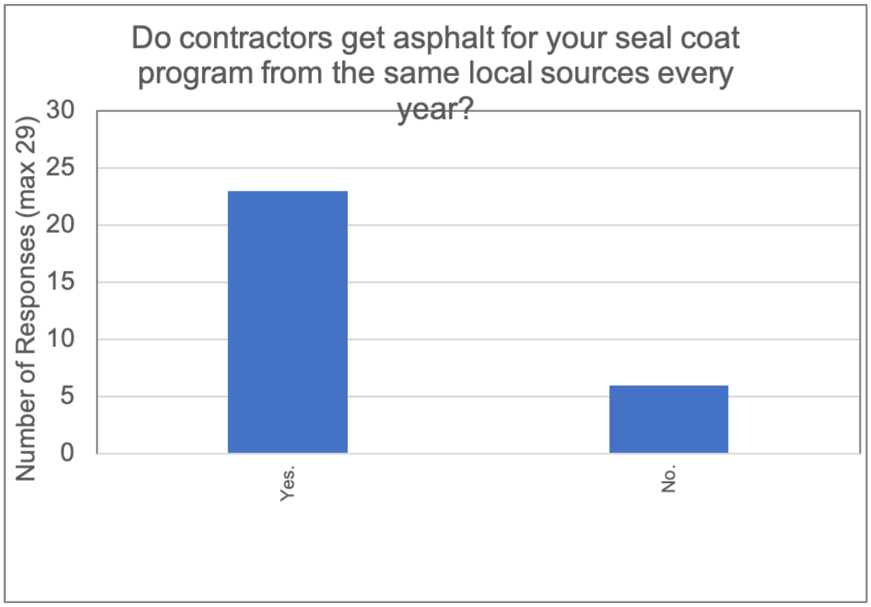


Figure A.32. Consistency in binder source for chip seal construction by different states (limited to survey respondents)

Figure A.33. Consistency in aggregate source for chip seal construction by different states (limited to survey respondents)

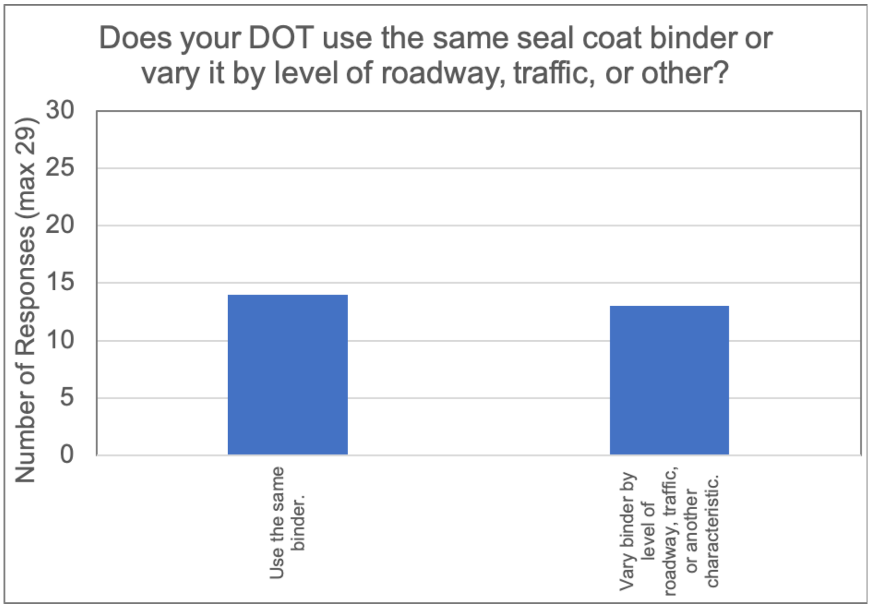


Figure A.34. Adjustment of binder based on roadway type for chip seal construction by different states (limited to survey respondents)

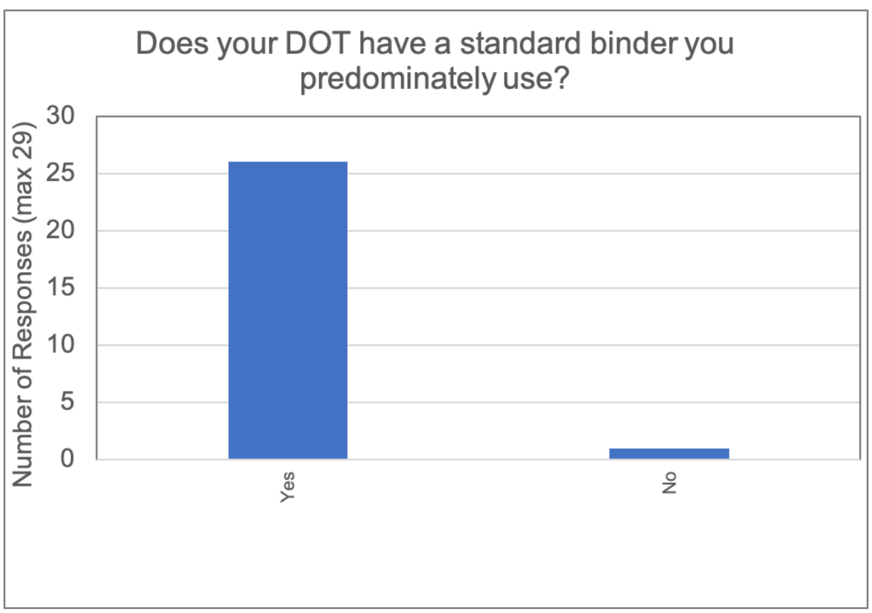


Figure A.35. Use of a standard binder grade for chip seal construction by different states (limited to survey respondents)

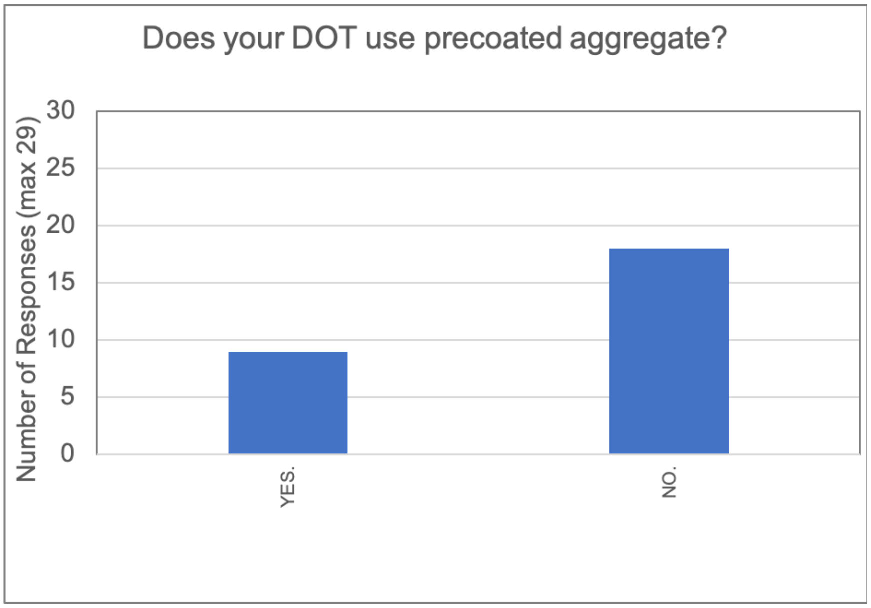


Figure A.36. Use of precoated aggregates for chip seal construction by different states (limited to survey respondents)

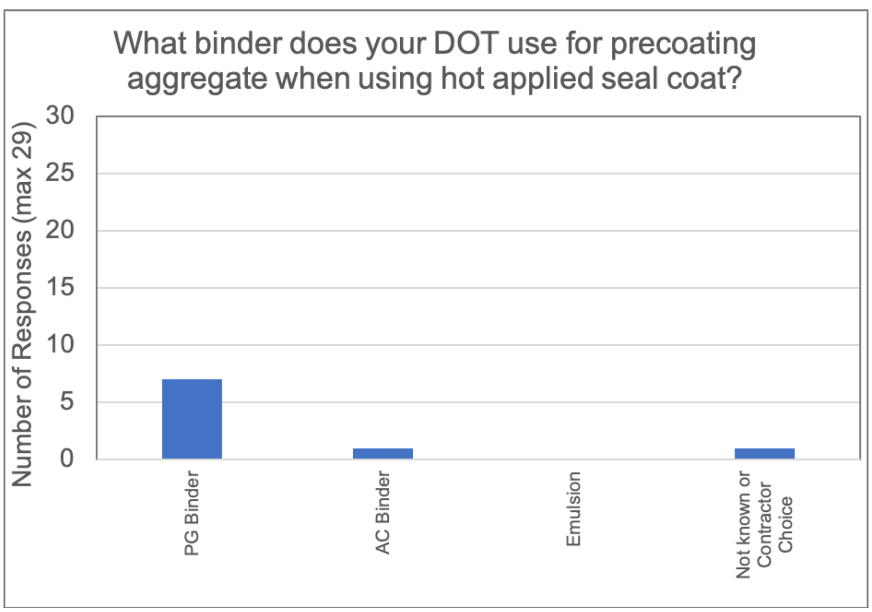


Figure A.37. Grade of binder used for precoating aggregates for chip seal construction by different states (limited to survey respondents)

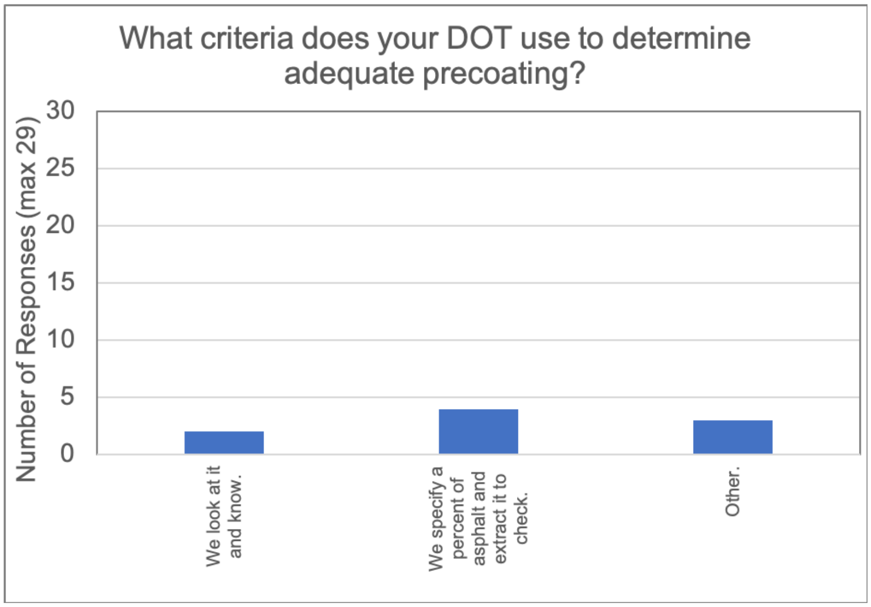


Figure A.38. Process used to check precoating of aggregates for chip seal construction by different states (limited to survey respondents)

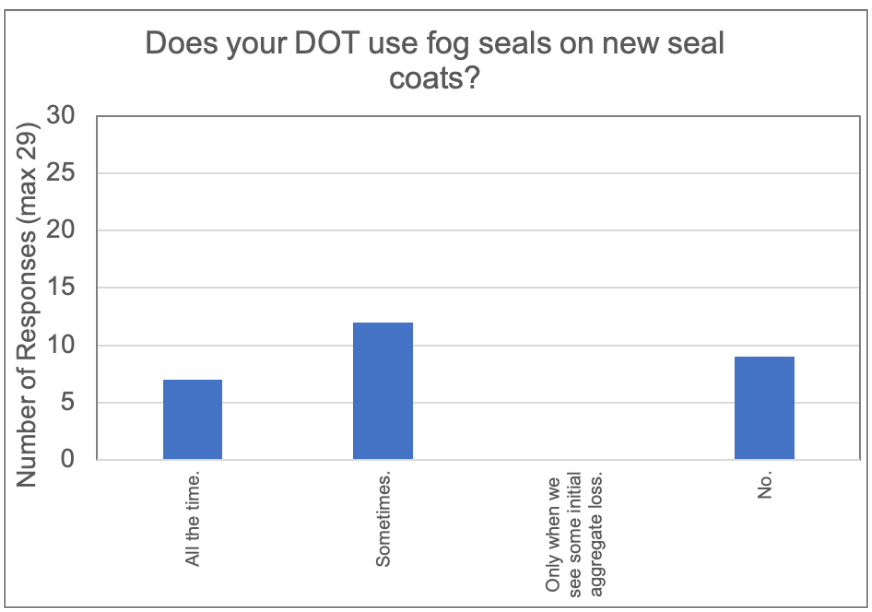


Figure A.39. Use of fog seals over new seal coat construction by different states (limited to survey respondents)

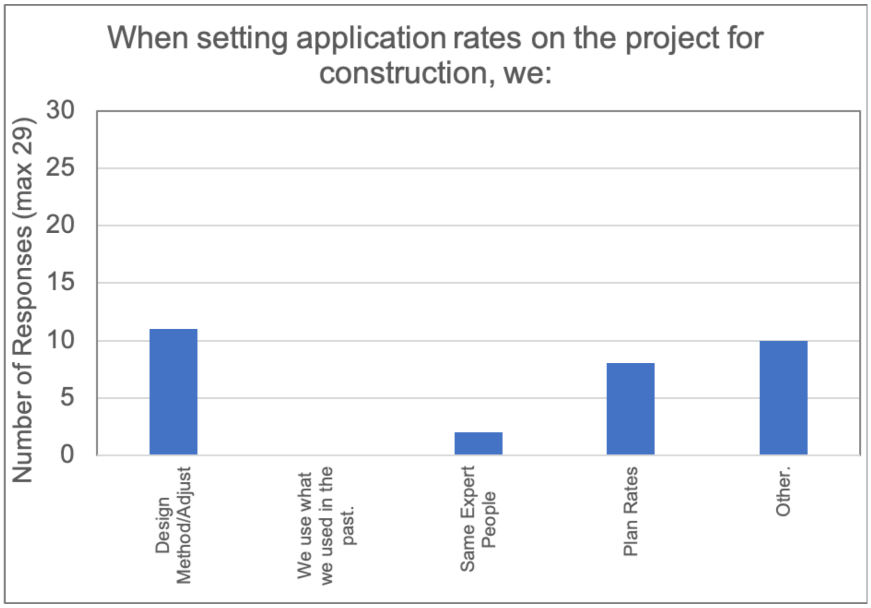


Figure A.40. Process used to select application rate for chip seal construction by different states (limited to survey respondents)

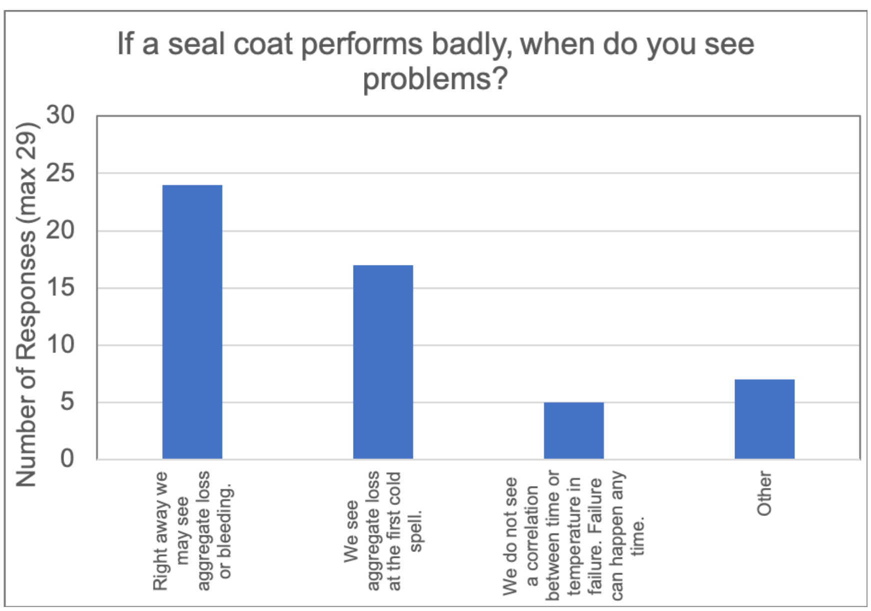


Figure A.41. Earliest detection of potential problems with seal coat construction by different states (limited to survey respondents)

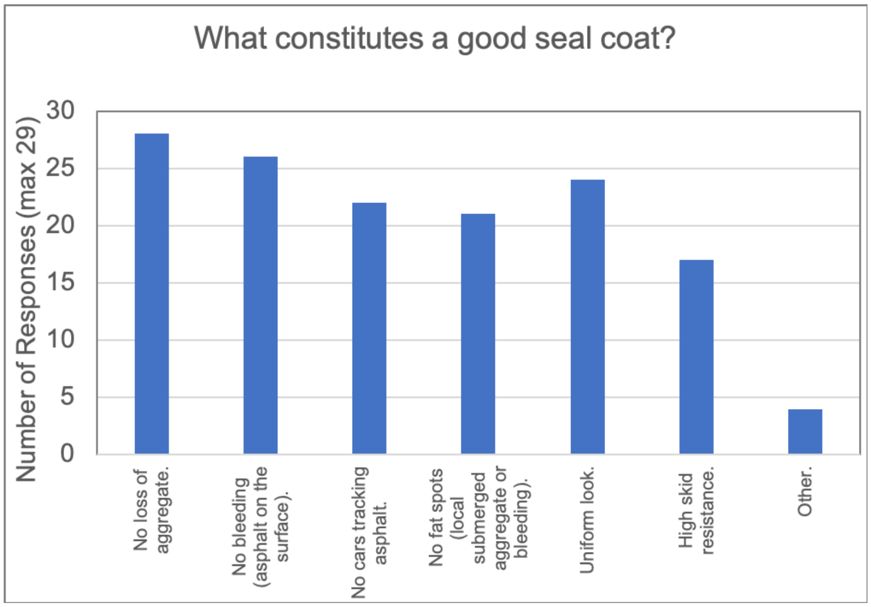


Figure A.42. Characteristics of a well performing seal coat as identified by different states (limited to survey respondents)

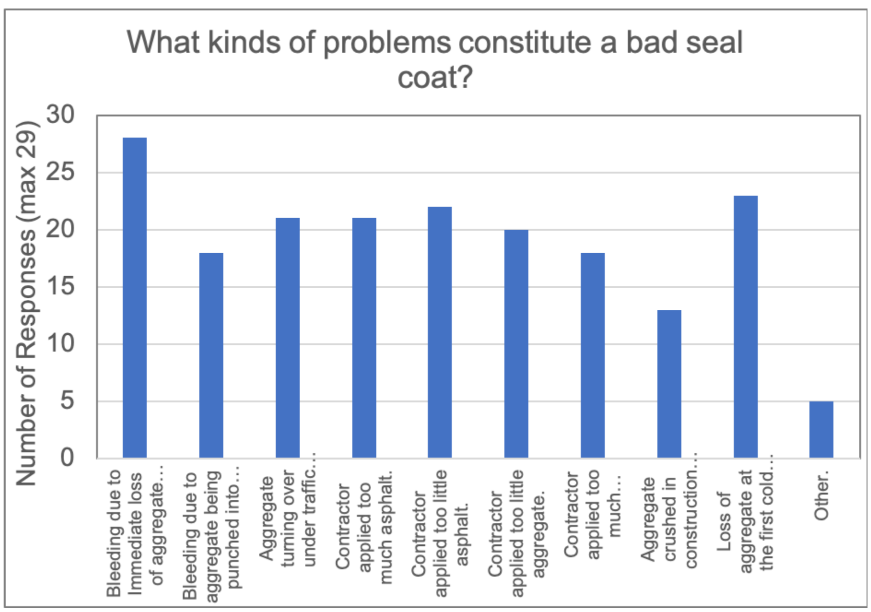


Figure A.43. Indicators of poor performance or failure of seal coat as identified by different states (limited to survey respondents)

APPENDIX B. REPRESENTATIVE IMAGES FROM FIELD SECTIONS

Pictures from Sections for Chip Seal Project

Section-1

June 2018 (Before the Construction)

June 2018 (After the Construction)

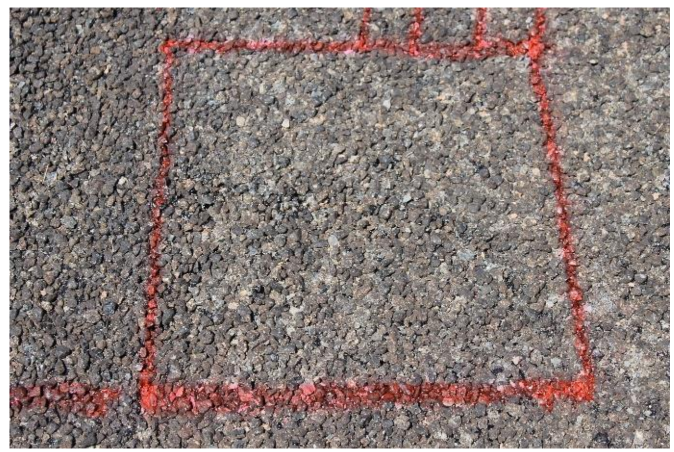
Section-1

July 2021 (3 Years 1 Month after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – 63%

Section-2



June 2018 (Before the Construction)

June 2018 (After the Construction)

Section-2

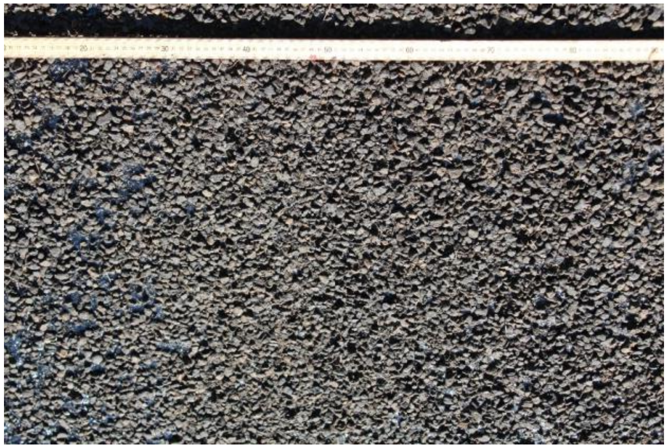


July 2021 (3 Years 1 Month after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – 31%

Section-3



June 2018 (Before the Construction)

June 2018 (After the Construction)

Section-3



July 2021 (3 Years 1 Month after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 66%

Section-4

June 2018 (Before the Construction)

June 2018 (After the Construction)

Section-4

July 2021 (3 Years 1 Month after the Construction)

Qualitative Rating – 2

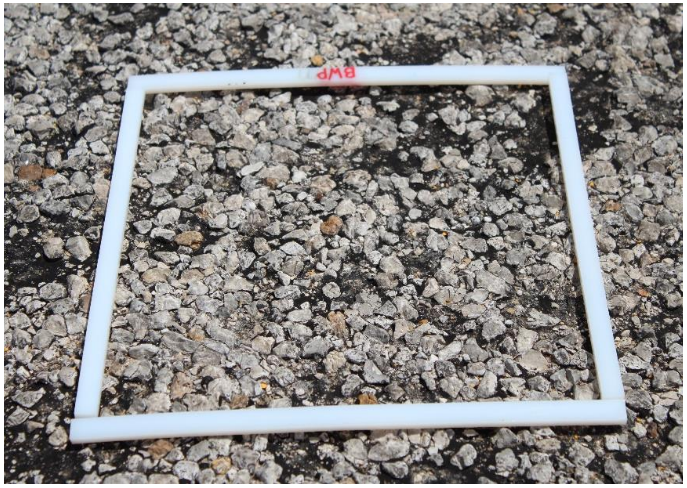
Quantitative Texture Loss Percentile – 9%

Section-5

June 2018 (Before the Construction)

June 2018 (After the Construction)

Section-5


July 2021 (3 Years 1 Month after the Construction)

Qualitative Rating – 2

Quantitative Texture Loss Percentile – 97%

Section-6

June 2018 (Before the Construction)

June 2018 (After the Construction)

Section-6

July 2021 (3 Years 1 Month after the Construction)

Qualitative Rating – 2

Quantitative Texture Loss Percentile – 17%

Section-7

July 2018 (Before the Construction)

July 2018 (After the Construction)

Section-7

July 2021 (3 Years after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 91%

Section-8

July 2018 (Before the Construction)

July 2018 (After the Construction)

Section-8

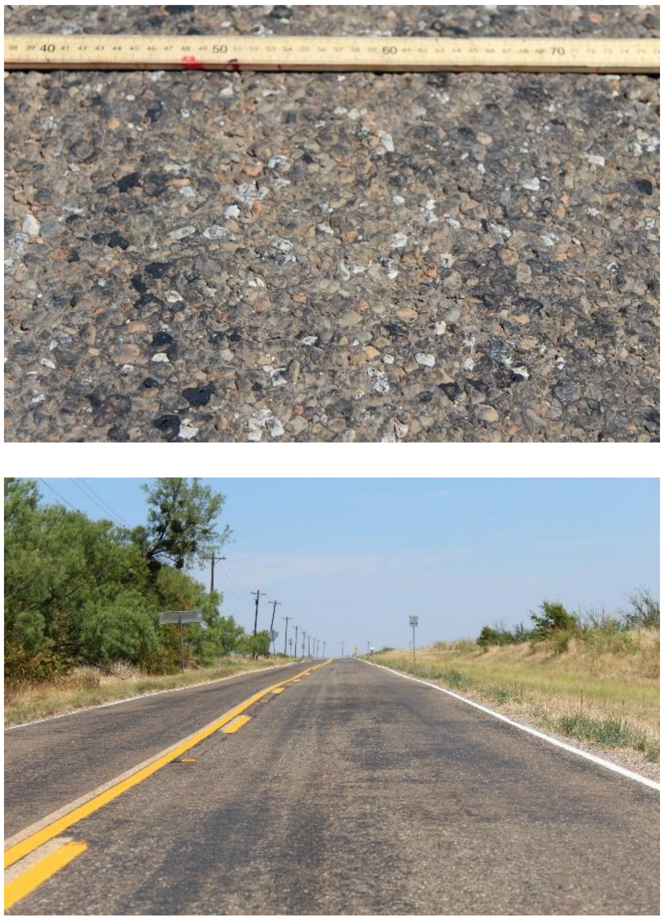


July 2021 (3 Years after the Construction)

Qualitative Rating – 2

Quantitative Texture Loss Percentile – 11%

Section-9



July 2018 (Before the Construction)

July 2018 (After the Construction)

Section-9

July 2021 (3 Years after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 100%

Section-10

July 2018 (Before the Construction)

July 2018 (After the Construction)

Section-10

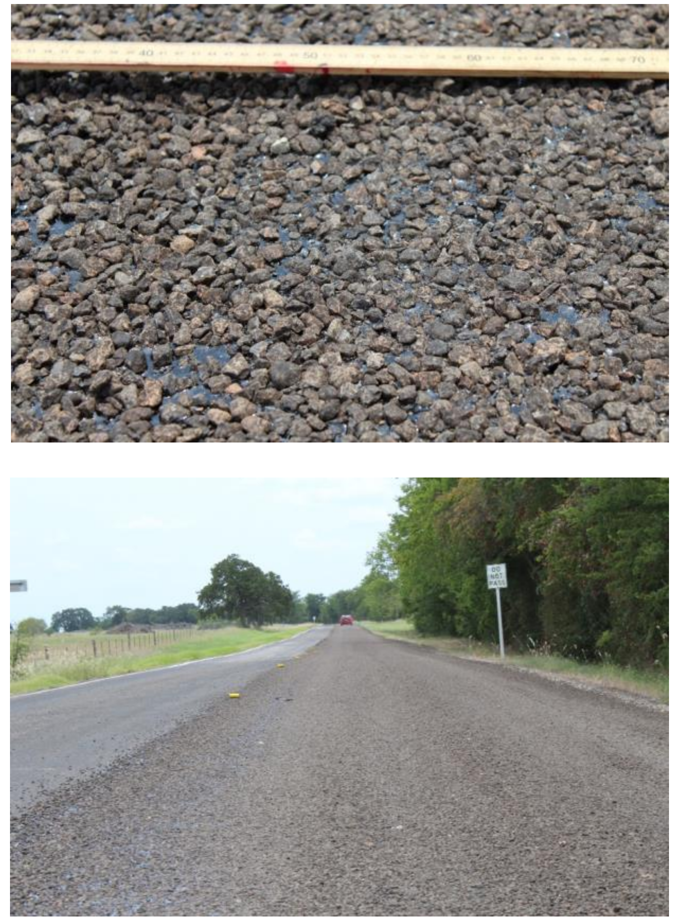
July 2021 (3 Years after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – 83%

Section-11

July 2018 (Before the Construction)



July 2018 (After the Construction)

Section-11

July 2021 (3 Years after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 77%

Section-12

July 2018 (Before the Construction)

July 2018 (After the Construction)

Section-12

March 2022 (3 Years 8 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 26%

Section-13

August 2018 (Before the Construction)

August 2018 (After the Construction)

Section-13


July 2021 (2 Years 11 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 6%

Section-14

August 2018 (Before the Construction)

August 2018 (After the Construction)

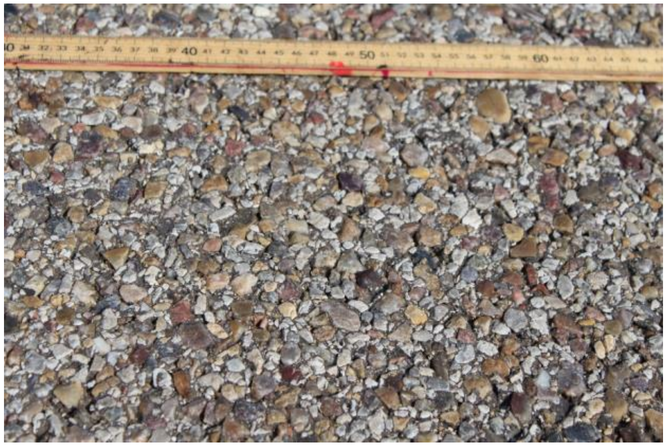
Section-14

July 2021 (2 Years 11 Months after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – 74%

Section-15



August 2018 (Before the Construction)

August 2018 (After the Construction)

Section-15

October 2021 (3 Years 2 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 34%

Section-16

August 2018 (Before the Construction)

August 2018 (After the Construction)

Section-16

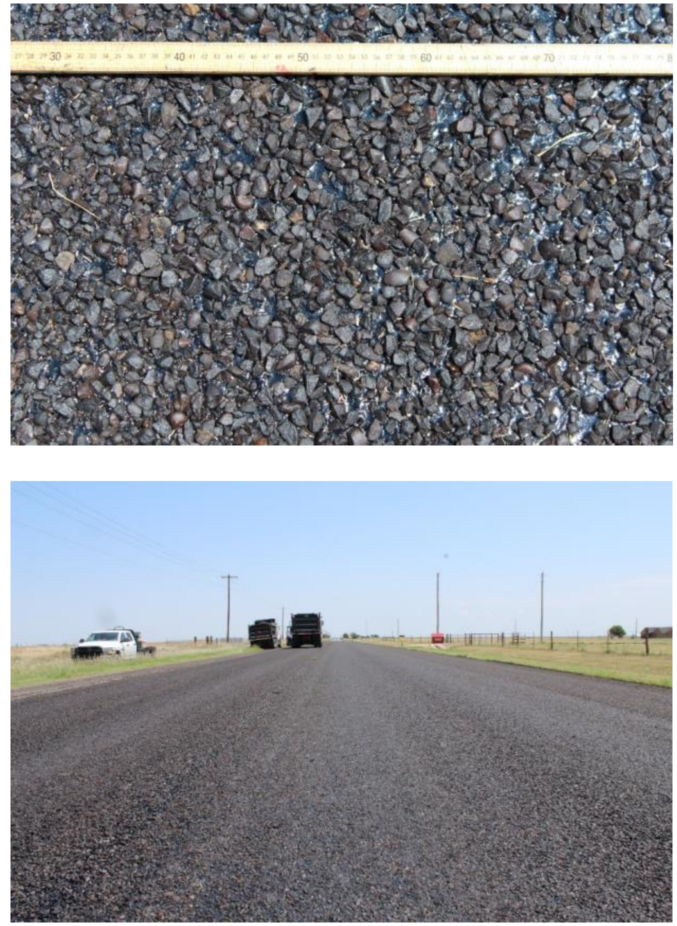
October 2021 (3 Years 2 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 69%

Section-17

August 2018 (Before the Construction)



August 2018 (After the Construction)

Section-17

October 2021 (3 Years 2 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 23%

Section-18

August 2018 (Before the Construction)

August 2018 (After the Construction)

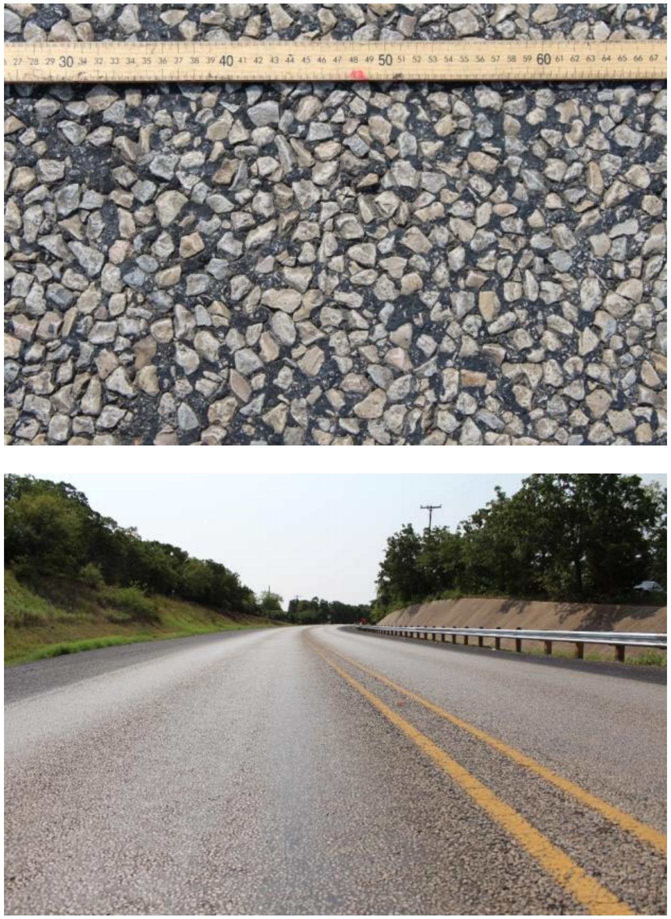
Section-18

October 2021 (3 Years 2 Months after the Construction)

Qualitative Rating – 1

Quantitative Texture Loss Percentile – 3%

Section-19



August 2018 (Before the Construction)

August 2018 (After the Construction)

Section-19



July 2021 (2 Years 11 Months after the Construction)

Qualitative Rating – 5

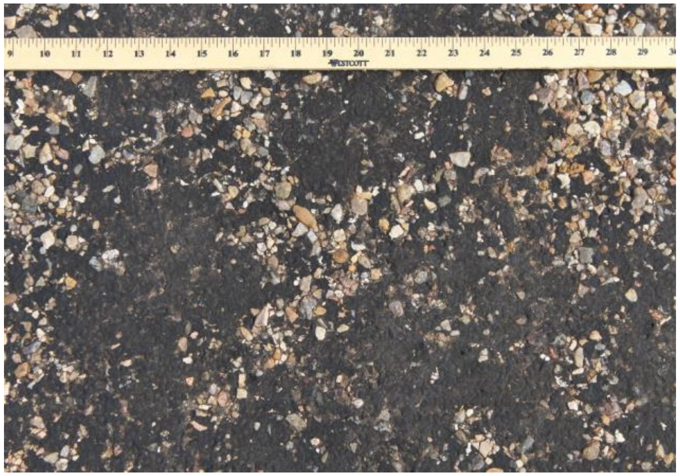
Quantitative Texture Loss Percentile – NA

Section-20

September 2018 (Before the Construction)

September 2018 (After the Construction)

Section-20



October 2021 (3 Years 1 Month after the Construction)

Qualitative Rating – 2

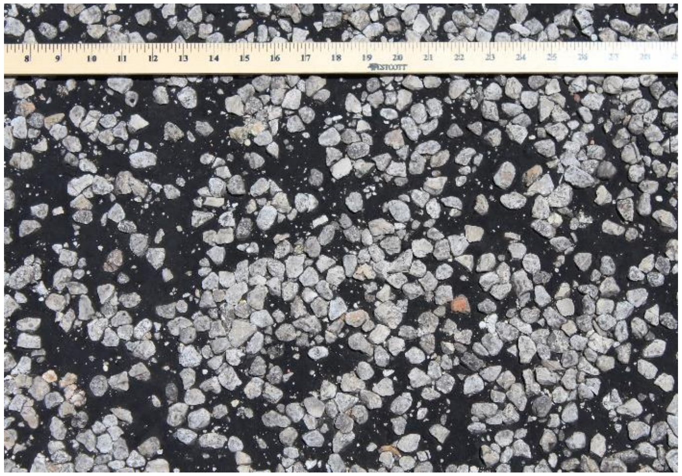
Quantitative Texture Loss Percentile – NA

Section-21

May 2020 (Before the Construction)

May 2020 (After the Construction)

Section-21



August 2021 (1 Year 3 Months after the Construction)

Qualitative Rating – 2

Quantitative Texture Loss Percentile – 60%

Section-22

May 2020 (Before the Construction)

May 2020 (After the Construction)

Section-22

August 2021 (1 Year 3 Months after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – 94%

Section-23

May 2020 (Before the Construction)

May 2020 (After the Construction)

Section-23

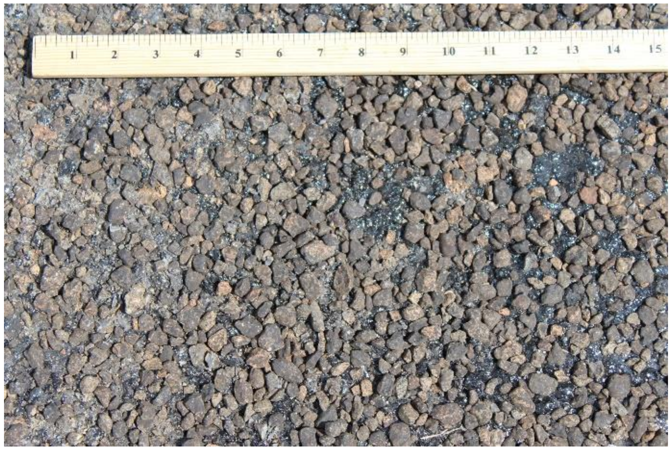


August 2021 (1 Year 3 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 71%

Section-24



June 2020 (Before the Construction)

June 2020 (After the Construction)

Section-24



July 2021 (1 Year 1 Month after the Construction)

Qualitative Rating – 2

Quantitative Texture Loss Percentile – 57%

Section-25

June 2020 (Before the Construction)

June 2020 (After the Construction)

Section-25

September 2021 (1 Year 3 Months after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – 89%

Section-26

June 2020 (Before the Construction)

June 2020 (After the Construction)

Section-26


July 2021 (1 Year 1 Month after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 46%

Section-27

June 2020 (Before the Construction)

June 2020 (After the Construction)

Section-27

July 2021 (1 Year 1 Month after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 86%

Section-28

June 2020 (Before the Construction)

June 2020 (After the Construction)

Section-28

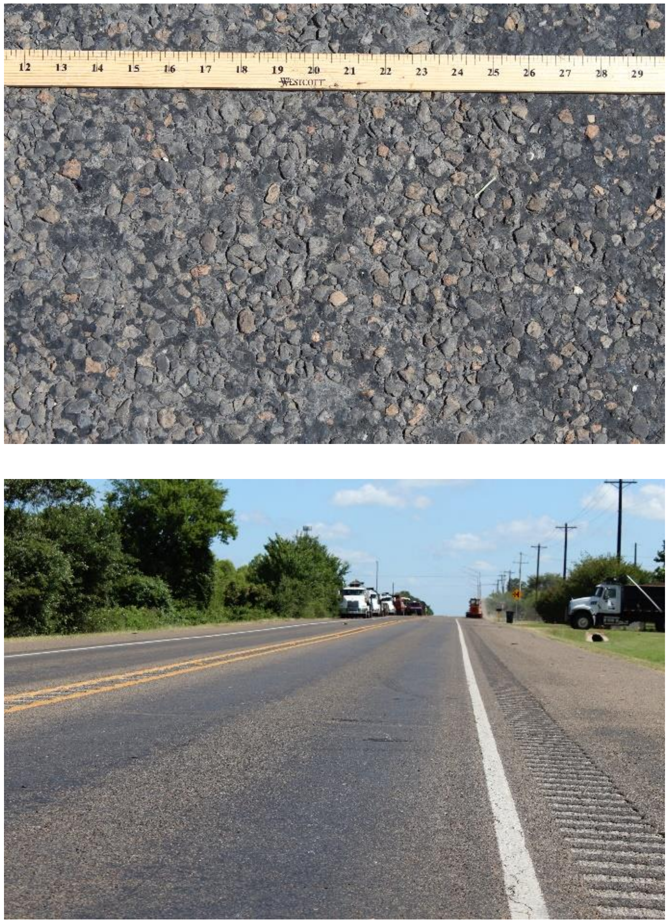


September 2021 (1 Year 3 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 40%

Section-29



June 2020 (Before the Construction)

June 2020 (After the Construction)

Section-29

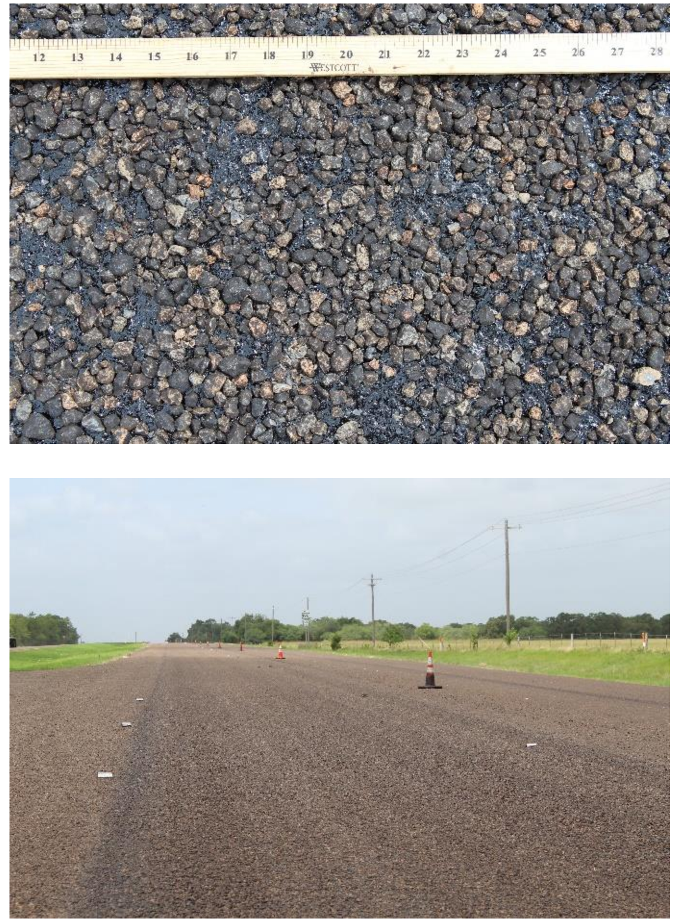
July 2021 (1 Year 1 Month after the Construction)

Qualitative Rating – 2

Quantitative Texture Loss Percentile – 29%

Section-30

June 2020 (Before the Construction)



June 2020 (After the Construction)

Section-30

July 2021 (1 Year 1 Month after the Construction)

Qualitative Rating – 2

Quantitative Texture Loss Percentile – 14%

Section-31

June 2020 (Before the Construction)

June 2020 (After the Construction)

Section-31

July 2021 (1 Year 1 Month after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – 80%

Section-32

July 2020 (Before the Construction)

July 2020 (After the Construction)

Section-32



July 2021 (1 Year after the Construction)

Qualitative Rating – 2

Quantitative Texture Loss Percentile – 20%

Section-33

July 2020 (Before the Construction)

July 2020 (After the Construction)

Section-33



March 2022 (1 Year 8 Months after the Construction)

Qualitative Rating – 4

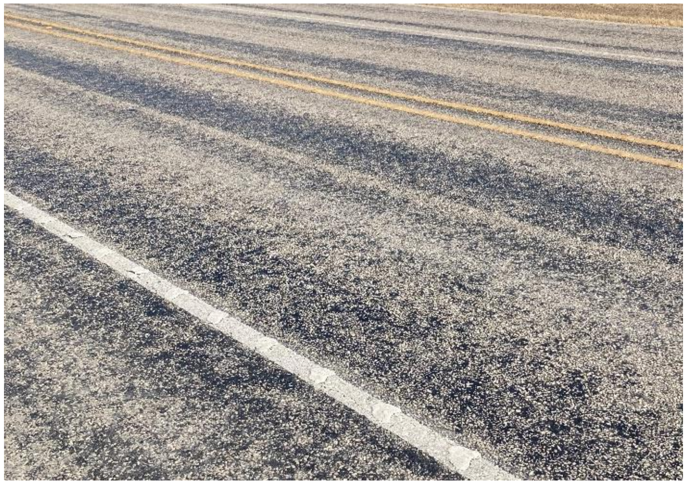
Quantitative Texture Loss Percentile – 43%

Section-34

July 2020 (Before the Construction)

July 2020 (After the Construction)

Section-34


March 2022 (1 Year 8 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 51%

Section-35

July 2020 (Before the Construction)

July 2020 (After the Construction)

Section-35

September 2021 (1 Year 2 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – 54%

Section-36

July 2020 (Before the Construction)

July 2020 (After the Construction)

Section-36



September 2021 (1 Year 2 Months after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – 37%

Section-37

July 2020 (Before the Construction)

July 2020 (After the Construction)

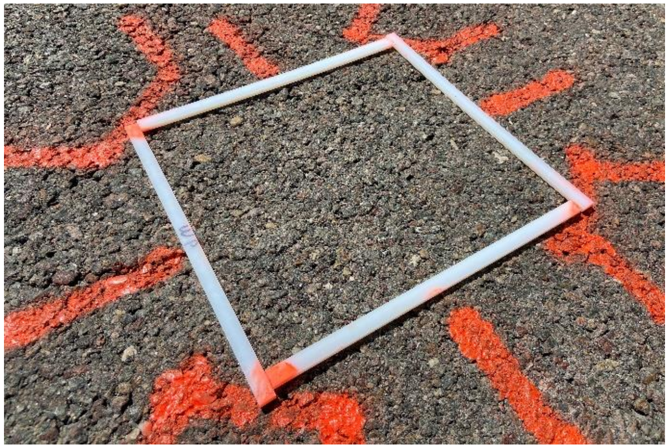
Section-37

September 2021 (1 Year 2 Months after the Construction)

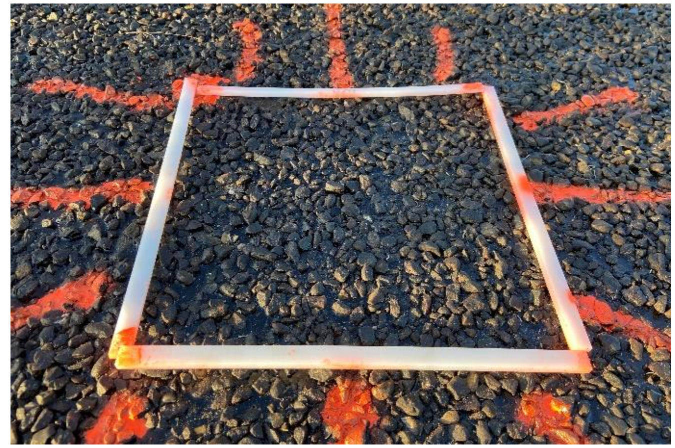
Qualitative Rating – 3

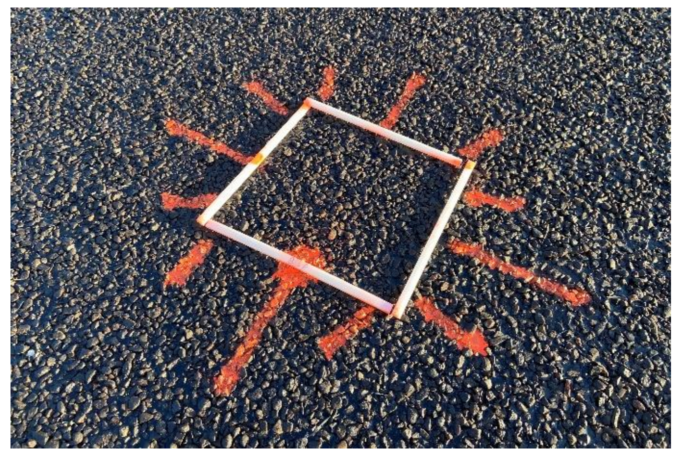
Quantitative Texture Loss Percentile – 49%

Section-38



June 2020 (Before the Construction)





June 2020 (After the Construction)

Section-38

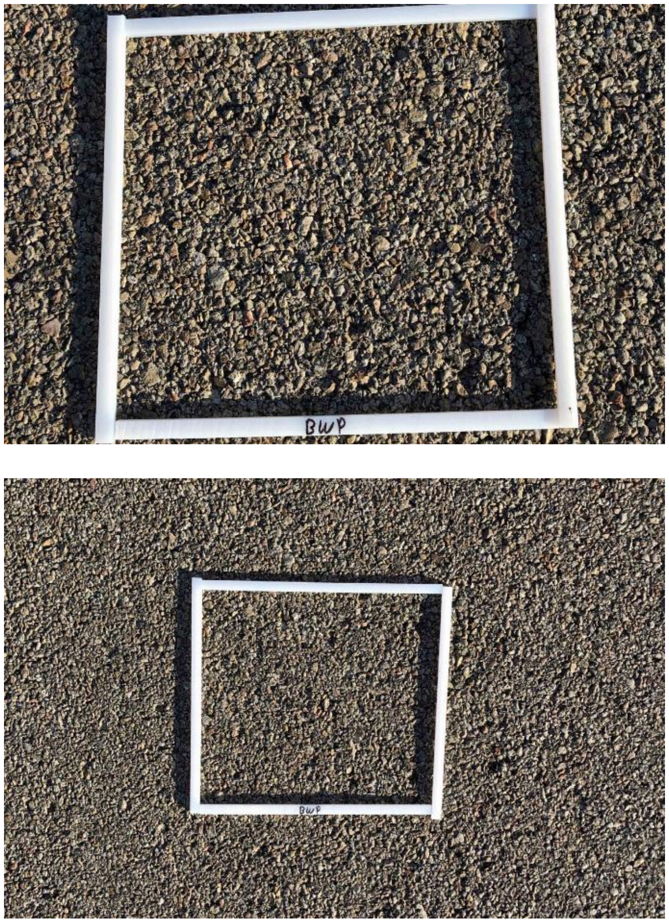
  

May 2022 (1 Year 11 Months after the Construction)

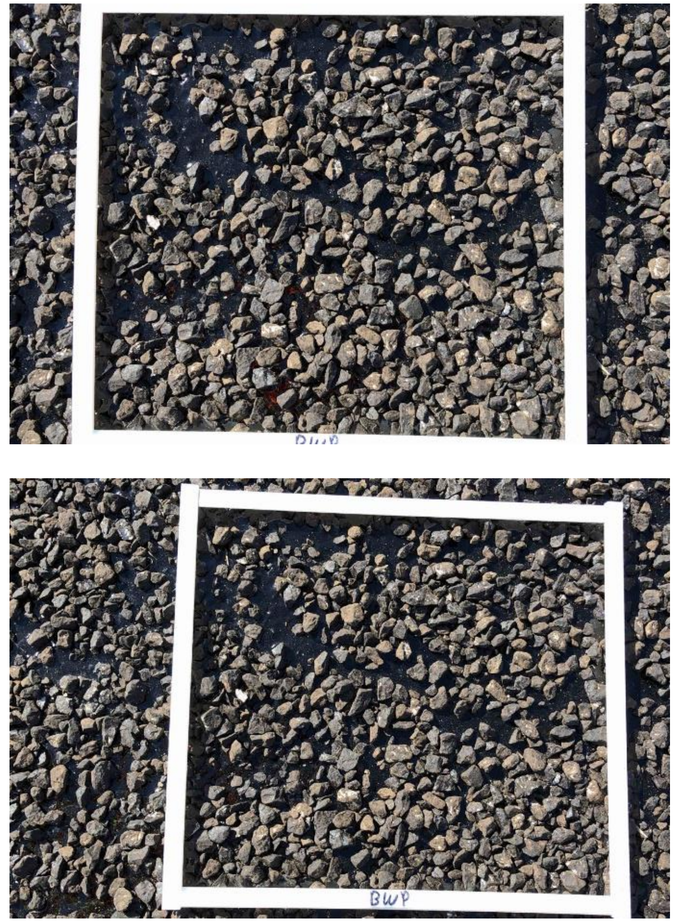
Qualitative Rating – 3

Quantitative Texture Loss Percentile – NA

Section-39



July 2020 (Before the Construction)



July 2020 (After the Construction)

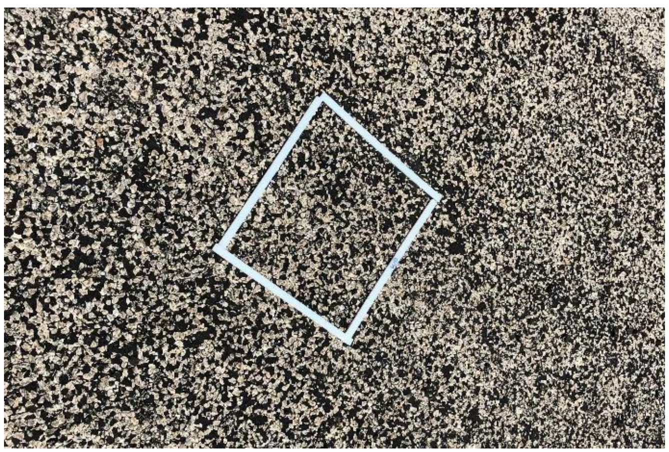
Section-39

May 2022 (1 Year 10 Months after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – NA

Section-40



July 2020 (Before the Construction)

July 2020 (After the Construction)

Section-40

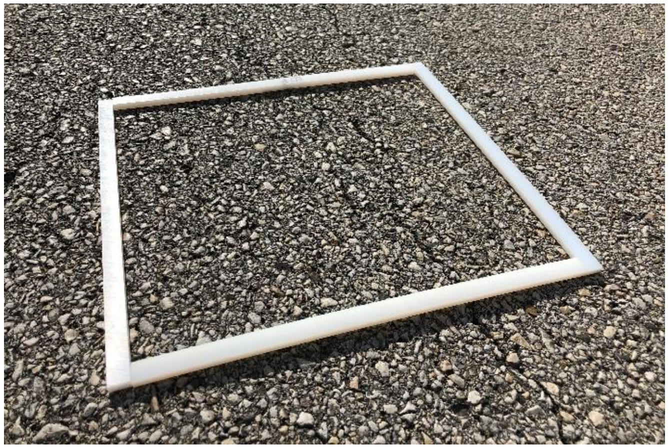


May 2022 (1 Year 10 Months after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – NA

Section-41



July 2020 (Before the Construction)

July 2020 (After the Construction)

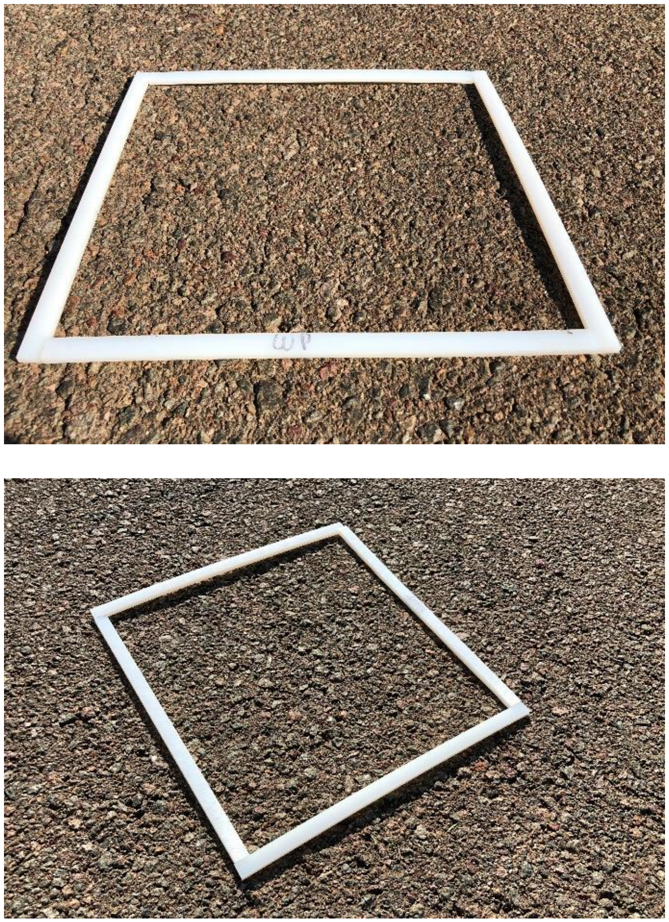
Section-41


May 2022 (1 Year 10 Months after the Construction)

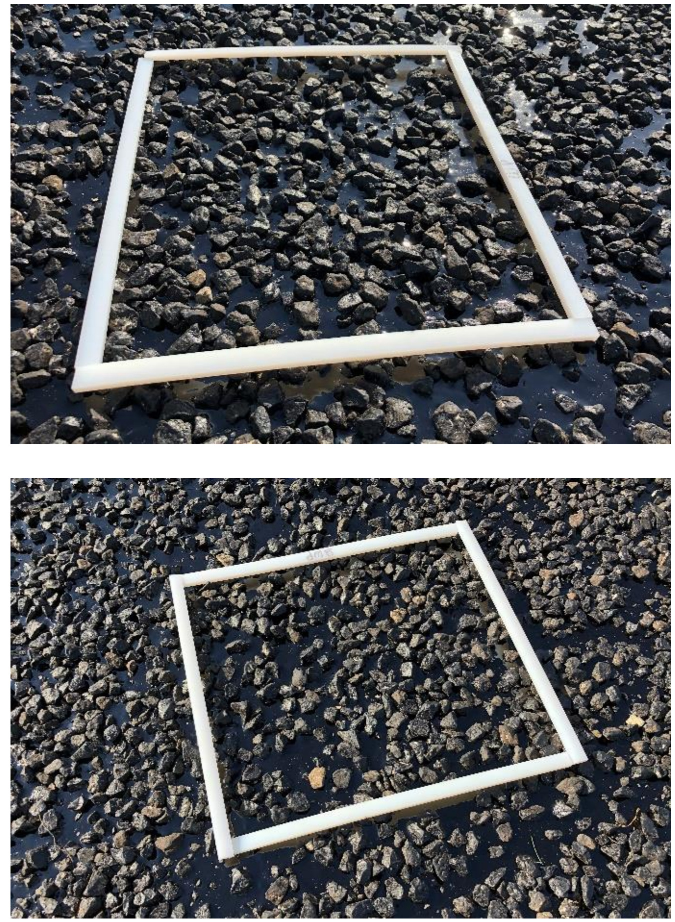
Qualitative Rating – 2

Quantitative Texture Loss Percentile – NA

Section-42



July 2020 (Before the Construction)



July 2020 (After the Construction)

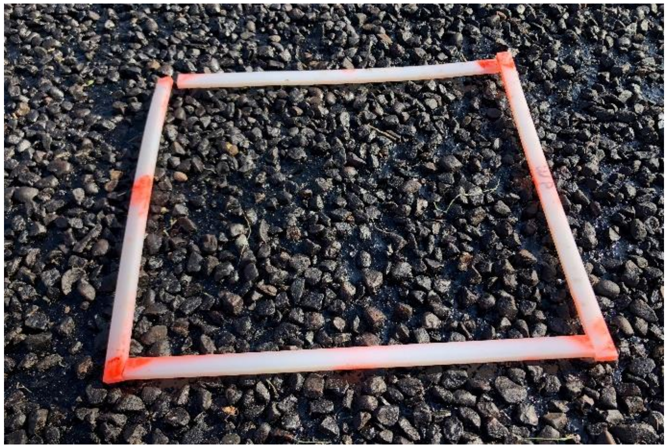
Section-42

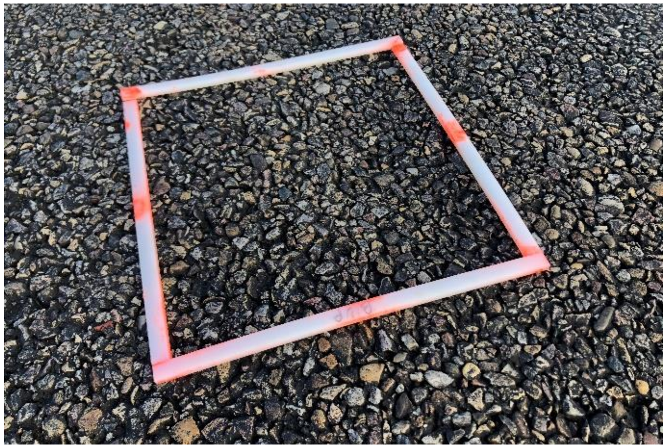
May 2022 (1 Year 10 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – NA

Section-43





August 2020 (Before the Construction)

August 2020 (After the Construction)

Section-43

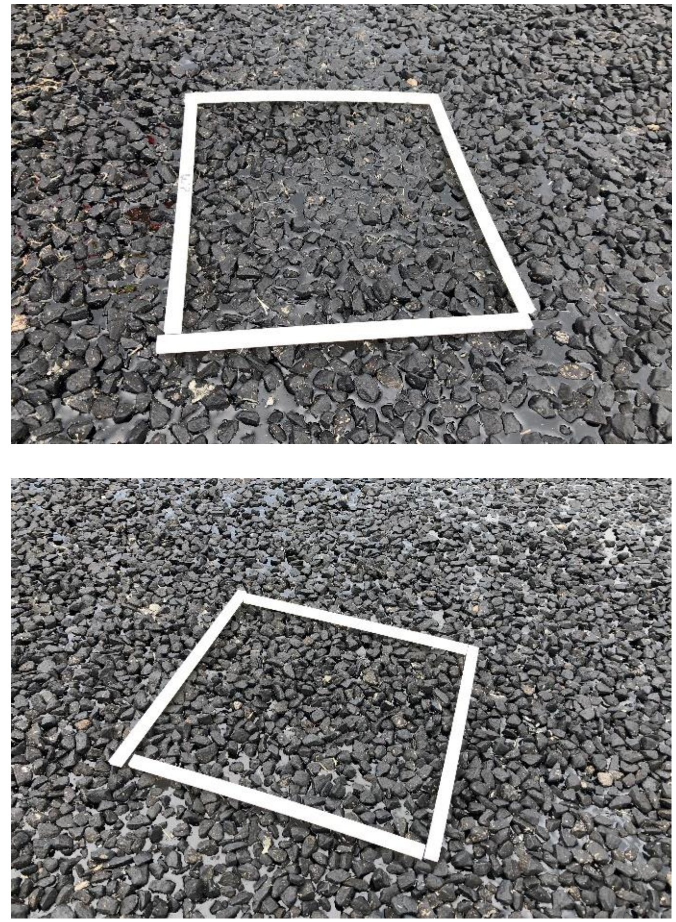
May 2022 (1 Year 9 Months after the Construction)

Qualitative Rating – 4

Quantitative Texture Loss Percentile – NA

Section-44

August 2020 (Before the Construction)



August 2020 (After the Construction)

Section-44

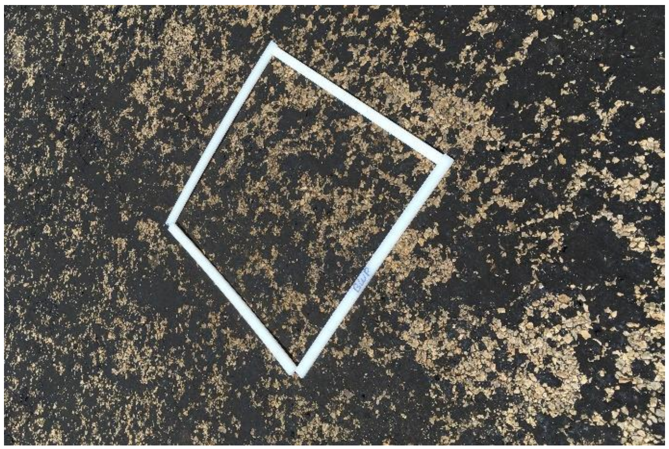


May 2022 (1 Year 9 Months after the Construction)

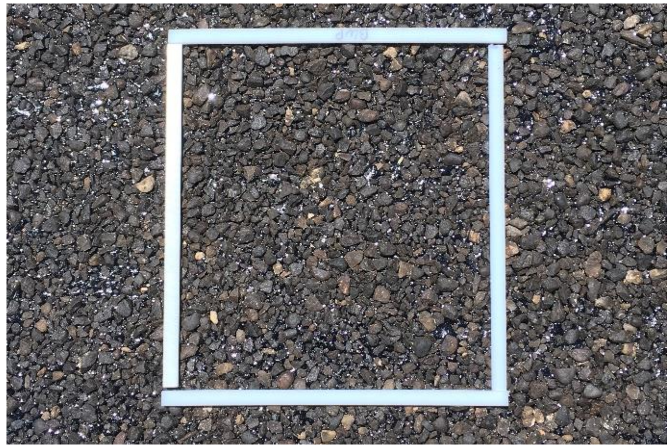
Qualitative Rating – 2

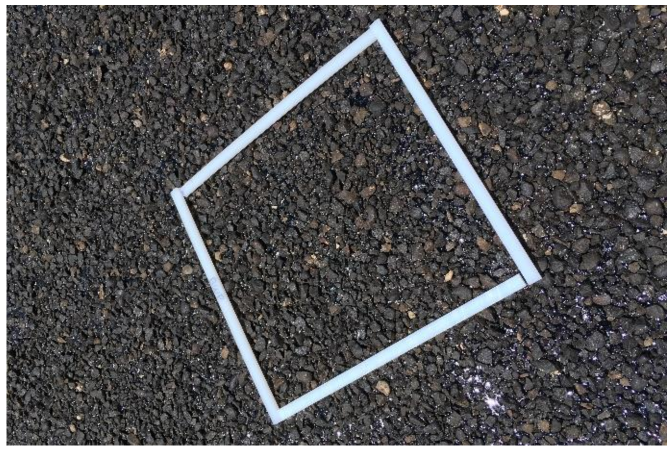
Quantitative Texture Loss Percentile – NA

Section-45



July 2020 (Before the Construction)





July 2020 (After the Construction)

Section-45

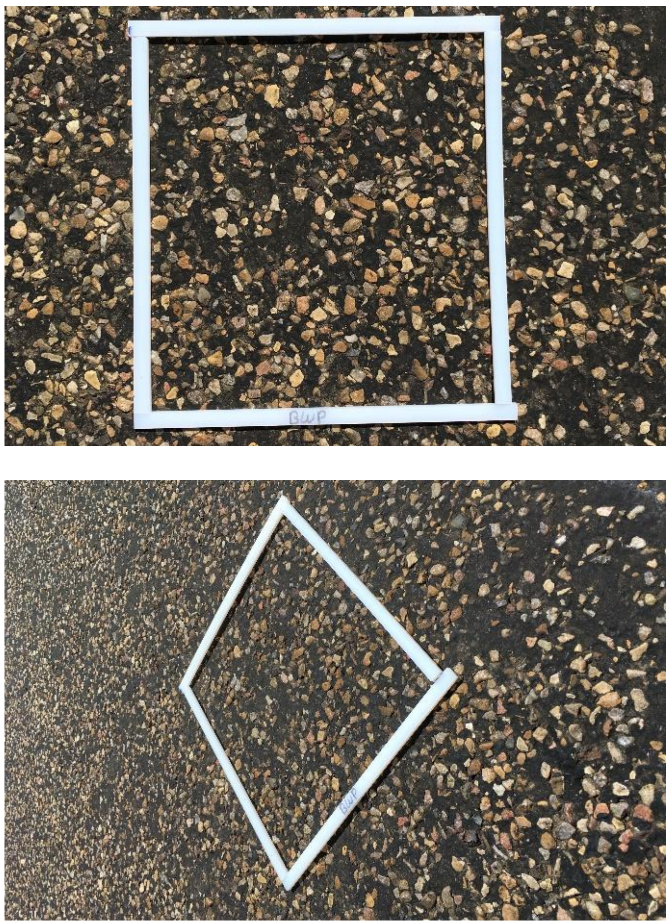


May 2022 (1 Year 10 Months after the Construction)

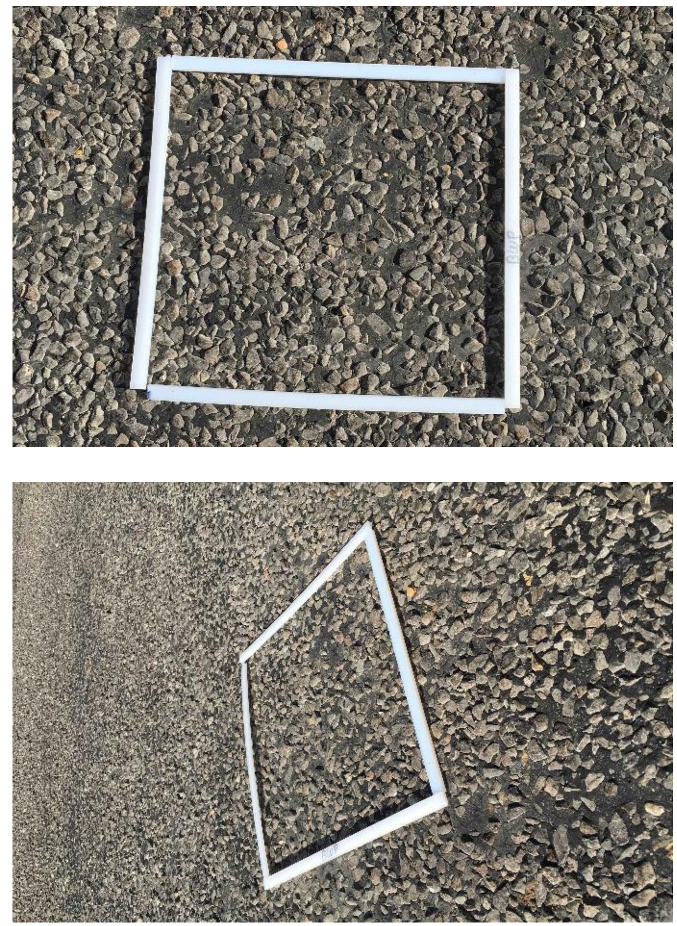
Qualitative Rating – 2

Quantitative Texture Loss Percentile – NA

Section-46



September 2020 (Before the Construction)



September 2020 (After the Construction)

Section-46

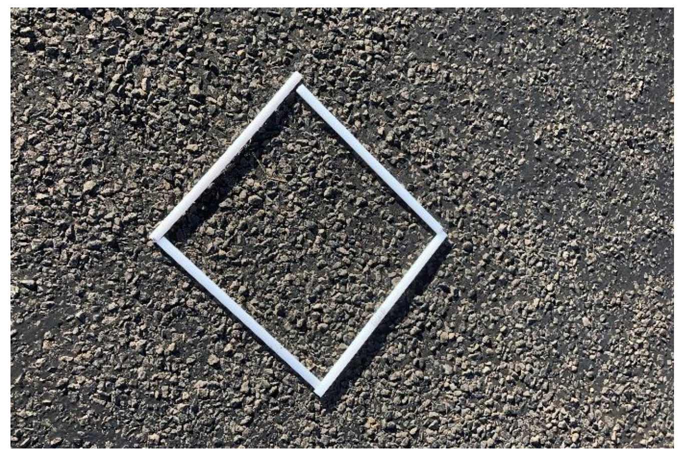
May 2022 (1 Year 8 Months after the Construction)

Qualitative Rating – 1

Quantitative Texture Loss Percentile – NA

Section-47

July 2020 (Before the Construction)



September 2020 (After the Construction)

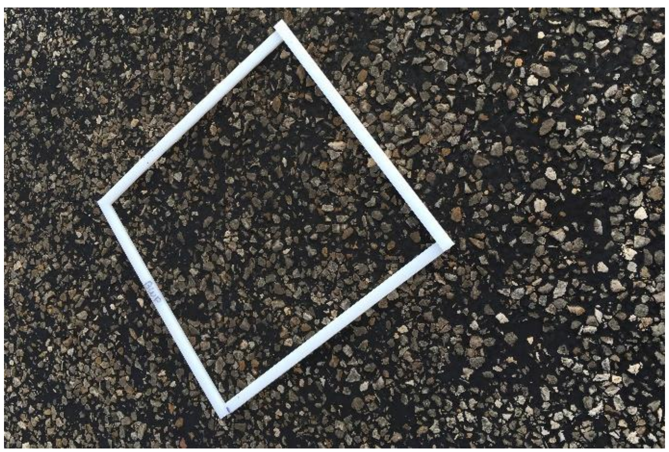
Section-47

May 2022 (1 Year 10 Months after the Construction)

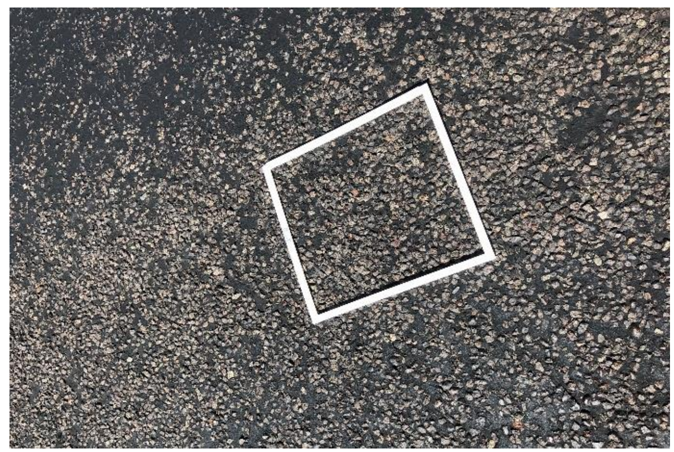
Qualitative Rating – 1

Quantitative Texture Loss Percentile – NA

Section-48



July 2020 (Before the Construction)



July 2020 (After the Construction)

Section-48

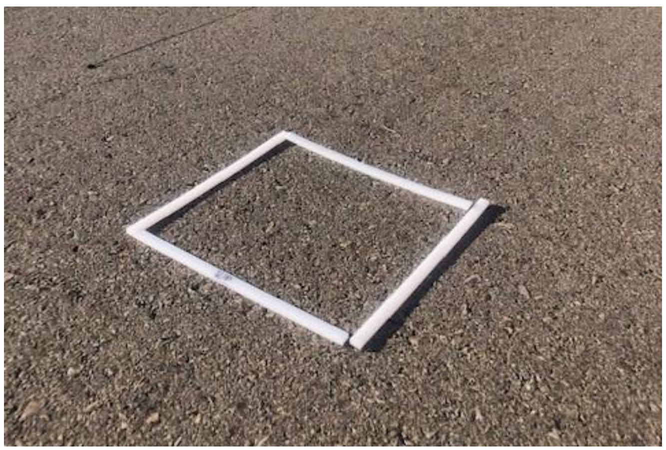
  

May 2022 (1 Year 10 Months after the Construction)

Qualitative Rating – 2

Quantitative Texture Loss Percentile – NA

Section-49



September 2020 (Before the Construction)

September 2020 (After the Construction)

Section-49

May 2022 (1 Year 8 Months after the Construction)

Qualitative Rating – 3

Quantitative Texture Loss Percentile – NA

APPENDIX C. TEST METHOD FOLLOWING TXDOT TEMPLATE

Test Procedure for

SWEEP TEST

TxDOT Designation: Tex-254-F

Effective Date: Draft

1. SCOPE

1.1 Use this test method to evaluate the compatibility of materials at early stages of seal coat construction.

1.2 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. APPARATUS

2.1 Sweep apparatus, according to ASTM D3910, except that the base is adapted to hold an 11-inch aluminum pan in place. Figure 1 shows the component parts of the apparatus.

Figure 1. Sweep Test Apparatus Components.

2.2 Eleven-inch diameter, disposable, aluminum plates with approximate 0.25-inch sides (commonly known as a pizza tin).

2.3 Heating oven with level shelves, capable of maintaining a temperature of at least 163 ± 3°C (325 ± 5°F) and support a minimum weight of 5000 g (for testing with hot applied binders).

2.4 Heating oven with level shelves, capable of maintaining a temperature of at least 60 ± 3°C (140 ± 5°F) and support a minimum weight of 5000 g (for testing with emulsified binders).

2.5 Oven Heat Sink (1/4 steel plate with dimensions larger than an aluminum sample plate and fitting on an oven shelf has been found to be adequate).

2.6 Insulating gloves for pouring asphalt binder and handling specimens.

2.7 Angle pliers for pouring cans of asphalt binder.

2.8 Metal stirring rod for hot applied binders and non-absorptive stirring rod for emulsified binders (this may be plastic).

2.9 Infrared thermometer. To ensure samples have cooled to room temperature.

2.10 Balance, Class G5 in accordance with Tex-901-K, minimum capacity of 10,000 g, and the ability to hold plywood insulator and one sample plate.

2.11 Plywood insulator, 19 mm (3/4 in.) or thicker, having an area larger than the aluminum sample plates (to act as an insulator to reduce sample cool-down rate when pouring binder onto the sample pan).

2.12 Rubber roller from Vialit apparatus.

2.13 Silicone pad. Approximate dimensions of 30 cm x 30 cm x 0.6 cm (12 in x 12 in x 0.25 in).

2.14 Soft-bristle bench brush (broom), approximately 20 cm (8 in) long.

2.15 Sweep test plate template. Two pieces of ¼ inch plywood with one solid base and top piece cutout for a sweep test plate, as shown in Figure 2. (Approximate outside dimensions of 2.5 ft. by 2.5 ft. have been found to be adequate.)

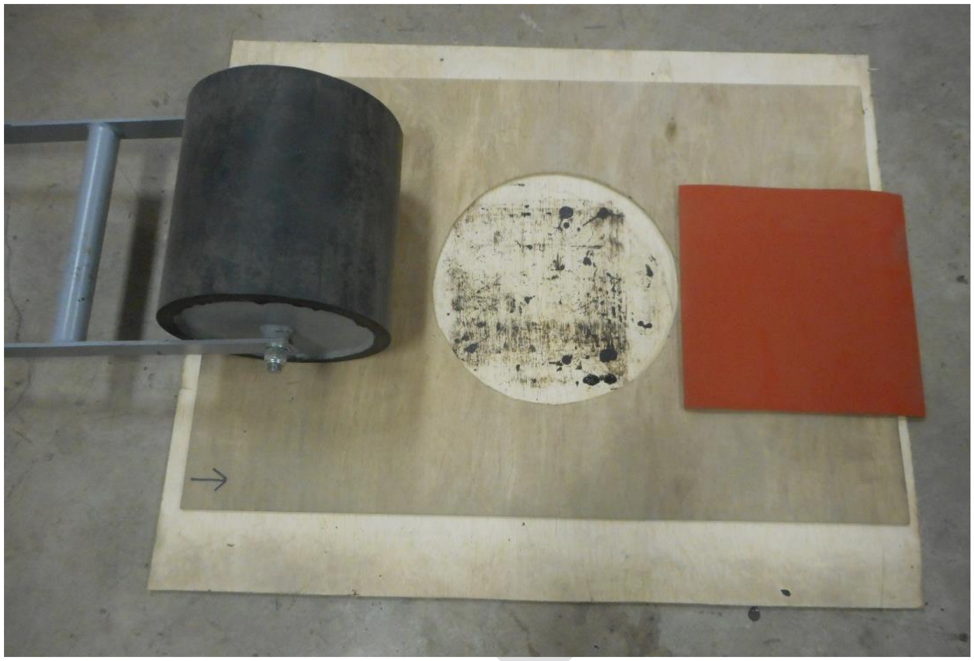


Figure 2. Sweep Sample Template with Silicone Pad and Roller.

3. MATERIALS

3.1 Asphalt cement (AC), Asphalt rubber (AR), or emulsified asphalt to be used in seal coat treatments.

3.2 Aggregates used for seal coat treatments.

4. PROCEDURE

4.1 Set the oven to the desired temperature. Ensure that the shelf in the oven is level in all directions. Place the heat sink in the oven on a level shelf. Ensure the oven is at the proper temperature before proceeding.

4.1.1 For hot applied binder, use the oven set to 163°C (325°F). Heat the binder until it is liquid.

Remove the binder from the oven, stir the binder with a stirring rod to thoroughly mix the contents and place it back in the oven to regain the temperature. Repeat one or two more times, particularly for AR binders to ensure temperature uniformity.

Note 1 - Split the binder into multiple smaller containers appropriate for one application to avoid reheating the binder more than once.

4.1.2 For emulsified asphalt, use the oven set to 60°C (140°F). Maintain the emulsion at room temperature in a container to prevent or minimize emulsion moisture loss.

4.2 For hot applied binders, place the plate in the oven on the heat sink for 10 min before pouring the binder.

4.3 Place the insulating plywood on the balance and tare the balance.

4.4 For hot applied binders, remove the plate from the oven and place it on the on the insulating plywood on top of the balance. For emulsified asphalt, place the room temperature plate on the insulating plywood on top of the balance. Weigh the plate to the nearest 1 gram and record as P in Section 5.

4.5 Tare the balance with the plate.

4.6 Immediately, using the binder (hot applied binder from the oven or room temperature emulsified asphalt), stir thoroughly to ensure uniformity, and pour the required binder on the plate using the following application rates. Weigh binder to the nearest 1 gram and record as B in Section 5.

4.6.1 For hot applied binders:

4.6.1.1 Use 90 g of binder on a Sweep plate for grade 3 aggregates or equivalent. For a binder with a specific gravity of 1.020, this equates to 0.32 gal/yd^2.

4.6.1.2 Use 80 g of binder on a Sweep plate for grade 4 aggregates or equivalent. For a binder with a specific gravity of 1.020, this equates to 0.28 gal/yd^2.

4.6.2 For emulsified asphalt:

4.6.2.1 Use 138 g of emulsion on a Sweep plate for grade 3 aggregates or equivalent. For an emulsion with a specific gravity of 1.010, this equates to 0.49 gal/yd^2 of emulsion and 0.32 gal/yd^2 of emulsion residue.

4.6.2.2 Use 120 g of emulsion on a Sweep plate for grade 4 aggregates or equivalent. For an emulsion with a specific gravity of 1.010, this equates to 0.43 gal/yd^2 of emulsion and 0.28 gal/yd^2 of emulsion residue.

Note 3 - Application rates for emulsions are adjusted to achieve equivalent residual binder rates.

4.7 Immediately after pouring, coat the plate by tilting the plate with plywood insulator as a unit (to ensure plate dimensional stability) side to side and back and forth to spread binder uniformly.

Note 4 - Use the plywood insulator beneath the plate together as a unit any time moving the plate could result in dimension changes or flexing of the plate.

4.8 For Hot applied binders, place the plate again in the oven on the heat sink for no more than 5 min at the application temperature (163°C (325°F). This is to reheat the binder and to achieve a compatible temperature before spreading the aggregates and to ensure that the binder spreads and uniformly coats the surface of the plate. For emulsions, do not place the plate in the oven and go directly to 4.9.

4.9 Place the plate with binder in the template and apply aggregate evenly on the plate to achieve a uniform coverage that fills the surface of the asphalt with some additional aggregate on the surface. Stop when this is achieved. Extra aggregate or aggregate that falls off the sample and on the template need not be used.

Note 5 - Aggregate **for a**pplication should be determined with the test aggregate to cover the sample plate with a uniform layer, one aggregate thick with some extra. For Grade 4 aggregates, 1000g has been found adequate. This is to ensure that sufficient aggregate is on hand for the test specimen.

4.10 Place the silicone mat over the test specimen and roll the test specimen using the rubber roller. Roll three passes in one direction and three passes in the transverse direction as shown in Figure 3.

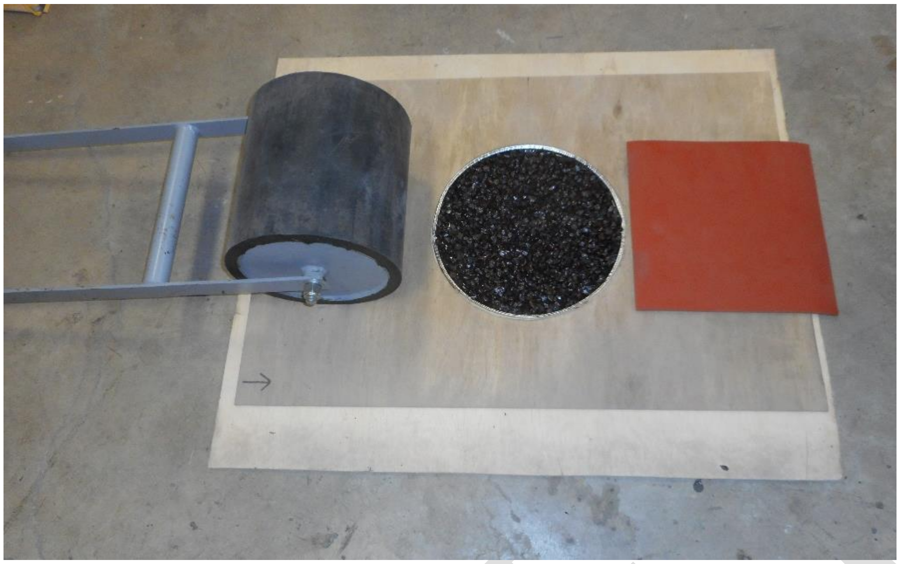


Figure 3. Rolling using the rubber roller (Silicone mat is not shown on the sample for illustration purposes).

4.11 For hot applied binders:

4.11.1 Carefully remove the test specimen from the template and allow it to come to room temperature.

4.11.2 While supported underneath with plywood, tip the test specimen at a 45-degree angle, and use a brush to remove any non-adherent aggregate.

4.11.3 Record the weight of the test specimen (plate, binder, and adhering aggregate particles) to the nearest 1 gram as A in Section 5.

4.12 For emulsified asphalt:

4.12.1 Carefully remove the test specimen from the template and cure the plate at 60°C (140 °F) for 4 hours at to ensure breaking and curing.

4.12.2 Remove the test specimen from the oven and let it come to room temperature. Ensure the test specimen is at room temperature.

4.12.3 While supported underneath with plywood, tip the test specimen at a 45-degree angle, and use a brush to remove any non-adherent aggregate.

4.12.4 Record the weight of the test specimen (plate, cured emulsion residue, and adhering aggregate particles) to the nearest 1 gram as A in Section 5.

4.12.5 Maintain the specimen at room temperature for 20 hours +/- 1 hour.

4.13 With the test specimen at room temperature, conduct sweep testing to determine aggregate Loss. The assembled apparatus is shown in Figure 4.

Note 6- Preferably testing should be initiated immediately but may be delayed no more than 3 days to accommodate work schedules.

Figure 4. Assembled Apparatus with Sample Ready to Test.

4.13.1 Clamp the test specimen to the sweep test machine.

4.13.2 Raise the test specimen to contact the tube head, making sure there is free-floating vertical movement.

4.13.3 Turn the mixer to the low-speed setting and abrade the test specimen for one minute (+/- 5 seconds).

4.13.4 Turn off the mixer and lower the sample.

4.13.5 Remove the test specimen from the mixer and hold vertically to remove any loose aggregate.

4.13.6 Weigh the tested specimen to the nearest 1 gram and record the weight as R in Section 5.

5. CALCULATIONS

For hot applied binders:

Sweep loss (%) = $\frac{A-R}{A-C} * 1.33 * 100$

Where:

P = Weight of plate.
B = Weight of binder.
C = P+B = Weight of plate and binder.
A = Weight of plate, asphalt, and aggregate.
R = Weight of plate, retained asphalt and retained aggregate after testing.

For asphalt emulsions:

Sweep loss (%) = $\frac{A-R}{A-C} * 1.33 * 100$

Where:

P = Weight of plate.
B = Weight of emulsion binder.
C = P+(B*0.65) = Weight of plate and emulsion residue.
A = Weight of plate, cured emulsion residue, and aggregate.
R = Weight of plate, retained asphalt and retained aggregate after testing.

6. REPORT

6.1 Report the average of three tests as the Sweep Loss for the material combination tested to the nearest 0.1 percent.

Note 7 – The Sweep Loss is a combination of aggregate and asphalt binder loss from testing based on the weight of the original aggregate.

Test Procedure for

VIALIT ADHESION TEST

TxDOT Designation: Tex-253-F

Effective Date: Draft

1. SCOPE

1.1 Use this test method to evaluate the adhesive properties of seal coat surface treatments for roadways in the laboratory.

1.2 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. APPARATUS

2.1 Vialit test apparatus, including sample plates, impact stage, steel impact ball, and roller as shown in Figure 1.

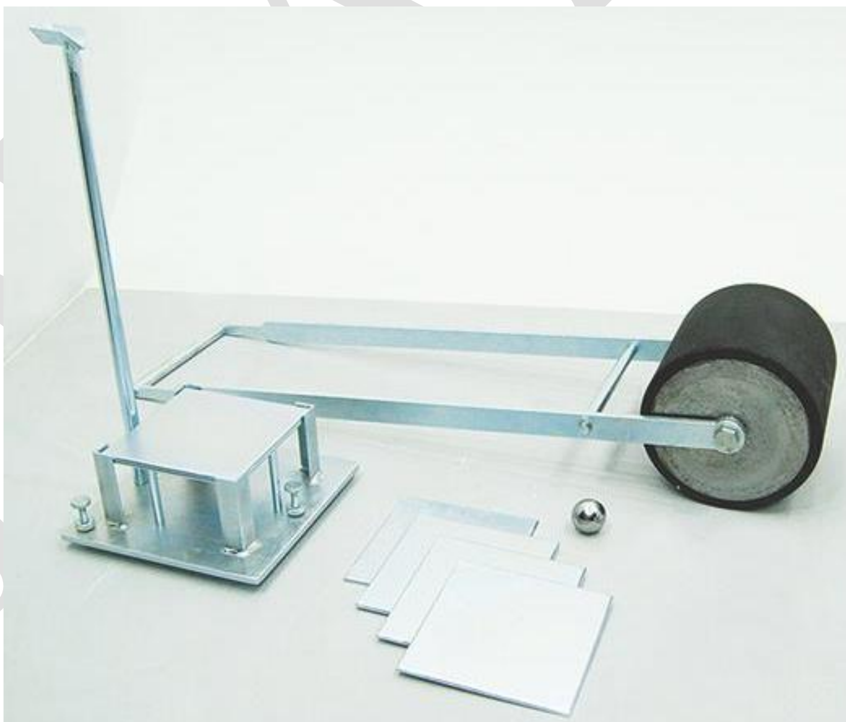


Figure 1. Vialit Apparatus (zealinternational.com)

2.2 Heating oven with level shelves, capable of maintaining a temperature of at least 163 ± 3°C (325 ± 5°F) and support a minimum weight of 5000 g (for testing with hot applied binders).

2.3 Heating oven with level shelves, capable of maintaining a temperature of at least 60 ± 3°C (140 ± 5°F) and support a minimum weight of 5000 g (for testing with emulsified binders).

2.4 Oven Heat Sink (1/4 steel plate with dimensions larger than an aluminum sample plate and fitting on an oven shelf has been found to be adequate).

2.5 Insulating gloves for pouring asphalt binder and handling specimens.

2.6 Angle pliers for pouring cans of asphalt binder.

2.1 Metal stirring rod for hot applied binders and non-absorptive stirring rod for emulsified binders (this may be plastic).

2.2 Infrared thermometer. To ensure samples have cooled to room temperature.

2.3 Balance, Class G5 in accordance with Tex-901-K, minimum capacity of 10,000 g, and the ability to hold plywood insulator and one Vialit plate.

2.4 Plywood insulator, 19 mm (3/4 in.) or thicker, having an area larger than the Vialit metal plates (to act as an insulator to reduce sample cool-down rate when pouring binder onto the sample pan).

2.5 Silicone pad. Approximate dimensions of 30 cm x 30 cm x 0.6 cm (12 in x 12 in x 0.25 in).

2.6 Soft-bristle bench brush (broom), approximately 20 cm (8 in) long.

2.7 Refrigerator, capable of maintaining a temperature of 5 °C ± 2°C (41 °F ± 4° F).

2.8 Vialit test plate template, two pieces of ¼ inch plywood with one solid base and top piece cutout for a Vialit plate, as shown in Figure 2. (Approximate outside dimensions of 2.5 ft. by 2.5 ft. have been found to be adequate.)

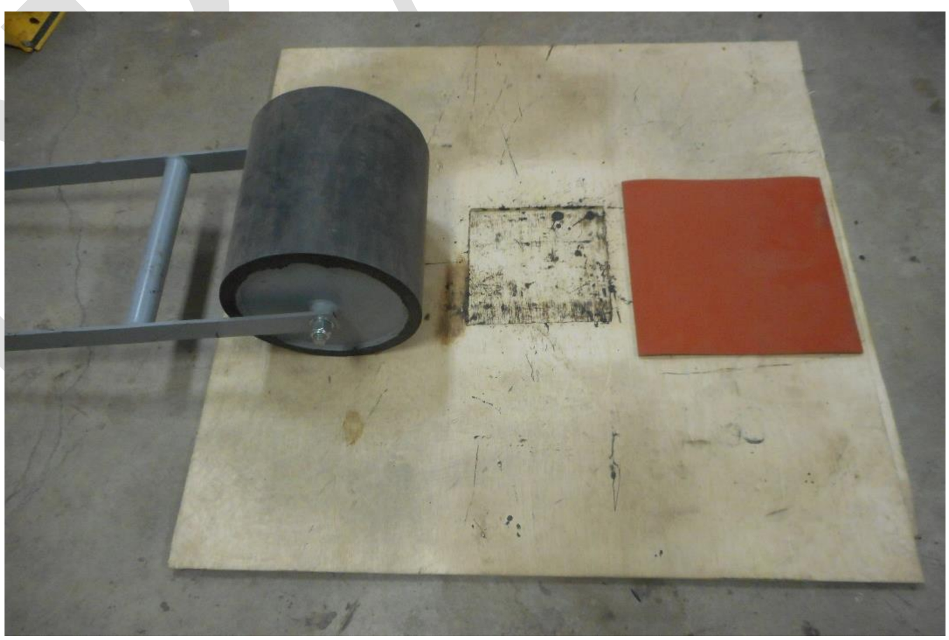


Figure 2. Vialit Sample Template with Silicone Pad and Roller.

3. MATERIALS

3.1 Asphalt cement (AC), Asphalt rubber (AR), or emulsified asphalt to be used in seal coat treatments.

3.2 Aggregates used for seal coat treatments.

4. PROCEDURE

4.1 Clean and dry the plate, as shown in Figure 1.

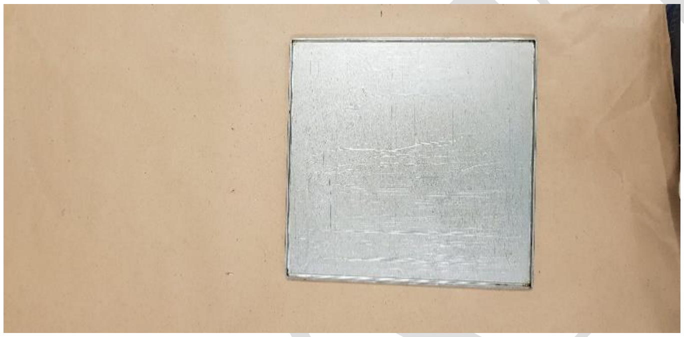


Figure 1. Clean and dry Vialit plate

4.2 Set the oven to the desired temperature. Ensure that the shelf in the oven is level in all directions. Place the heat sink in the oven on a level shelf. Ensure the oven is at the proper temperature before proceeding.

4.2.1 For hot applied binder, use the oven set to 163°C (325°F). Heat the binder until it is liquid.

Remove the binder from the oven, stir the binder with a stirring rod to thoroughly mix the contents and place it back in the oven to regain the temperature. Repeat one or two more times, particularly for AR binders to ensure temperature uniformity.

Note 1 - Split the binder into multiple smaller containers appropriate for one application to avoid reheating the binder more than once.

4.2.2 For emulsified asphalt, use the oven set to 60°C (140°F). Maintain the emulsion at room temperature in a container to prevent or minimize emulsion moisture loss.

4.3 For hot applied binders, place the plate in the oven on the heat sink for 10 min before pouring the binder.

4.4 Place the insulating plywood on the balance and tare the balance.

4.5 For hot applied binders, remove the plate from the oven and place it on the on the insulating plywood on top of the balance. For emulsified asphalt, place the room temperature plate on the insulating plywood on top of the balance. Weigh the plate to the nearest 1 gram and record as P in Section 5.

4.6 Tare the balance with the plate.

4.7 Immediately, using the binder (hot applied binder from the oven or room temperature emulsified asphalt), stir thoroughly to ensure uniformity, and pour the required binder on the plate using the following application rates. Weigh binder to the nearest 1 gram and record as B in Section 5.

4.7.1 For hot applied binders:

4.7.1.1 Use 52 g of binder on a Vialit plate for grade 3 aggregates or equivalent. For a binder with a specific gravity of 1.020, this equates to 0.28 gal/yd^2.

4.7.1.2 Use 40 g of binder on a Vialit plate for grade 4 aggregates or equivalent. For a binder with a specific gravity of 1.020, this equates to 0.22 gal/yd^2.

4.7.2 For emulsified asphalt:

4.7.2.1 Use 80 g of emulsion on a Vialit plate for grade 3 aggregates or equivalent. For an emulsion with a specific gravity of 1.010, this equates to 0.44 gal/yd^2 of emulsion and 0.28 gal/yd^2 of emulsion residue.

4.7.2.2 Use 62 g of emulsion on a Vialit plate for grade 4 aggregates or equivalent. For an emulsion with a specific gravity of 1.010, this equates to 0.34 gal/yd^2 of emulsion and 0.22 gal/yd^2 of emulsion residue.

Note 3 - Application rates for emulsions are adjusted to achieve equivalent residual binder rates.

4.8 Immediately after pouring, coat the plate by tilting the plate side to side and back and forth.

4.9 For Hot applied binders, place the plate again in the oven on the heat sink for no more than 5 min at the application temperature (163°C (325°F). This is to reheat the binder and to achieve a compatible temperature before spreading the aggregates and to ensure that the binder spreads and uniformly coats the surface of the plate. For emulsions, do not reheat in the oven and go directly to 4.10.

4.10 Place the plate with binder in the template and apply aggregate evenly on the plate to achieve a uniform coverage that fills the surface of the asphalt with some additional aggregate on the surface. Stop when this is achieved. Extra aggregate or aggregate that falls off the sample and on the template need not be used.

Note 4 - Aggregate **for a**pplication should be determined with the test aggregate to cover the sample plate with a uniform layer, one aggregate thick with some extra. For Grade 4 aggregates, 500g has been found adequate. This is to ensure that sufficient aggregate is on hand for the test specimen.

4.11 Place the silicone mat over the test specimen and roll the test specimen using the rubber roller. Roll three passes in one direction and three passes in the transverse direction as shown in Figure 3.

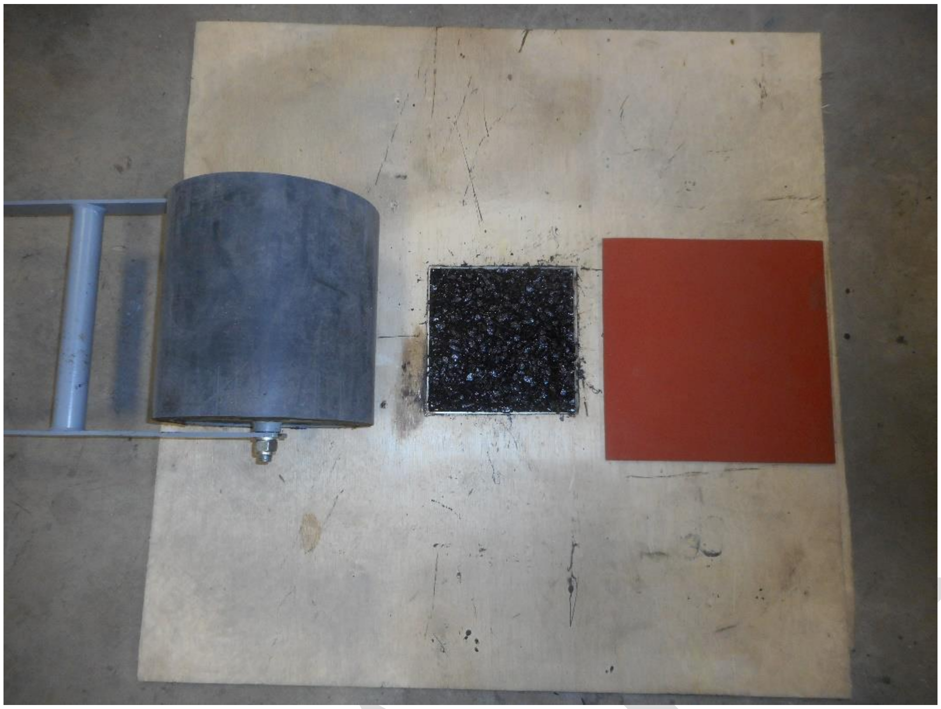


Figure 3. Rolling using the rubber roller (Silicone mat is not shown on the sample for illustration purposes).

4.12 For hot applied binders:

4.12.1 Carefully remove the test specimen from the template and allow it to come to room temperature.

4.12.2 While supported underneath with plywood, tip the test specimen at a 45-degree angle, and use a brush to remove any non-adherent aggregate.

4.12.3 Record the weight of the test specimen as (plate, binder, and adhering aggregate particles) to the nearest 1 gram as A in Section 5.

4.13 For emulsified asphalt:

4.13.1 Carefully remove the test specimen from the template and cure the plate at 60°C (140 °F) for 4 hours at to ensure breaking and curing.

4.13.2 Remove the test specimen from the oven and let it come to room temperature. Ensure the test specimen is at room temperature.

4.13.3 While supported underneath with plywood, tip the test specimen at a 45-degree angle, and use a brush to remove any non-adherent aggregate.

4.13.4 Record the weight of the test specimen (plate, cured emulsion residue, and adhering aggregate particles) to the nearest 1 gram as A in Section 5.

4.14 Conduct Vialit testing to determine aggregate Loss. The assembled apparatus is shown in Figure 4.

Note 5- Preferably testing should be initiated immediately but may be delayed no more than 3 days to accommodate work schedules.

4.14.1 Condition the test specimen to test temperature in a refrigerator at 5°C (41°F) for one hour.

4.14.2 For testing, place the test specimen upside down on the 3-point supports as shown in Figure 4

Figure 4 Vialit plate on the 3-point supports.

4.14.3 Place the steel ball on the holder, as shown in Figure 5, and let the ball drop three times within one minute.

Figure 5. Initial position of the steel ball.

4.14.4 Weigh the tested specimen to the nearest 1 gram and record as R in Section 5. Figure 6 shows a test specimen before and after testing.

Figure 6. Vialit Plate Before and After Testing.

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5. CALCULATIONS

For hot applied binders:

Vialit Loss (%) = $\frac{A-R}{A-C} * 100$

Where:

P = Weight of plate.

B = Weight of binder.

C = P+B = Weight of plate and binder.

A = Weight of plate, asphalt, and aggregate.

R = Weight of plate, retained asphalt and retained aggregate after testing.

For asphalt emulsions:

Vialit loss (%) = $\frac{A-R}{A-C} * 100$

Where:

P = Weight of plate.

B = Weight of emulsion binder.

C = P+(B*0.65) = Weight of plate and emulsion residue.

A = Weight of plate, cured emulsion residue, and aggregate.

R = Weight of plate, retained asphalt and retained aggregate after testing.

6. REPORT

6.1 Report the average of three tests as the Vialit Loss for the material combination tested to the nearest 0.1 percent.

Note 6 – The Vialit Loss is a combination of aggregate and asphalt binder loss from testing based on the weight of the original aggregate.

APPENDIX D. VALUE OF RESEARCH

PROJECT TITLE

Development of a Performance Related Test for Designing Seal Coats.

PROJECT STATEMENT

TxDOT's seal coat program is critical to preserve its existing roadway infrastructure and ensuring roadways retain adequate skid resistance. However, sometimes seal coats fail prematurely either due to incompatibility between aggregate and binder or to binder that has poor durability or adhesive characteristics while meeting specification requirements. The goal of this study is to identify or develop and validate a test method(s) to evaluate seal coat materials as system to avoid poor material combinations. Table D.7 presents a summary of the functional areas and benefits from Project 7057.

Table D.7. Functional Areas for Project 0-7058

Benefit Area	Qual	Econ.	Both	Tx-DOT	State	Both
Level of knowledge				X		
Customer satisfaction	X			X		
					X	
Reduced Construction, Operations, and Maintenance Cost					X	
					X	

QUALITATIVE BENEFITS

Level of knowledge

This project conducted an extensive survey of TxDOT districts on their practices pertaining to seal coats. The results from this survey provide a comprehensive summary regarding the material specifications (e.g. binder grade, emulsion grade, precoating binder grade, precoating rate), practices (e.g. method used for design, percentage of seal coat carried out internally versus contracted outside), and experiences (e.g. failure types, failure rates) from different districts. This information is a valuable resource for TxDOT for understanding the breadth and depth of its seal coat program and to make any critical decisions in the future. In addition to a district survey, this study also reviewed specifications and practices from other states across the US and provided a comprehensive but relatively less granular summary.

Customer Satisfaction and Infrastructure Condition

Surface treated roads such as surfaces with seal coats comprise over 40% of the on system roadways. Poor adhesion between the aggregate and the seal coat binder causes aggregate particles to debond, which in turn not only reduces the quality of the pavement surface but it also causes windshield damage for any vehicle that may be following a vehicle that causes the aggregate particles to break loose. Improving seal coat performance directly impacts the adhesive loss and accidents caused through such loss.

ECONOMIC BENEFITS

Increased service life and Reduced costs

This project started on January 1, 2020 and completed on August 31, 2022 with a duration of 2.67 years. The total budgeted cost for this project was $391,695. For the purposes of this analysis and considering full implementation of the recommendations, the following were considered:

- The TxDOT seal coat program costs approximately $280 million (based on estimate from 2022).
- Field examination of different sections show that more than 10% of pavement sections had lost significant texture within one to two years of placement instead of the expected five to seven years of service life.
- Further, as an extremely conservative estimate, premature failures due to poor precoating are estimated as 0.1% of the total seal coat placed in any given year. Considering the size of the seal coat program, this amounts to $280,000. This

amount was used as the expected value per year.

The aforementioned parameters were used to obtain the NPV for this project as shown in Figures D.1 and D.2.

Texas Department of Transportation	Project #	0-7057		
	Project Name:	Develop guidelines to precoat aggregates for seal coats		
	Agency:	CTR	Project Budget	$ 391,695
	Project Duration (Yrs)	2.7	Exp. Value (per Yr)	$ 280,000
	Expected Value Duration (Yrs)	10	Discount Rate	0%
Economic Value				
Total Savings:	$ 2,128,305		Net Present Value (NPV):	$ 2,520,000
Payback Period (Yrs):	1.398911		Cost Benefit Ratio (CBR, $1 : $___):	$ 6

Figure D.1. Parameters used for economic analysis for VOR.

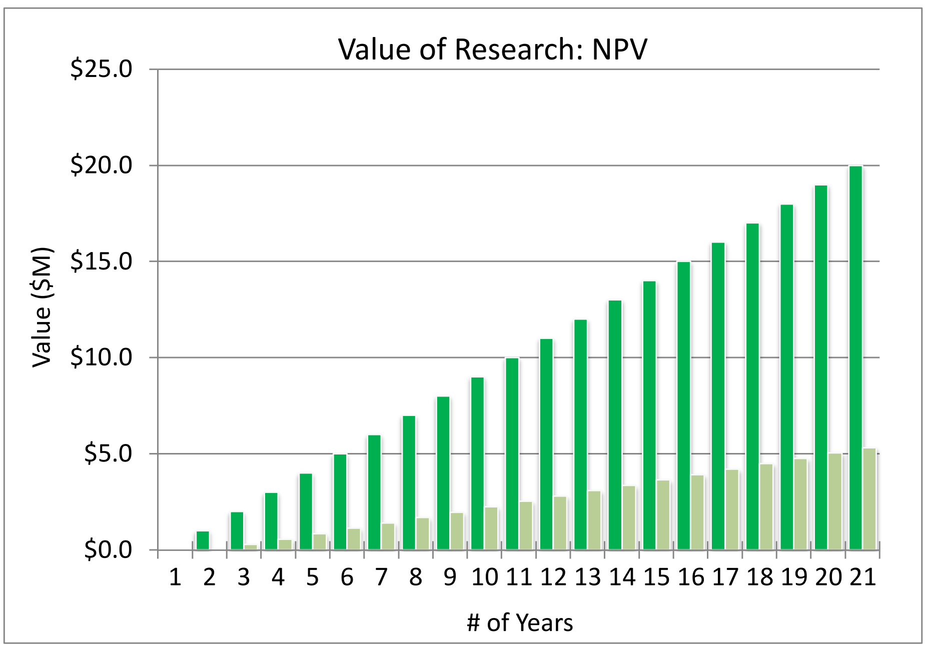

Figure D.2. Illustration of the NPV over a period of 20 years.