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Design and Construction of Ultra Thin Overlays as an Alternative to Seal Coats

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16. Abstract
Friction loss is one of the most critical issues faced by agencies responsible for preserving a pavement structure. There are various methods used for surface treatments including seal coats, slurry seals, and ultra thin asphalt concrete overlays. Ultra thin overlays have increased in popularity due to their lack of noise and improved ride quality, as well as their reduced overall cost owing to the reduced layer thickness. This study had three major objectives: (i) determine the best mix type for use as an ultra thin overlay, (ii) evaluate the volumetric-based criterion that is currently used to determine the optimum binder content for mixes used in ultra thin overlays using performance tests relevant for surface mixes, and (iii) identify the properties of the tack coat that are required to construct such mixes in the field. The performance evaluation was conducted using laboratory techniques including the Hamburg Wheel Tracking Device and the Three Wheel Polishing Device. Out of the six potential gradations or aggregate structures that could be used as an ultra thin overlay, three were found to be suitable based on the performance tests. It was also observed that the optimum binder content, as defined by the volumetric criterion, was also generally the optimum based on performance tests conducted in the laboratory.

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Ultra thin overlays, seal coat, binder content

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Products

This report contains two products as appendices. Appendix C is P1 (*Guidelines for Micromilling and Tack Coat Application*). Appendix B is P2 (*Development of a Direct Shear Test Setup for Tack Coat*).

EXECUTIVE SUMMARY

Pavement preservation is critical to maintain and operate a cost effective and safe pavement infrastructure. Wear from traffic results in loss of skid resistance accompanied or followed by cracking, penetration of water and oxygen into the pavement structure, and concomitant deterioration of the pavement. Loss of skid resistance is especially significant from a safety point of view, because a pavement with low skid resistance can increase the braking time for vehicles. Timely maintenance can also increase the serviceable life of the pavement.

Seal coats, also sometimes called chip seals, are one of the most common types of treatment used to restore skid resistance of an asphalt concrete pavement as well as to protect the existing pavement structure from moisture, and to some extent oxygen. Seal coating is a cost effective preventive maintenance strategy compared to reactive maintenance, which can be significantly more expensive per lane-mile of a roadway. Despite its advantages, there are some limitations and drawbacks associated with seal coats. The application process for a seal coat is very sensitive and leaves little margin for error. Slight variations from the optimal design and application conditions such as application temperature, weather, binder application rate, or aggregate application rate can render the seal coat susceptible to failure. Failure of a seal coat can occur in the form of aggregate loss (also associated with windshield damage), premature loss of surface texture, and/or bleeding of the asphalt binder to the surface. Bleeding or flushing of the asphalt binder can cause a reduction in skid resistance and compromise safety of the pavement surface. Also, even when seal coats are properly designed and applied, traditional seal coat surfaces often create very noisy roads that are unpleasant to drive on.

An alternative to seal coats is to use a thin asphalt concrete overlay. However, in order to make thin overlays cost effective and competitive compared to chip seals, an ultra thin overlay with a thickness of 0.5 inches was developed in this study. The main goals of this study were to: (i) explore the different possible aggregate structures that could be used to design a mix for application as an ultra thin overlay, (ii) identify and validate a volumetric mix design criterion to design such mixes using laboratory based performance indicators, (iii) identify requirements for the tack coat to be used with such mixes and ultra thin overlays, and (iv) demonstrate the life-cycle cost for such overlays compared to chip seals.

In order to achieve the aforementioned goals, a nationwide survey of aggregate structures that could potentially be used as an ultra thin overlay was conducted. Six different aggregate structures were identified and used in the remainder of this study. These mixes

were used with a volumetric mix design criterion to determine the optimum binder content. Mixture specimens were prepared and performance tests at the optimum, as well as above and below this optimum content for each mix were conducted. These performance tests included Hamburg Wheel Tracking Device or HWTD, Modified Specimen HWTD, Overlay Tester, and Three Wheel Polishing Device - Direct Friction Tester or TWPD-DFT combination. Performance metrics included resistance to rutting, cracking, bleeding, and raveling while also maintaining a desirable level of skid resistance. In addition, four different field mixes were also used to benchmark the results from the performance tests. Skid resistance results from the mixes were compared to skid resistance of chip seals using data and correlations available from the existing literature for the latter.

Of the six possible aggregate structures evaluated in this study, the mixes with majority coarse aggregates behaved better than those with finer aggregates in the TWPD and HWTD tests. Three of the six candidate aggregate structures were ultimately deemed viable for use as an ultra thin overlay. Measurements of skid resistance show that mixes designed for ultra thin overlays had comparable, and in most cases better, performance when compared to equivalent DFT friction values obtained on seal coats from other studies. Although it may not be economically feasible in all cases, ultra thin can provide an alternative to seal coating with improved ride quality and noise characteristics. Finally, this study also demonstrated that the Three Wheel Polishing Device (TWPD) combined with Direct Friction Tester (DFT) is sensitive to differences in performance of the selected mixes in terms of raveling, bleeding, rutting and skid resistance and can be used on a routine basis to validate the performance of mixes designed for use in ultra thin overlays.

The findings from this study are documented in this final report. Findings suggest that although ultra thin overlays are expensive than seal coats, the reduction in traffic delay, reduced noise pollution, and longer service life are major advantages of ultra thin overlays. Recommendations from this study are condensed into a proposed specification and two standard test methods that accompany this research report (Appendices E, F and G). The first test method is for the use of the TWPD as a performance screening tool for design of mixes used in ultra thin overlays. The second test method is to evaluate the properties and acceptability of the tack coat used in an ultra thin overlay to bond with the existing pavement surface. Some of the aspects related to the proposed specification, such as the use of a PG70 binder, must be validated through additional field implementation studies.

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CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

1.1 PROJECT BACKGROUND

Each year, the Texas Department of Transportation (TxDOT) spends a significant portion of their budget on road maintenance. Wear from traffic along with the penetration of water and oxygen into the pavement structure results in distresses such as potholes, cracking, and loss of skid resistance. The Texas Department of Transportation (TxDOT) has successfully used seal coats as a cost-effective strategy to improve the long-term performance of the pavement structure, provide a safe riding surface, and forestall expensive maintenance projects.

There are several advantages to using seal coats as a tool for pavement preservation. For example, seal coats are a cost effective preventive maintenance strategy compared to reactive maintenance, which can be drastically more expensive per lane-mile of a roadway. Seal coats preserve the pavement structure by blocking access to moisture and to some extent oxygen. Seal coats also provide a safe riding surface by improving or preserving the braking time and driving control. Despite these advantages, there are some limitations and drawbacks associated with the use of seal-coats. The application process for a seal-coat is very sensitive and leaves little margin for error. Slight variations from optimal in terms of application temperature, weather, binder application rate, or aggregate application rate can render the seal coat susceptible to failure. Failure of chip seal can occur in the form of aggregate loss (also associated with windshield damage), premature loss of surface texture or bleeding of the asphalt binder to the surface. Bleeding or flushing of the asphalt binder can cause a reduction in skid resistance and compromise safety of the pavement surface. Also, even when seal coats are properly designed, and applied, traditional seal coat surfaces often create very noisy roads that are unpleasant to drive on.

In response to the aforementioned limitations and issues associated with seal coats, TxDOT has begun investigating and developing various ultra thin asphalt mixtures to be used as alternatives to traditional seal coat overlays. While traditional mixes are between 2 to 4 inches thick, these new thin-lifts are under 1 inch thick. The new items 347 and 348 in TxDOT specification extends the design of typical thin overlay mixtures (TOM) to allow the use of an ultra thin mixture as an overlay to maximize economic benefits without compromising the ability of the overlay to preserve the pavement structure and surface. These ultra thin mixtures (UTMs) are typically placed and compacted in a single lift that is around 0.5 inch thick or less. The current design and testing of thin overlays is mostly conducted using available equipment and procedures such as the Hamburg Wheel Tracking Device (HWTD), the Overlay Tester (OT), and the Indirect Tensile Strength (IDTS) test. However, these performance tests were originally developed and intended for conventional asphalt mixtures with traditional layers over 2 inches thick.

At about 0.5 inch thickness, the proposed UTM overlays are significantly thinner than traditional overlays. The state of stress in a traditional overlay subjected to highway traffic is significantly different from the state of stress in an ultra thin overlay that experiences the same traffic conditions. In general, stress reduces with pavement depth; however in the case of ultra-thin layers, contact stresses may not dissipate to the same degree. For optimal performance it is important to ensure that the strength of the asphalt mix placed in ultra-thin layers is adequate to accommodate these stresses. The existing performance test methods and metrics do not accurately reflect the stress states in very thin layers. As a result the use of these test methods may result in UTMs that are either under designed and risk expensive and premature failures or are over designed and are therefore not cost effective. One of the main goals of this study was to develop a mix design method that will result in cost effective and optimal mix designs for UTMs that can be used in lieu of seal coats.

1.2 REPORT STRUCTURE

This project was a joint effort between the Center for Transportation Research (CTR) at The University of Texas at Austin (UTA) and the University of Texas at El Paso (UTEP). In order to achieve the objectives of this study, the project was divided into seven major tasks:

- Task 1: Conduct an expanded literature review and develop a synthesis of information on the desired performance characteristics of surface mixes (seal coats and ultra thin mixes), tack application practice, and best methods to evaluate performance of UTMs (Chapter 2 and Appendix A).

- Task 2: Develop specifications and guidelines for placement of UTMs (Appendices B and C).

- Task 3: Design a suite of different asphalt mixes intended for use as an ultra-thin surface layer by varying factors such as aggregate gradation, binder grade and binder content (Chapter 3).

- Task 4: Identify and sample field mixes or cores from new or existing pavements surfaced using thin or ultra-thin mixes to serve as field performance benchmarks

(Chapter 4).

- Task 5: Evaluate the performance of laboratory designed mixes from Task 3 as well as the performance of field mixes from Task 4 (Chapter 5).
- Task 6: Evaluate cost effectiveness of ultra-thin mixes (Appendix D).
- Task 7: Develop preliminary guidelines and specifications for mix design and performance testing of UTMs (Appendices E, F, G).

The structure of this report follows the above tasks and objectives.

CHAPTER 2. BACKGROUND AND REVIEW

One of the main goals of this study was to develop a mix design method that will result in cost effective and optimal mix designs for ultra thin mixes (UTMs) that can be used in lieu of seal coats. To this end, one of the first tasks of this project was to conduct a comprehensive review of the literature from two different points of view: (1) performance requirements and distresses in seal coats that can be used as a basis to compare the performance of the proposed ultra thin mixes, and (2) current approaches to design ultra thin or similar mixes. The performance of an ultra thin mix is strongly dependent on the condition of the existing asphalt layer and the use of proper tack coats to bond the two layers. Therefore, an important part of this task was also to review literature on the practice and properties of tack coats and their relationship to overlay performance.

2.1 SEAL COATS

Seal coats, also known as chip seals, are simple, relatively inexpensive pavement surfaces that are highly effective if adequate care is taken in the planning and execution of the work. A seal coat consists of a layer of asphalt binder that is overlaid by a layer of aggregate. This coat provides protection to the asphalt layer from tire damage and creates a macro-texture that generates a skid-resistant surface on which the vehicles may pass safely. The main purpose of a seal coat is to seal the fine cracks in a pavement's surface and prevent water intrusion into the base and subgrade (Gransberg and James, 2005).

Seal coats have been widely used in the United States, Australia, New Zealand, South Africa, and the United Kingdom (Gransberg and James, 2005). The Texas Department of Transportation (TxDOT) alone uses approximately 300,000 tons of binder annually for seal coat applications in nearly all of its districts. The performance of seal coats is mainly affected by the (1) material selection, materials' mechanical properties and their chemical compatibility; (2) pavement surface condition and preparation; (3) the rate of application of asphalt binder and aggregates; (4) the level of aggregate embedment; and (5) environment and traffic conditions. The current seal coat design (e.g., binder type, application rate) in Texas is semi-qualitative, based on experience and in most cases it is provided by a TxDOT engineer. Seal coats that are not optimally designed and placed for a given combination of materials may fail prematurely.

2.1.1 Design methods for seal coats

In order to improve upon current seal coats and present a viable ultra-thin overlay alternative, it is imperative to have a clear picture of the current state of seal coat design. Seal coats and similar surface treatments have been implemented since 1920s (Hinkle, 1928). Since its original inception, there have been several design methods that have been developed for seal coat application. Most of these methods are based on local empirical experience rather than on sound engineering principles. A survey conducted by the National Cooperative Highway Research Program (Gransberg and James, 2005) revealed that there are two methods which are mainly used in North America: the Kearby method and McLeod method. Table 2.1 summarizes the percentage use of different methods in North America.

Table 2.1. Seal coat design methods in North America (Gransberg and James, 2005)

Seal Coat Design Method	United States (%)	Canada (%)
Kerby / Modified Kerby	7	0
McLeod / Asphalt Institute	11	45
Empirical / past experience	37	33
Own formal method	19	0
No formal method	26	22

The two more formal design methods are briefly discussed here. Kearby (1953) developed a design method for the binder application rate based on filling a specific percentage of the void between aggregates. This method recognizes that the recommended rate does not guaranty satisfactory results and that there is a need for visual inspection of the field and use of judgment in choosing the rate of materials application. Kearby's design method (1953) is summarized in the form of a nomograph that provides binder application rates based on three variables: average thickness, percent aggregate embedment, and percent voids. McLeod (1969) developed a design procedure partially based on a method developed by Hanson (1934). McLeod's design determines the aggregate application rate based on specific gravity, gradation, shape, and a wastage factor (McLeod, 1969). The binder application rate is based on the type of asphalt binder, the aggregate gradation, condition of the existing pavement, and traffic volume. This method also includes correction factors for the amount of binder lost through absorption of aggregates and the texture of existing pavement surface. The Asphalt Emulsion Manufacturers Association and the Asphalt Institute (AI) have adapted this method and made recommendations for choosing binder types and grades based on aggregate gradations.

Epps and coworkers (Epps et al., 1980) conducted field validation of Kearby's method and realized that it predicts lower asphalt rates than what was used in practice in Texas. Therefore, Epps proposed the use of a correction for the binder application rate that was based on the level of traffic and existing pavement condition. They also suggested a shift in the original design curve (proposed by Kearby) due to the use of lightweight aggregates. This method is known as Modified Kearby Method.

The modified Kearby method also recommends a board laboratory test to find the quantity of aggregate needed to cover 1 yd2 of roadway. It should be noted that Epps and coworkers modified Kearby method based on what seemed to be working well in practice (Epps et al. 1980). Later, Brownwood District of TxDOT has expanded this study by including the adjustments for truck traffic and existing surface condition. The NCHRP survey reported that the binder application rate, calculated using both Modified Kearby method and McLeod method, needs to be adjusted by experienced field personnel. This adjustment is mainly due to changing surface conditions found in the actual project. This survey also demonstrated that the current methods to design seal coats in The United States are mainly considered to be art rather than science.

The methods discussed above are highly empirical and are not based on the performance of the seal coat. Consequently, not all seal coats are optimally designed for a given combination of materials resulting in either over designed systems or premature failure. This is primarily the reason that has led to the development of three performance-based design methods that are more common outside of the United States:

- Road Note 39, developed in the United Kingdom,
- 2004 Austroads Sprayed Seal Design Method, developed in Australia,
- South African Method (TRH3), developed in South Africa (Beatty, 2002).

The performance-based approach for the above methods makes them distinctly different from the methods used in the United States. For instance, Road Note 39 is an advanced design that extensively uses a computer design program based on decision trees. This design uses a multitude of input parameters: traffic level, road hardness, surface conditions, site geometry, skid-resistance requirements, and likely weather conditions and it can be used to design different types of seal coats: single dressing, pad coat plus single dressing, racked-in dressing, double dressing, and sandwich dressing. Similarly, the Austroads' 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. The South African design method, TRH3, is a hybrid of the Austroads' method and the Road Note 39 method.

2.1.2 Performance for seal coats

The main goal of this study was to develop an alternative of seal coats. To this end, it was important to review and discuss the performance requirements for seal coats that would also serve as the basis or benchmark for the design and use of ultra thin mixes. 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. The existing literature suggests measuring the skid resistance and texture depth as the only two repeatable and objective quantitative metrics.

2.1.2.1 Skid Resistance

Skid resistance is an indicator of safety for a road surface. It can be used to measure the performance of seal coated and ultra-thin overlaid surfaces (Roque et al., 1991). Skid resistance or friction is a function of pavement macrotexture and microtexture. The microtexture is dictated by the aggregate surface texture, while the macrotexture is dictated by the size, shape, and spacing of the aggregate particles. The most common method to measure 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, which is also referred to as the locked-wheel skid test (LWST), measures the sliding friction force between a locked-wheel and pavement surface in terms of skid number (SN). Agencies typically use this tool to decide whether a road needs a seal coat or not. 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 British pendulum test can be used as a laboratory surrogate to measure the skid resistance of an asphalt mixture and related it to the SN in the field.

2.1.2.2 Texture Depth

Texture Depth, which is a function of pavement macrotexture, is another indicator of the performance of a seal coat, which could also be extended to ultra thin surface layers. In general, there are several methods to measure the macrotexture of a pavement surface. The survey conducted by NCHRP (Gransberg and James, 2005) indicated that the sand patch method (ASTM E965) is widely accepted. Roque et al. (1991) measured the mean texture depth (MTD) of seal coated surfaces by conducting the sand patch method, and found that the mean texture depth serves as the best indicator of the seal coat performance compared to other methods. Roque et al. (1991) also found that the macrotexture as quantified by the mean texture depth decreased 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 the mean texture depth.

In addition to the sand patch method, image analysis can also be used to assess the mean texture depth of the surface (seal coat or other surface treatment). For example, Gransberg et al. () 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 calculated from AIMS measurements on small specimens and the mean profile depth measured on the pavement or on the large fabricated slabs using circular track meter. Figure 2.1 shows how the change in the macrotexture can be quantified using image analysis.

Figure 2.1. Mean texture depth using image analyses for a surface with a satisfactory texture (left) and a surface with heavy flushing (right) (Gransberg et al.)

The Dynamic Friction Tester (DFT) can be used to conduct measurements of the friction of a pavement surface as a function of speed. The DFT is a machine consisting of a rubber disk attached to three spring loaded rubber sliders, which make contact with the pavement surface. As the disk spins, water is applied to the surface, and measurements of the torque generated by the sliders are taken, which indicate the friction resistance of the surface as a function of speed. This equipment can be applied both in the lab and field. The test is often used to determine the effectiveness of various surface-polishing techniques (ASTM E1911). In using this equipment, the Florida Department of Transportation (FDOT) determined that data from the DFT had a good correlation with traditional locked-wheel friction tests. However, the data did not correlate as well with mean profile depth, which is an indicator of pavement texture (FDOT).

The Circular Track Meter (CTM) is a device that can be used in conjunction with the DFT to measure the same circular track on a pavement surface. The CTM uses a charged coupled device laser displacement sensor that rotates on an arm in a circular motion, along a track of diameter 28.4 cm. Like the DFT, the CTM can be used both in lab settings and in the field on actual pavement surfaces. The software associated with the CTM reports two values, the Mean Profile Depth (MPD) and the Root Mean Square (RMS) values of the profiles of the macrotexture of the pavement (ASTM E 2157). FDOT also found a strong correlation between MPD values found using the CTM and the 64 kHz high-speed laser texture device that FDOT currently uses for profiling highways (FDOT).

2.2 ALTERNATIVES TO SEAL COATS OTHER THAN THIN OVERLAYS

In order to overcome the various shortcomings and issues associated with the design and application of seal coats, engineers and researchers have attempted to find economically viable alternatives that can be used to achieve the same purpose. A review of the literature shows that a proprietary method, (NovaChip®), microsurfacing and cape seals are three common technologies (other than thin or ultra thin hot mix overlays) that are commonly used as alternatives to chip seals. This section briefly reviews these technologies. The following section will review the use of thin and ultra thin hot mix layers as an alternative to chip seal.

NovaChip is one of the technologies that can be used in place of seal coats. NovaChip was first developed in France in 1986 and introduced to American engineers through the European asphalt study tour around 1990. It is a thin hot mix asphalt application, usually 0.5 to 0.75 inch, placed over polymer modified asphalt membrane. One of the key features of this technology is a proprietary single vehicle that carries and places both the asphalt emulsion or tack coat followed by a thin layer of the hot mix in a single pass. The very high quality of tack coat and ability to place both the tack coat and the hot mix in a single pass is critical for the successful construction of an ultra thin layer. This is because a very thin

Table 2.2. Typical gradation of NovaChip

Aggregate Size	Percent Passing
1/2 inch	85-100
3/8 inch	60-80
No. 4	25-38
No. 8	22-32
No. 16	15-23
No. 30	10-18
No. 50	8-13
No. 100	6-10
No. 200	4-7

tack coat placed by one one vehicle followed by a paver with hot mix asphalt would result in damaging the tack coat layer and making is dysfunctional. However, the introduction of trackless tack coats can make it possible to use traditional paving approaches to be applied in ultra thin layers.

NovaChip has several advantages that makes it a competitive alternative to traditional seal coats. As discussed before, it can be fully placed in a single pass (Hansen, 2013) and it can be opened to traffic faster than traditional emulsion based seal coats. In terms of aggregate structure, this is somewhat similar to an open graded friction course. Table 2.2 presents a typical gradation used by WSDOT for such mixes. The aggregate structure lends the surface other advantages, such as the ability of the overlay to dispose of water quickly off the surface, thus reducing roadway spray from vehicles and providing greater visibility in wet weather (Uzarowski, 2005). NovaChip is also reported to be quieter (almost 3 decibels lower) than a conventional HMA surface (Uzarowski, 2005). However, in some cases there have also been issues reported with the use of this technology. For example, Missouri Department of Transportation reported that this surface treatment developed shelling problems in some areas of an initial test section placed in October 1998.

Microsurfacing is a cost-effective polymer modified cold-mix paving system that can remedy a broad range of problems on today's streets, highways, and airfields. It is basically a thin, tough layer of asphalt emulsion blended with finely crushed stone for traction (Gransberg and James, 2005). Table 2.3 provides the typical gradation for two different types of microsurfacing mixes as described in the International Slurry Surface Association's manual. The mix is designed so that it is able to accept traffic after a short period of time (International Slurry Surfacing Association, 2010). Introduced in the U.S. in 1980, Microsurfacing is now routinely used in more than 30 states. Microsurfacing provides a high quality skid resistant surface for an existing asphalt concrete pavement, seals the pavement surface, restores surface profile, eliminates hydroplaning, and provides a surface that is more resistant to rutting and shoving (Uzarowski, 2005).

Table 2.3. Typical gradation for microsurfacing

Aggregate Size	Type 2 Percent Passing	Type 3 Percent Passing
3/8 inch	100	100
No. 4	90 - 100	70 - 90
No. 8	65 - 90	45 - 70
No. 16	45 - 70	28 - 50
No. 30	30 - 50	19 - 34
No. 50	18 - 30	12 - 25
No. 100	10 - 21	7 - 18
No. 200	5 - 15	5 - 15

In terms of workability, the microsurfacing mixes are designed so that they remain in a workable state during mixing and transportation and at the same time break and cure quickly after being put in place. In terms of material selection, high durability aggregates (similar to SAC A used by TxDOT) and emulsified binder are recommended for use (International Slurry Surfacing Association, 2010). Finally, in terms of mix design and performance, the microsurfacing mixes are designed to optimize between raveling and bleeding or flushing. Two different laboratory scaled devices are used to establish the relationship between binder content and raveling and the relationship between binder content and bleeding. The range of binder contents that is not too low to cause raveling or too high to cause bleeding is then used as the optimum for application (Cite ISSA manual AB). A loaded wheel tester is used to assess performance of the mix. Some of these methods developed by ISSA to design and evaluate microsurfacing can also be modified for use in this study to evaluate the performance of ultra thin mixes.

The third alternative to a conventional chip seal to overcome some of its limitations is a cape seal. This pavement treatment method was originally developed in South Africa in the late 1950's by the Cape of Good Hope Provincial Administration. A Cape Seal is a multiple surface treatment that consists of the application of an asphalt emulsion chip seal followed by the application of asphalt emulsion slurry seal. In this sense, cape seal combines the advantages of the two different sealing methods (Michigan Department of Transportation, 2005). Solaimanian reported that bleeding and shoving have been the most common problems identified with cape seal (Solaimanian and Kennedy, 1998). However, if constructed properly, a cape seal provides a smooth, dense surface, with good skid resistance and a relatively long service life. Table 2.4 presents a typical gradation for cape seal according to Maryland DOT specifications.

Table 2.4. Typical gradation for a cape seal

Cape Seal			
Chip Seal		Slurry Seal Cover	
Aggregate Size	Percent Passing	Aggregate Size	Percent Passing
3/4 inch	100	3/8 inch	100
1/2 inch	90 - 100	No. 4	90 - 100
3/8 inch	40 - 70	No. 8	65 - 90
No. 4	0 - 15	No. 16	45 - 75
No. 8	0 - 5	No. 30	30 - 50
		No. 50	18 - 30
		No. 100	10 - 21
		No. 200	5 - 15

2.3 THIN AND ULTRA THIN OVERLAYS AS ALTERNATIVES TO SEAL COATS

Thin and ultra thin overlays are asphalt mixtures that are placed over existing pavement structures to as a preventive maintenance treatment used to extend the pavement's service life, protect the pavement structure and restore its skid resistance. In the context of this study, the term ultra thin mix (UTM) or overlay is used to describe overlays that are 0.5 inch thick or thinner. Overlays thicker than 0.5 inch and thinner than 2 inches are referred to as thin overlay mixes (TOM). This section presents a synthesis from a review of existing literature on the current state of practice and research efforts on the use of think asphalt overlays for pavement maintenance, rehabilitation, and preservation. Note that the literature review covered thin as well as ultra thin overlays, since the latter are not yet in use as a mainstream application.

2.3.1 Selection criteria for thin overlay application

The decision to apply a thin overlay to an existing pavement surface is typically made only after a careful evaluation of the pavement condition and after elminating the need to perform a structural rehabilitation. The degree to which thin asphalt overlays are successful depends in large part on the project selection and amount of distress in the existing pavement. Pavements that are at the end of their intended design life or have significant distresses cannot be successfully treated with a thin overlay alone; such pavements must be structurally repaired so that a stable foundation is provided before a thin overlay can be placed if needed.

The NCHRP conducted a survey in 2014 (Watson and Heitzman, 2014). The state transportation agencies were interviewed about their use of thin overlays. The survey found that most agencies used a condition survey of the existing pavement to determine whether or not a thin overlay mix is appropriate. Agencies also reported that such condition surveys were performed every year on the roads with higher traffic or every other year for some roads. Agencies also reported that the condition rating of a pavement must fall within a specific range in order to be considered for the application of a thin overlay. A very low condition rating would imply that the pavement is in need of a structural repair and a thin overlay would not be an appropriate strategy. A very high condition rating would indicate that the benefits of applying a thin overlay may not be adequate to outweigh the cost of application. Some highlights from this survey are summarized below.

According to the survey, Pennsylvania recommends the use of thin overlays under the following conditions: "Low to moderate raveling, low to medium longitudinal cracking not in wheel path, temporary short term fix for longitudinal cracking in wheel path (fatigue), low severity transverse cracks (milling is recommended), low severity rutting ≤ 0.50 inches, increase in skid resistance needed, existing pavement in fair to good condition. Not for alligator cracking, not for severe raveling where pavement deterioration exists, and not for rutting > 0.50 inches without correcting rutting first" (Watson and Heitzman, 2014). The survey indicated that 11 agencies (19% of respondents) do not carry out specific investigations in order to determine whether or not a thin overlay should be applied (Figure 2.2). This is because these agencies already had a policy for dictating which method of treatment is to be used under a given set of conditions. However, other agencies reported that they used multiple methods (Figure 2.2) to determine if a thin overlay should be applied. For example, Ohio uses a decision matrix that includes criteria such as the traffic expected on the road, the pavement condition rating of the road, and structural defects to determine whether or not a thin overlay would be appropriate. There are two separate decision trees available, one for primary roads of four or more lanes, and one of general roads of two lanes. If the pavement condition rating falls within a certain range for each type of road, then the application of a thin overlay would be considered cost-effective.

The survey also asked the states to identify conditions under which a thin overlay would not be recommended. Figure 2.3 summarizes the results from this part of the survey. Figure 2.3 clearly illustrates that a pavement that has severe rutting or cracking is generally not considered as an ideal candidate for thin overlay mixes. In fact, these considerations are very similar to those made during the selection of chip seal as a surface treatment.

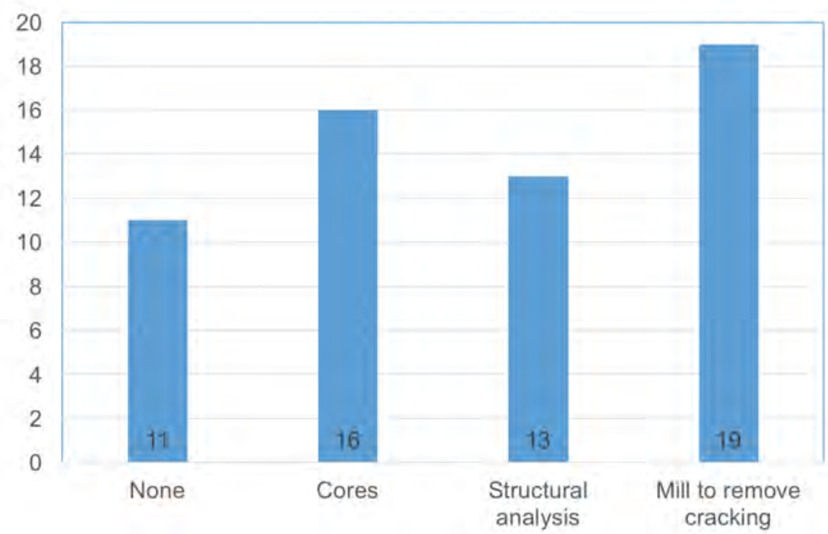

Figure 2.2. Information sources to decide whether a thin overlay is appropriate; number of respondents shown in the bar (Watson and Heitzman, 2014)

Finally, it is also important to summarize the recommendations being used by the TxDOT Austin district, which are consistent with the results from the NCHRP survey. The following are some of the scenarios in which an ultra thin mix can serve as a good alternative to a 1.5 to 2 inch thin overlay mix:

- Urban areas where it is necessary to maintain the grade at entrances to driveways or curb lines.
- Situations where a bridge clearance or guardrail height clearance must not be changed.
- Roads which need a high level of friction, such as high traffic roads, high speed roads, roads with large grades, and any other roads that have features that could cause more crashes.
- Roadways that require a high shear force resistance due to turning or frequent stopping and starting. In areas such as intersections, PFCs often ravel or cannot be placed, so thin overlays are used as an alternative.

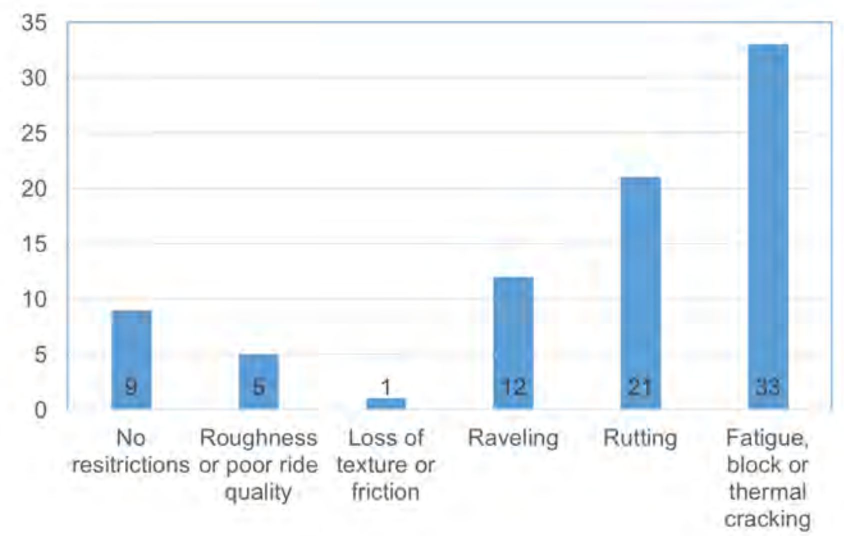

Figure 2.3. Conditions under which thin overlays are not recommended; number of respondents shown in the bar (Watson and Heitzman, 2014)

- Roads that have performed well after surface treatment, but where another seal coat cannot be applied due to noise level concerns, friction, or ride quality concerns.
- Low-traffic roads that require an overlay, but with shoulders that do not need an overlay.
- Roads where a crack-resistant overlay is necessary because of cracking. Thin overlays with an underseal are effective in this situation.
- New pavements that need a final surface that will limit maintenance costs.

2.3.2 Surface preparation and bonding

Previous studies have suggested that similar to conventional overlays, spot base repair (mill and fill), level-up, and crack sealing in isolated areas must be carried out prior to the placement of a thin surface mix (Wilson et al., 2013). It is also recommended that milling should be considered if roughness or cracking are present.

Milling can be very effective for thin overlay projects and particulary more so with ultra thin mixes. Milling is useful for maintaining the current grade so that important quantities such as the clearances of bridges or the curb and gutter are not changed. Milling also creates a rough surface texture that strengthens the bond between the overlay and the existing pavement. Grade and slope controls are used with milling equipment to maintain the original geometric shape and to improve the ride quality. In some states, there are smoothness requirements that the milled surface must meet. These requirements are useful to eliminate isolated high or low spots and measurements are usually taken with a straightedge. According to the NCHRP survey only one state, Georgia, used inertial profiler measurements on milled surfaces (Watson and Heitzman, 2014).

Nine of the agencies that NCHRP surveyed responded that surface preparation was one of the biggest factors when it came to variations in service life of the overlays. It is crucial to clean the existing surface in order to remove dirt and silt and to apply a uniform tack coat in order to create a good bond between the new surface mix and the existing surface (Hansen, 2013). This is particularly important for thin and ultra thin mixes since the interface is very close to the vehicle tire and experiences high shear stresses (Hansen, 2013). Inadequate tack coat and surface preparation can result in debonding and slippage of the new overlay, particularly in areas where braking will occur. If the tack coat is not adequate, slippage may be a problem for the new overlay, especially in areas where braking will occur. Tack application rates are highly variable according to the NCHRP survey and depend on the type of mix used in the overlay and type of tack coat (e.g. asphalt emulsion, asphalt binder, or a "trackless" tack). The application rate also depends on the existing surface, and whether or not milling was performed. For emulsion tack coats, the application rate is also dependent on the asphalt binder content in the emulsion. Georgia has required asphalt binder for the last 30 years, and has found that slippage can be a problem during summer when emulsion tack coats are used. Appendix A of this report provides a tabulated summary of the literature on issues related to surface preparation and bonding.

2.3.3 Mix design for thin and ultrathin asphalt overlays

One of the original designs that was used as a thin mix for ovelay in Texas was the Crack Attenuated Mix (CAM), although, as the name suggests, CAM was not originally intended to serve as a surface mix by itself. CAM is a dense-grade mix and a full description can be found in the TxDOT specification (SS) 3615. These mixes use high quality aggregate and high amount and quality binder. CAM is recommended for use on pavements with minor to moderate cracking and is considered to improve raveling and reduce noise. However, due to the amount of fine material used, surface skid problems during wet weather conditions have been reported (Wilson et al., 2013). These mixes led to the development of the current thin overlay mixes (TOM) and ultra thin bonded wearing course (UTBWC) that are included in

Items 347 and 348 of the TxDOT specifications.

In recent years, Item 347 has been the most widely used guideline for these designs. Item 347 provides specifications for constructing a thin surface course known as the TOM mix, and it is designed and constructed under SS 3239. The Austin District has taken the lead in developing their version of a thin overlay mix. Austin's TOM mix is similar to the Fine SMA mix but does not include the use of fiber. Due to the high asphalt content and quality materials used in the thin mixes, the cost per ton is higher than that of conventional dense-graded mixtures (Wilson et al., 2013). Item 348 specifies film thickness in addition to the laboratory molded density laboratory density for Ultra-Thin Bonded Hot Mix Wearing Course (UTBHMWC). In general, the performance testing procedures used for the design and quality control of thin overlay mixes are very similar to those of conventional asphalt mixes placed in thicker lifts. However, specification item 348 provides guidelines for layers as thin as 0.5 inches thick, and this specification do not venture into thickness of less than 0.5 in, which is the goal of the present study. The existing thin overlay guidelines may not guarantee satisfactory field performance because the adopted quality control procedures were not originally designed for these ultra-thin overlay mixes. Therefore there is a need to revisit the design and performance test procedures that are specifically tailored to the requirements of ultra-thin asphalt layers in Texas, which is also one of the main goals of this study.

The design of any mix has basically three components:

1. selection of aggregates and asphalt binders,

2. selection of maximum aggregate size and gradation, and

3. determination of the optimal binder content preferably based on performance related criteria or volumetrics in lieu of performance related criteria

Aggregate and binder quality and selection

Most studies recommend that the the type and durability of the aggregate is an important factor in dictating the overall performance of a thin surface layer. For example, a study from Kansas Rahman et al. (2011) examined a 4.75-mm mix placed at thicknesses varying from .6 to .75 in. The researchers determined that the mix that was made up of crushed gravel aggregates had significantly better performance than the one made up of crushed limestone. For skid resistance and surface texture, hard, durable non-polishing aggregates with low absorption rates are recommended (Walubita and Scullion, 2008). Currently TxDOT requires hard and durable aggregates for use in surface mixes. Item 347 suggests that the aggregates must have a MgSO4 soundness of less than or equal to 20. While Surface Aggregate Classification (SAC) A aggregates are recommended, SAC B aggregates are also acceptable, as long as the soundness loss does not exceed 20. SAC B aggregate with a soundness loss of 10 or lower can provide the same skid resistance as SAC A. For the purposes of this research, and based on the comments from the project monitoring committee during the initial project meeting, this study will continue to adopt the aggregate quality requirements that are currently in force.

The requirements for binder quality can be evaluated from two different points of view: by considering that the ultra thin mix will experience distresses that are similar to that of a chip seal owing to its reduced layer thickness (raveling and flushing) or by considering that the ultra thin mix will experience distresses that are similar to that of a conventional asphalt mixture (rutting and cracking). TxDOT projects 0-1710-1 and -2 focused on the development of a performance grading (PG) system for binders used in surface treatments (Epps et al., 2001). Based on the preliminary results from these studies, it appears that the proposed binder quality requirements may be less stringent compared to the requirements for a conventional hot mix asphalt. Therefore in the context of this study, it may be more prudent to assess the binder quality by treating the UTM as a conventional hot mix placed in an ultra thin lift.

The asphalt binder for conventional hot mix asphalt is specified based on the performance grading (PG) system that was originally developed by the Strategic Highway Research Program (SHRP) and includes performance requirements for high, intermediate and low temperatures. However, the test methods used in the original SHRP specifications for high and intermediate temperatures are now being replaced by alternative methods. Specifically, the high temperature requirements based on the $G^*/\sin\delta$ parameter from a cyclic torsional shear test are now being replaced by a non-recoverable compliance J_{nr} measured using a multiple stress creep and recovery (MSCR) test. One of the advantages of the MSCR test is that it can also be used to measure the elastic recovery of an asphalt binder, which is a surrogate indicator for the presence of elastomeric polymers in the binders. This is important because binders with elastomeric polymers tend to have significantly better performance in terms of rutting and cracking (Bhasin et al., 2004). Interestingly, current Items 347 and 348 do not have specific requirements for polymer content or elastic recovery in selecting the asphalt binder. This will be investigated and considered as a part of this research project.

Aggregate size and gradation

The selection of the maximum aggregate size and gradation are the two of the most important design variables that can influence the overall performance of a UTM. In terms of aggregate structure, thin HMA overlays are divided into three categories: dense-graded mix, fine graded mix and gap graded mix (Wilson et al., 2013). However, based on a review of the literature conducted during this study and discussed later, at least six different gradation approaches were determined as possible options for thin lift overlays.

The most common dense graded mixes used in Texas are the Type C and D mixes based on Item 340 of the TxDOT specification. However, these mixes are based on larger aggregate sizes and cannot be placed in layers that are less than 1 inch thick. The current specifications for fine-graded and gap-graded (also referred to as Stone Matrix Asphalt or SMA) mixes are also not well suited for ultra thin layers. For example, TxDOT's fine SMA as defined in Item 346 as Type F does not allow for lift thickness that is less than 1.25 inches (Wilson et al., 2013).

Several different potential aggregate structures, including CAM, gap graded, and dense graded for ultra thin mixes have been suggested in the literature (Cooley et al., 2002; Cooley Jr and Brown, 2003; Michigan Department of Transportation, 2005; Xie et al., 2003; Nicholls et al., 2002). For the purposes of this study researchers surveyed the types of aggregate gradations that were used by different state agencies for thin and ultra thin layers. The different aggregate sizes and gradations could be classified into six different categories:

1. Dense graded mixes with maximum aggregate size that approaches the thickness of the asphalt layer, i.e. in this case 12.5 mm. For such mixes a single layer of coarse aggregate will make direct contact with the pavement surface and the remaining mix will serve as a filler around the largest aggregate particles. This is somewhat similar to a dense graded mixture. Figure 2.4 shows the range of gradations used by several states (OH, NY, MI, MD, NY, NV, UT, NE, ND, ME, MA, NH, NM, WA, WI, NM, IA).

2. Dense graded mixes with maximum aggregate size that is about 1/3 the layer thickness, in this case the overlay is very similar to a conventional hot mix except with smaller layer thickness and proportionally smaller maximum aggregate size. Figure

2.5 shows the range of gradations used by several states (AL, OH, OK, MO, KY, LA, MN, MS, SC, TN, VT, WV, OR) including the TOM F mix in Texas.

3. Gap graded or SMA mixes that are tailored for thin layers. Figure 2.6 shows the range of gradations used by several states (AL, CA, CO, CT, VA).

4. A hybrid of gap graded and open graded specifically designed for use as an ultra thin mix. Figure 2.7 shows the range of gradations used by three states (TX, NC, MN) and New Zealand including the UTBWC-A used in Texas. Ultra thin layers such as those used by NovaChip also have a similar gradation.

5. The thin overlay mix (TOM C) typically used in the state of Texas (Figure 2.8)

6. A fine open graded or PFC mix designed for use in thin layers. Figure 2.9 shows the range of gradations used by some of the states (AZ, TX, KS, RI, SD) including the fine or Type F PFC used in Texas.

These six gradations form the basis for further investigation into optimizing the mixture design procedure for this project.

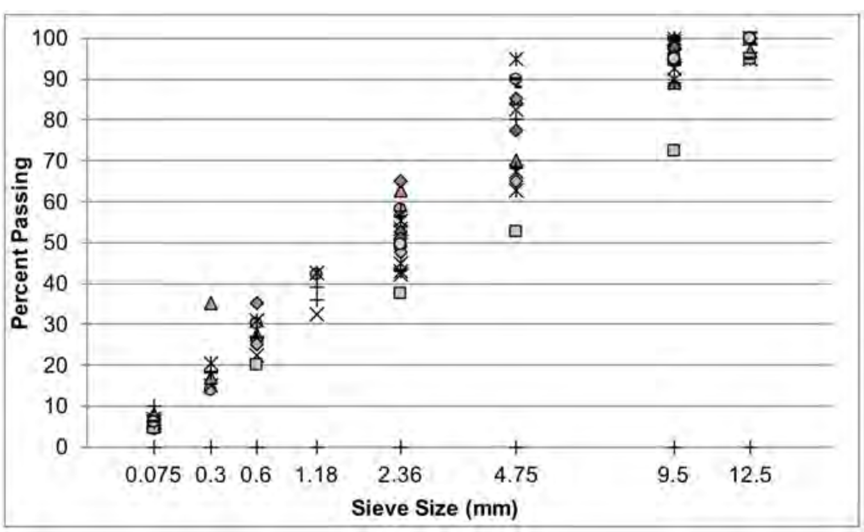

Figure 2.4. Range of gradations for a dense mix with maximum particle size approaching that of the layer thickness.

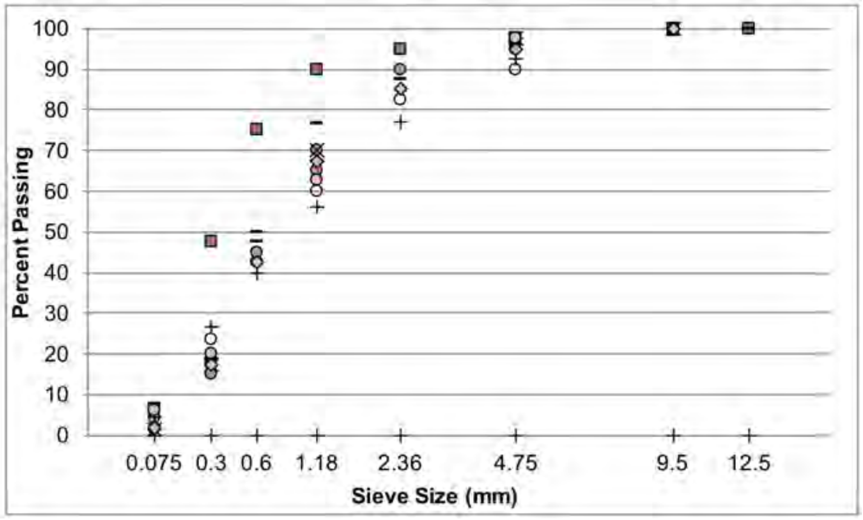

Figure 2.5. Range of gradations for a dense mix with maximum particle size about 1/3 that of the layer thickness.

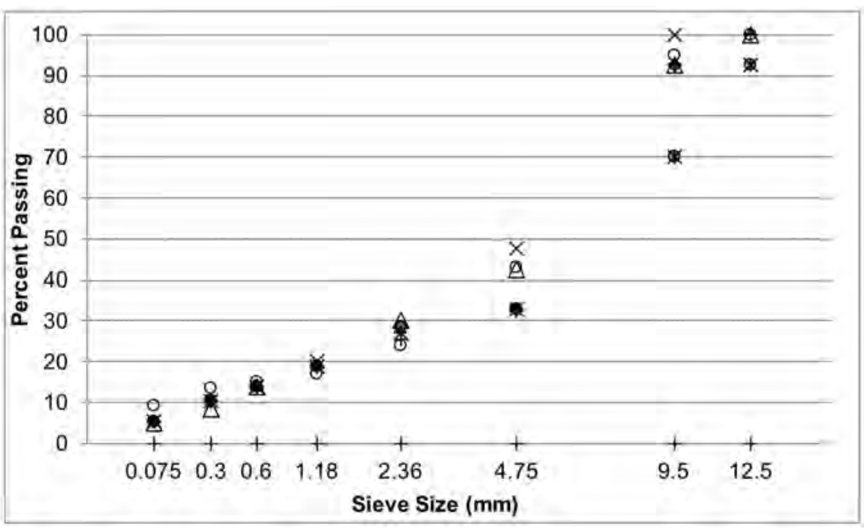

Figure 2.6. Range of gradations for a open graded or SMA mix for thin overlays.

Optimum binder content

Item 347 in TxDOT's Standard Specifications provides details about the design of thin overlay mixtures. Section 4.4 specifically discusses the procedure for calculating the optimum binder content for a thin overlay mix. The procedure can be found in the specification Tex-204-F. This procedure involves the use of either a Texas Gyratory Compactor or a Superpave Gyratory Compactor (SGC) to compact the mix. In this procedure, a total of 2

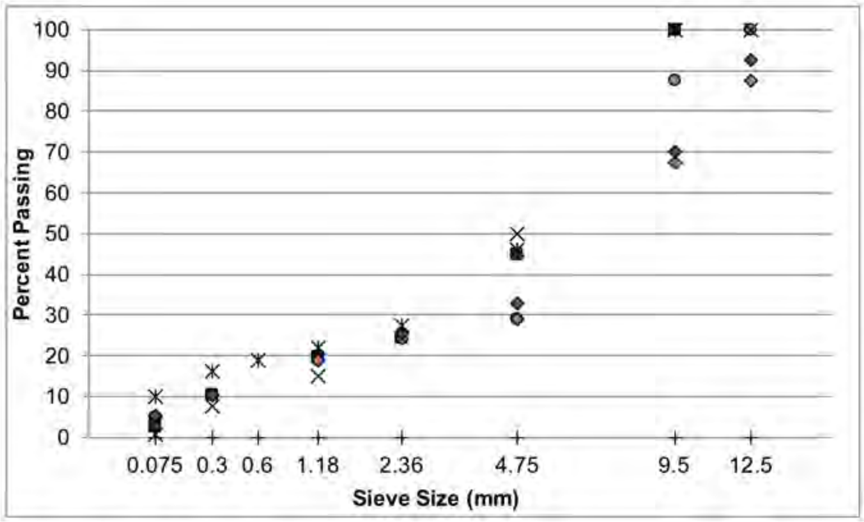

Figure 2.7. Range of gradations for a open graded - gap graded hybrid type mix for thin overlays.

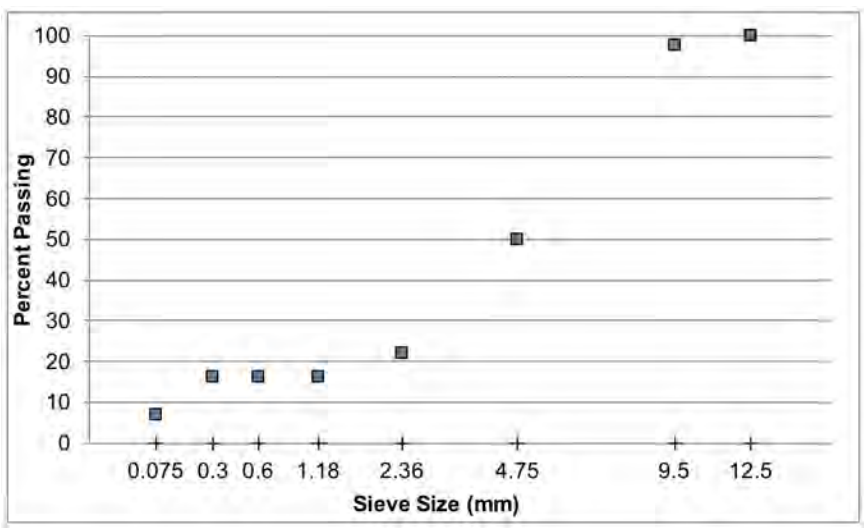

Figure 2.8. Gradation used in Texas for thin overlay mixes.

asphalt mix cylinders are created at three different binder contents using gyratory compaction, for a total of six different cylinders. For the SGC, a target of 50 gyrations is used. In addition, two samples of loose mix are created for each binder content, again for a total of six separate mixes to measure theoretical maximum specific gravity. The mix should meet a minimum VMA requirement, as described in the specification. In addition, there are specific requirements regarding the Indirect Tensile Strength that the material should

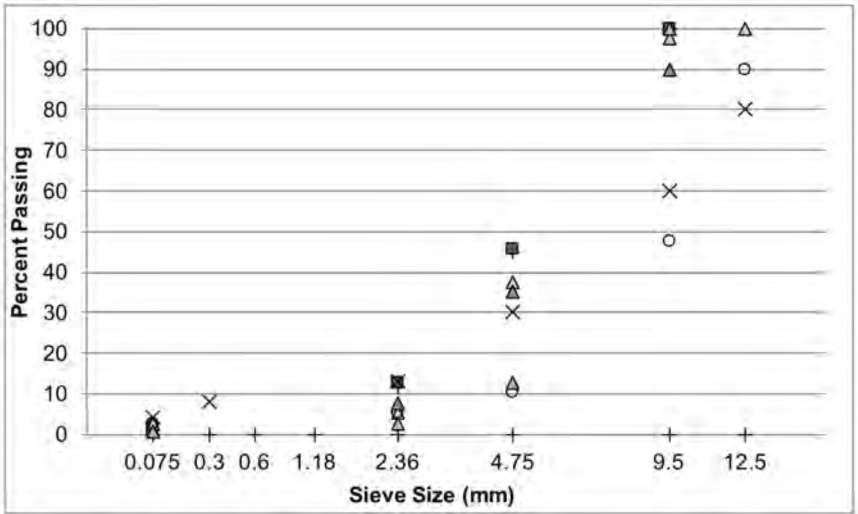

Figure 2.9. Range of gradations for a fine PFC mix for thin overlays.

meet as well. Finally, the two replicates at each binder content should be within a specific tolerance of each other. If these requirements are all met, then the optimum binder is calculated using a target air void content of 4%. The above procedure clearly indicates that the optimal binder content is determined based on a volumetric criterion. In terms of performance requirements, indirect tensile strength, Hamburg wheel tracking device, and overlay tests are specified. However, these tests may not be appropriate for an overlay that is only half an inch in thickness. One of the goals of this project will be to use a more performance based measure to design ultra thin mixes.

2.3.4 Summary

A review of the literature indicates that it is feasible to develop an optimal and cost-effective mix design procedure for ultra thin mixes that can be used in lieu of chip seals. The current TxDOT standards for aggregate and asphalt binder selection appear to be appropriate for use with UTM. A review of the practices by different state agencies indicates that there are at least six different aggregate structures that can be used to design and evaluate UTMs. The traditional methods used to evaluate the performance of conventional asphalt mixtures (e.g. Hamburg Wheel Tracking Device or Indirect tensile strength) may not be applicable for use with ultra thin asphalt mixes. In addition, ultra thin mixes may be prone to additional modes of failure such as raveling or flushing. One of the goals of this project was to identify modes of failure and ensure that the design and associated test methods developed for ultra thin mixes are based on mixture performance.

CHAPTER 3. POTENTIAL MIX DESIGNS FOR ULTRA THIN MIXES

3.1 MIX DESIGN VARIABLES

One of the main goals of this study was to develop an ultra-thin asphalt mix that can economically and functionally replace chip seals and other surface treatments. Task 3 of this study addressed the most important variables in the mixture design process. These variables are:

1. Aggregate type or class
2. Aggregate gradation
3. Binder grade
4. Binder content

The primary purpose of investigating mixture designs was to identify the most appropriate aggregate gradation or structure of the mix. In order to achieve this, the aggregate type or class and binder source were kept constant during this task. Each of the aforementioned variables are discussed below in more detail.

Aggregate Class

Traditionally, Class A aggregates are considered the most appropriate for surface applications. However, in many cases, Class A aggregates are not locally available. In this task, researchers developed mix designs using Class A aggregates for the coarse aggregates (material retained on the No. 8 sieve) and Class B aggregates for fine aggregates. Blends of Class A and Class B aggregates, in the coarse portion, were not considered in this initial round in order to maintain the best case scenario in terms of aggregate quality. In other words, even though Class A aggregates are not locally available in many geographic regions within Texas, these aggregates provide the best behavior to avoid particle loss, and cracking as well as to improve surface friction.

Aggregate Gradation

Ultra-thin mixes will typically be applied in a layer that is no more than 0.5 inch thick. Therefore, the selected maximum aggregate size would be 0.5 inch or less combined with other sizes to achieve a desirable aggregate structure. This is somewhat similar to a slurry seal. Different aggregate gradations were used to develop a total of six different mix types; these are discussed in more in the subsequent subsections. Most gradations can be classified into one of three categories based on aggregate structure: fine or coarse dense graded, gap graded, and open graded. Within each aggregate structure, different gradation can further be developed using different maximum aggregate sizes.

Dense graded HMA is a versatile mixture. It is also the most common and well-understood mixture type used in the asphalt industry. Gap graded, also referred to as the Stone Mastic Asphalt (SMA), is relatively new in the United States. It has been used in Europe as a surface course for several years to support heavy traffic loads and resist studded tire wear (e.g. in Germany). Open graded mixtures include both open-graded friction course (OGFC) and asphalt treated permeable materials (ATPM). Open-graded mixes are typically used as wearing courses (OGFC) or underlying drainage layers (ATPM) because of the special advantages offered by their porosity. This type of gradation is typically the weakest in terms of its structural carrying capacity. The gradations that were selected in this study are discussed in a later section.

Binder Grade

The mix designs were developed using one grade of the asphalt binder. Previous studies have shown that in some cases with poor quality aggregates it may be necessary to use stiffer grades of the asphalt binder to compensate for the aggregate quality. However, this was not the case in the context of this task since the aggregates used were 100% Class A for coarse aggregates.

Binder Content

Binder content is the most important part of the mix design both from a performance and cost point of view. The cost of binder combined with the binder content dictates the overall cost of the chip seal. In this task, ultra-thin mixes were initially designed to have an optimum binder content based on current TxDOT standards (Item 347). In subsequent tasks, additional mixes were prepared at binder contents that were higher and lower than this optimum binder content in order to evaluate whether the current optimum binder content criteria yields an optimally designed and well performing ultra-thin layer mix.

3.2 MATERIALS

Aggregates and Binder

Class A aggregates were used for the coarse aggregates (material retained on the No. 8 sieve) and Class B aggregates were used for the fine aggregates. The aggregates were primarily dolomitic in nature. They were obtained from two different sources: Capital Aggregates at the Bolm Road plant and Capital Aggregates Delta at Marble Falls. The asphalt binder grade was PG70-22. The asphalt binder was obtained from a producer in the state of Texas. For the purposes of this task, no additives were used in all the six asphalt mixtures.

Aggregate Gradation

As mentioned earlier, six different asphalt mixes were developed by using different aggregate structures or gradations. The rationale for the selection of these six gradations was discussed in an earlier chapter and is briefly summarized below. A survey of all fifty states was conducted (Figure 3.1) to determine the aggregate gradations specified by different states, that could potentially be used in an ultra-thin mix. Some states specified gradations for thin overlays specifically, while others do not have a criteria for thin overlay pavements. In case of the latter, only gradations with a maximum aggregate size of less than 12.5 mm (the thickness of the overlay) were chosen. After analysis of the different types of gradations, it was determined that there are six broad categories of aggregate gradations that cover the different mix types used throughout the country (appropriate for ultra-thin mixes). From each of these categories, a representative gradation was chosen. Figure 3.2 shows the six gradations chosen for mix design.

1. 9.5 SMA Gap Graded (Figure 3.3a)

2. 4.75 SMA Gap Graded (Figure 3.3b)

3. 4.75 Fine Dense Graded (Figure 3.3c)

4. 9.5 Fine Dense Graded (Figure 3.3d)

5. 9.5 Coarse Dense Graded (Figure 3.3e)

6. 4.75 Gap Graded/Open Graded (Figure 3.3f)

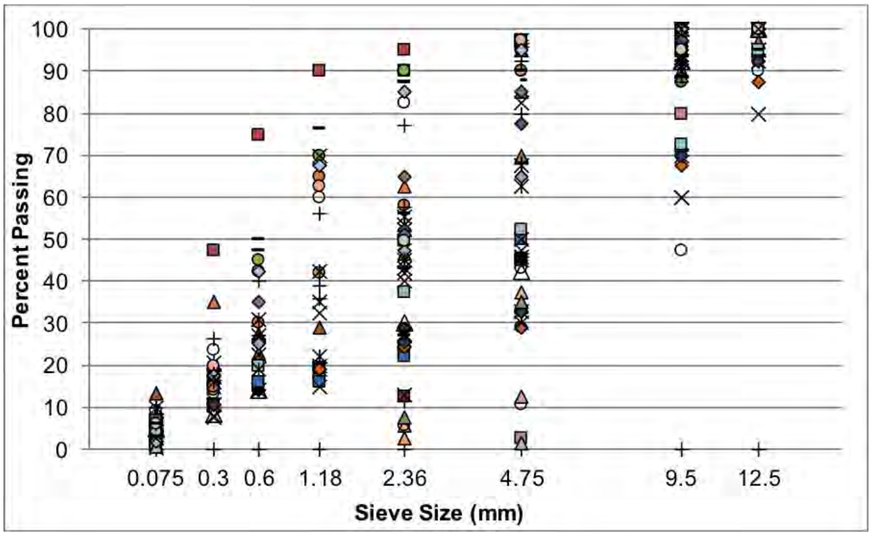

Figure 3.1. Gradations From 50 States Surveyed

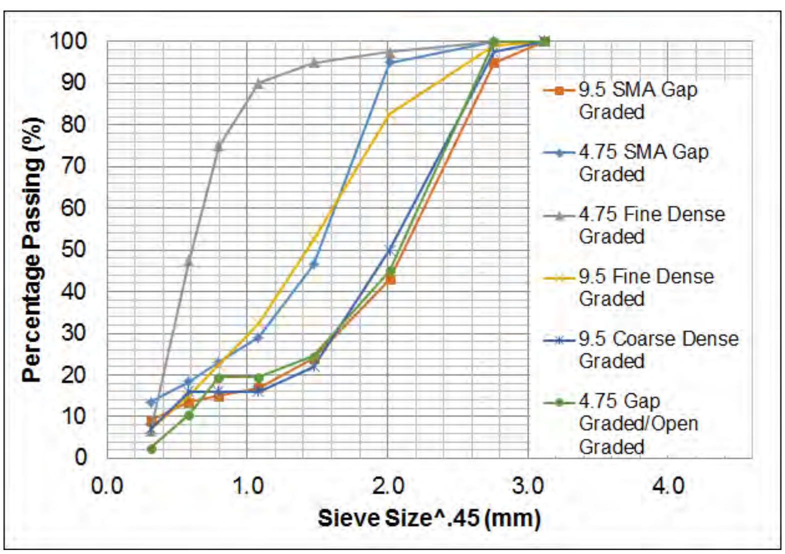

Figure 3.2. Visual Representation of the Six Gradations

3.3 MIXTURE DESIGN

In order to avoid raveling and bleeding in the field, it is crucial to use the optimum binder content in an asphalt mixture. As per TxDOT 2014 Specifications, Item 347 specifies the criteria to determine the optimum asphalt binder content. For this task, the optimum asphalt binder content was determined using the aforementioned specification. The procedure used to determine the optimum binder content is briefly described below:

1. The asphalt binder was heated inside the oven at 150 °C. The binder was heated until the binder was workable and of consistent viscosity throughout the container. The temperature was based on the PG of the asphalt binder (TxDOT Tex-241-F), which was PG70-22 in this case.

2. The aggregates sampled from the field were from different stock piles. For this task, researchers did not use the stock pile gradations to prepare aggregate blends. Instead, aggregates from each stock pile were sieved into different size fractions and recombined later. Also, aggregate samples obtained from the field had a high dust content. All aggregates were washed and then used in the mixture design.

3. The washed aggregates were heated overnight inside the oven at 150 °C. This was to ensure that the moisture is removed from the aggregates.

4. The aggregates in their predetermined proportions were mixed with the asphalt binder in the mixer until all the aggregate particles were coated by the asphalt binder.

5. The mixture was placed inside the oven at 135 °C for 2 hours. This temperature simulates the short-term aging during mixing and transportation in the field. The temperature was selected based on the PG of the asphalt binder (TxDOT Tex-241-F).

6. After 2 hours, the mixture was remixed for about 5 minutes to avoid segregation between the aggregates and asphalt binder. During this process all the aggregates were coated by the asphalt binder.

7. Two samples were prepared at each binder content in the Superpave Gyratory Compactor (SGC). The specimens were used to measure the volumetric bulk specific gravity (G_{mb}) of the asphalt mixture (TxDOT Tex-207-F). The height of each SGC sample was between 110 and 120 mm at N_{design} of 50 gyrations.

8. Two loose mixture samples were prepared at each binder content, in order to obtain the theoretical maximum specific gravity (G_{mm}) of the asphalt mixture (TxDOT Tex-227-F).

9. The air void content was then calculated using the values for G_{mm} and G_{mb}. The air void content vs. binder content was then plotted, and this plot was used to determine the optimum binder content, which was defined as the binder content at 4% air voids.

The optimum binder content was determined for all six mixes. The mix design has been verified for four of these mixes. The optimum binder contents are summarized in Table 3.1.

Table 3.1. Summary optimum binder contents for the six mix designs

Mixture type	Optimum binder content %	VMA @Optimum %
9.5 SMA Gap Graded	6.3	17.2
4.75 SMA Gap Graded	6.0	16.6
4.75 Fine Dense Graded	8.8	23.2
9.5 Fine Dense Graded	6.9	18.3
9.5 Coarse Dense Graded	6.2	17.3
4.75 Gap Graded / Open Graded	6.8	18.3

(a) 9.5 SMA Gap Graded Gradation

(b) 4.75 SMA Gap Graded Gradation

(c) 4.75 Fine Dense Graded Gradation

(d) 9.5 Fine Dense Graded Gradation

(e) 9.5 Coarse Dense Graded Gradation

(f) Gradation 4.75 Gap Graded/Open Graded

Figure 3.3. Illustration of the volumetric proportions for different gradations selected in this task

CHAPTER 4. SELECTION AND FIELD EVALUATION OF ULTRA THIN MIXES

4.1 INTRODUCTION

One of the cornerstones of this project was to use the three wheel polishing device (TWPD) coupled with a dynamic friction tester (DFT) as a tool to evaluate the performance of ultra thin mixes. The TWPD was originally developed and demonstrated by the National Center for Asphalt Technology (NCAT) as an effective tool to evaluate the skid resistance of asphalt pavements in conjunction with the DFT. Figures 4.1, 4.2 and 4.3 show images of the TWPD, a specimen under the TWPD and the DFT, respectively. The TWPD has three pneumatic tires at 50 psi inflation pressure and an overhead load of 100 lbs that rotate at 60 rpm on the test surface in a circular path 11-inch in diameter. The TWPD makes an excellent candidate to simulate loading to evaluate ultra-thin overlay. The three rotating wheels create the high shear stresses that the surface treatment experiences under traffic loading. The loading configuration of the TWPD produces a circular track with a diameter that is similar to the configuration used for the DFT, making the task of measuring surface distress more straightforward. Although different wheels and loadings can be used with the TWPD, the default configuration was used with air inflated rubber tires that simulate realistic loading conditions.

While the TWPD simulates repeated action of wheel loads, the DFT measures the performance of the mixture in terms of its skid resistance. It is important to note that skid resistance of the surface is sensitive to several other performance related factors such as: (i) aggregate loss or raveling (excess raveling will alter the micro texture and influence skid resistance, (ii) bleeding or flushing (excess bleeding or flushing will reduce the texture of the surface), and (iii) polishing of aggregates (polishing of aggregates directly impacts micro texture and skid resistance). As such, the combination of the TWPD with the DFT is a valuable tool to evaluate the performance of the ultra-thin mixes.

However, before using this tool to evaluate asphalt mixtures designed in the laboratory, it was important to benchmark the performance measured using the TWPD against some of the observed performance in the field. To this end, researchers from the University of Texas at Austin and El-Paso met with TxDOT representatives from different districts to identify potential ultra-thin and close to ultra-thin (e.g. 1 or 1.5 inch thick) mixes that had been used in the field and could be replicated in the laboratory. Mixes that were placed a few years ago to more recent mixes were considered for this. The following sections of this chapter present more details on this.

Figure 4.1. Three wheel polishing device used in this study

Figure 4.2. Thin asphalt layer being tested under the three wheel polishing device

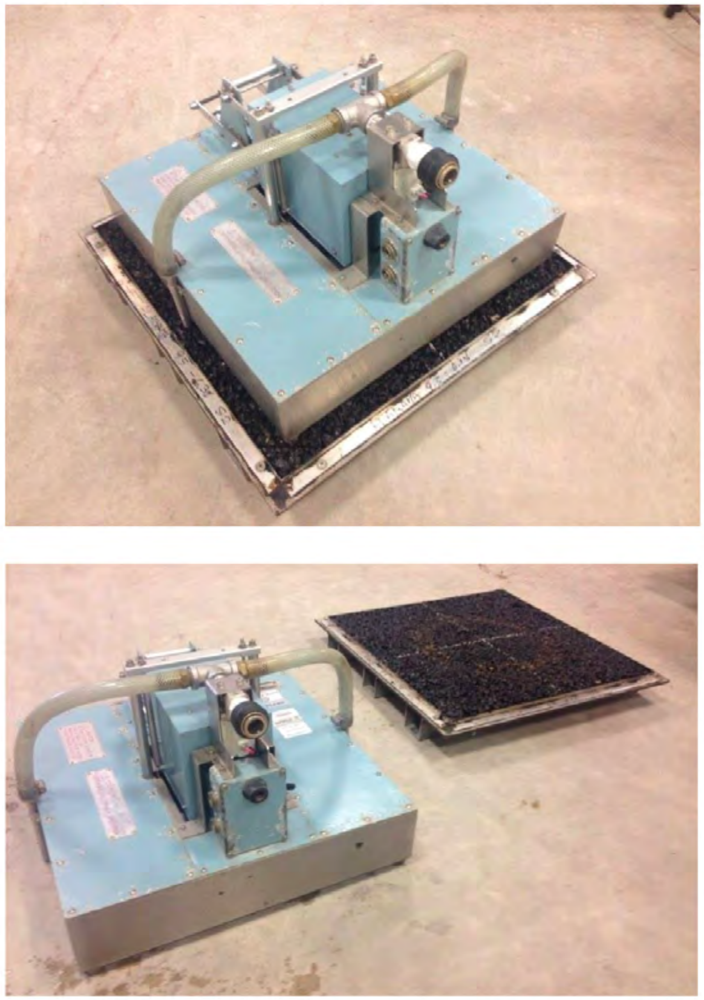

Figure 4.3. A direct friction tester used on the same specimen as the TWPD after pre specified number of load cycles

4.2 FIELD VISIT AND SELECTION OF FIELD MIXES

The purpose of selecting existing sites was to identify performance of pavements constructed with thin layers. After selection of sites, the material was collected and tested in the laboratory to evaluate their performance. As per the proposed workplan, two sites, identified and approved by PMC, will be visited and data from each site will be collected. The selection of sites and mix material collected from the site is included in the following paragraph.

At the Kick-Off meeting of this project, Mr. Richard Williammeee, Ms. Darlene Goehl, and Mr. Mike Arellano indicated that they have placed thin overlays which have mostly performed well over the years. Additionally, Mr. Miles Garrison indicated that at four different sites thin overlay layers will be placed in August, 2015 and a visit to the construction site in Atlanta District was planned accordingly. Therefore, UTEP and UT made arrangements and visited Bryan, Fort Worth, and Austin District in the second week of June, 2015 while a visit to the Atlanta District was planned in August 2015.

The Bryan District (BD) has placed thin overlays over the years with different mix types (SMA, TOM, CAM, PFC, etc.) with different results. Although Bryan District has placed more CAM mixes than TOM mixes, their experience suggests that the TOM mixes perform better than CAM mixes. The failure of CAM mixes was attributed to the water being trapped leading to blisters and delamination. In terms of performance ranking, PFC mixes generally performed better than SMA, which has performed better than TOM, which has performed better than CAM. The research team (UTEP and UT) visited four sites in BD:

1. Frontage to Highway 6 FM and West 974 south (SMA mix placed as overlay),
2. Ramp to BD TxDOT office (thin PFC mix placed as overlay),
3. Highway 6 (PFC mix placed as overlay), and
4. Briarcrest Drive and Highway 6 (CAM mix placed as overlay).

The PFC and SMA mixes performed well over the years while CAM mix had issues like delamination and shoving. Since the CAM mix did not perform well over the years, it was selected as one of the mixes to evaluate the sensitivity of the TPWD, DFT, and HWTD tests.

The Fort Worth District (FWD) has also placed thin overlays over the years and have mixed success. The research team visited two sites where thin overlays have been placed. The first site was on I-20 where ultra-thin bonded wearing course (UTBWC) was placed while other site was on Pumphrey Street (near the entrance of Naval Air Station Joint Reserve Base, Fort Worth) where CMHB-F mix was used as an overlay. The site visit indicated that CMHB-F did not perform well even though it was mixed with latex and GTR modified asphalt. On the other hand, UTBWC was performing well on I-20 even though it was exposed to higher traffic in comparison to Pumphrey Street. After discussion with Mr. Williammee, it was decided to select UTBWC mix for performance evaluation in this study.

Although researchers had planned to visit sites in Austin District (AD) in June 2015, they were not able to visit the sites due to unavoidable circumstances. However, Mr. Mike Arellano and Ms. Elizabeth Lukefahr of AD provided research team with a list of thin overlays placed over the years in AD. The list included sites on SH 16, US 290, US 281, and RM 1431. The mixes placed on these sites included TOM-F (SAC-B), UTBHMWC (Membrane) UTBHMWC (TY C), and TSM UT. The mixes were placed between 2010 and 2015 and have performed well over the years. Based on discussion with Ms. Lukefahr and Mr. Arellano, it was decided to select mix Ultra-Thin Mixture prepared with SAC Type A aggregate for performance evaluation.

Mr. Miles Garrison of Atlanta District provided a list of new sections which will be placed in the summer of 2015. The list included the following four sites:

1. CSJ 0610-06-078; Bowie County; IH 30; Substantial quantity of "Tiny" TOM to be placed on main lanes primarily inside traffic lanes, from West of SP 86 to West of SH 98, small placements (leaveouts) remaining, siliceous gravel primary aggregate, 96.5 target lab density TGC.

2. CSJ 0218-02-039; Bowie County; IH 369; Small quantity, same mix design as on IH-30.

3. CSJ 0063-12-019; Panola County; BU 59-D; Contractor's plan is to kick-off in August; TOM-C will be a new mix design with different aggregates.

4. CSJ 0401-04-035; Upshur County; SH 154; Let with above BU 59-D project; TOM-F may be a new mix design.

Based on discussion with Mr. Garrison, the research team decided to incorporate "Tiny" TOM mix to be placed on IH-30 in the test matrix because of the available quantities and difference in the type of mix from other selected sites. Although the research team planned for the visit, the construction delay (due to rainfall) made it difficult to visit the site at the time of construction. Ultimately, the research team requested material to be sampled at the time of construction and stored in the Atlanta District Office and was collected for performance evaluation. Although the research team proposed to select two field mixes, the final selection included four different sites. Three of the selected sites had been placed in the past while the fourth mix was collected from a new construction.

4.3 EVALUATION OF FIELD MIXES USING TWPD AND DFT

4.3.1 Materials

Four different field mixes were selected for this part of the study. Table 4.1 lists the mixes selected and their characteristics. All mixes were subjected to the TWPD-DFT test. At the time of this interim report, testing with three of the four mixes was complete and testing with the fourth mix was underway. Also, testing of these mixes with the Hamburg Wheel Tracking Device was also underway.

4.3.2 TWPD Specimen Fabrication

Depending on the date of construction, two methods were used to recreate the field mixes as shown in Table 4.1. For the new construction site, loose plant mix was sampled from the contractor's hot mix production site. This method ensures that the same exact materials that were used in the field are also used in the laboratory for performance evaluation. However, this mix also has a drawback that long-term field performance data is unavailable for immediate comparison since these sections have been placed only very recently. In this case, the loose plant mix was heated in the oven for two hours at 150°C in order to make it workable.

A standard steel base was used to place and compact the specimens; this was also the substrate over which the specimen was subjected to repeated loads using the TWPD. An aluminum channel corresponding to the desired layer thickness was bolted on the sides of the tray to serve as a mold and guide for compaction. The overall dimensions of the mold or tray was 20 inch x 20 inch (Figure 4.4). A tack coat was applied to the base and corner frame to create a bond between the thin asphalt layer and the mold. The amount of mix that was to be used was selected based on the theoretical maximum specific gravity provided in the job mix formula and a target of 7% air voids. The hot loose mix was then placed and spread over the tack coat covered tray. The mix was then manually compacted with a few passes using a steel roller. The mold edges served as a guide for the final compacted height. The mix was then allowed to cool before being used for testing with the TWPD.

A different method was used for pavements that had been constructed a few years ago and had been in service at the time of this project. In this case, the component materials (aggregates, binder, and additives) that had been used in the construction of the pavement were obtained from the appropriate suppliers, and loose mixes were prepared in the lab

Table 4.1. List of field mixes incorporated in the study

Location	Label	Layer Thickness	Type of Mix	Approximate Age and Other Notes
Atlanta	Field 1	1 inch	TOM Type B according to TxDOT SS 3280	07/2015. Plant mix obtained during construction and used in the lab. No issues have been reported to date.
Austin	Field 2	0.5 inch	Ultra Thin Bonded Wearing Course according to TxDOT SS 3239	04/2013. Mix was recreated using same or similar materials based on JMF. Mix has been reported to have good performance to date.
Bryan	Field 3	1 inch	CAM according to TxDOT Item 3131 2002	04/2009. Mix was recreated using the same or similar materials based on JMF. Mix was reported to have performance issues in the field.
Fort Worth	Field 4	0.5 inch	Ultra Thin Bonded Wearing Course according to TxDOT SS 3142	08/2012. Mix was recreated using same or similar materials based on the specifications and JMF. Mix has been reported to have good performance to date.

using the original JMF. The advantage with this method is that the performance of the mix measured in the laboratory can be compared to the known field performance of the mix. However, a drawback of this approach is that although the gradation and volumetrics can be replicated exactly, the materials used in the laboratory to replicate the mixture could be slightly different from the original materials; this is particularly true with regards to the composition of the asphalt binder. Not withstanding this limitation, researchers have made

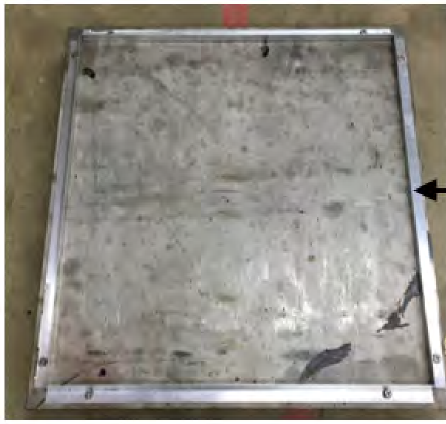

Figure 4.4. Mold and substrate used to prepare and test the sample

every possible effort to obtain aggregates from the exact same source and quarry as the original mix and also to obtain binder from the same producer and grade.

The aggregates obtained from the same sources and stockpiles used in construction, were sieved in the laboratory and recombined according to the final JMF to ensure the most accurate representation of the aggregate gradation. The asphalt binder and additives, when required, were obtained from the same supplier. Then, the aggregates, binder, and additives were mixed together at the recommended mixing temperature temperature and placed in an oven for two hours to simulate short-term aging. After this, the test specimen was compacted in the same way as the plant mix specimen.

4.3.3 TWPD Test Method

As mentioned earlier, the Three Wheel Polishing Device (TWPD) consists of three pneumatic tires, which rotate at a constant speed in order to simulate traffic effects on the performance of the mix with regards to aggregate polishing, raveling, bleeding and rutting under the wheel path. The total load applied by the device is 105 pounds of normal force distributed to the three wheels. A stream of water is sprayed onto the specimen as the polisher runs in order to prevent more abrasion due to the aggregates that may break loose during the test and overheating of the rubber tires. The sample is placed under these conditions for a designated number of cycles (Table 4.2), and then removed after set of cycles for testing with the DFT.

Table 4.2. List of field mixes incorporated in the study

Stop Point	Cycles Applied	Cumulative Cycles
1	500	500
2	500	1000
3	1000	2000
4	2000	4000
5	4000	8000
6	8000	16000
7	16000	32000
8	32000	64000
9	36000	100000

4.3.4 Evaluation Using the DFT

The Dynamic Friction Tester (DFT) is a 13.75-inch disk with three rubber sliders attached by a spring (Figure 4.3). The disk rotates with increasing speed while the sliders are initially above the asphalt mixture surface. When the speed of the disk reaches 80 km/h, the sliders are dropped to the test surface, and the coefficient of friction is measured as the disk speed is decreased to zero. The output (Figure 4.5) provides the relationship between the coefficient of friction versus speed from 0 to 80 km/h. Three measurements are also output on the equipment display, which are the measures of friction at 20, 40, and 60 km/h. The final value used in this study for friction is the average of these three measurements.

4.3.5 Typical Results

The TWPD applies cyclic loading to the asphalt surface while the DFT measures performance in terms of skid resistance, which in turn reflects resistance to raveling, bleeding, and polishing. Figure 4.6 shows the surface of one of the mixes at some of the stop points as

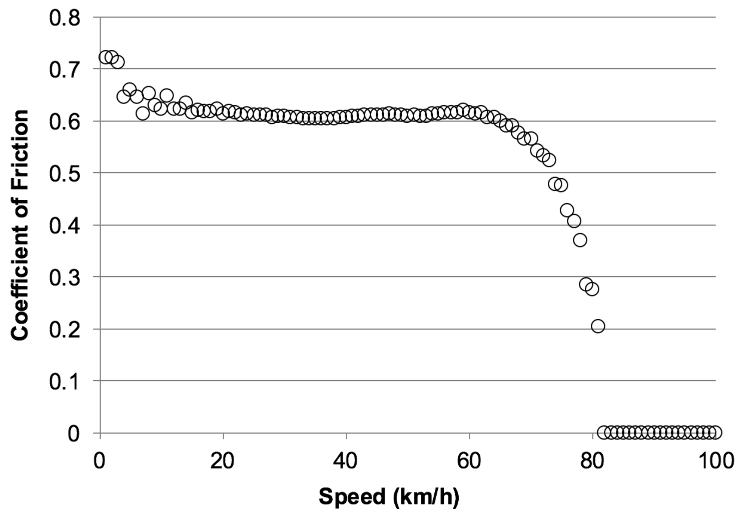

Figure 4.5. Typical results using the DFT

indicated in Table 4.2. Figure 4.5 shows the results from the DFT as a function of the number of cycles applied using the TWPD. The initial low friction number for a fresh specimen is typical because the asphalt binder film coats the aggregate surface preventing the microtexture of the aggregate to contribute to the surface friction. After about 500 cycles, the microtexture of the aggregate is revealed increasing the surface friction significantly. From this point on factors such as raveling, bleeding, or polishing contribute to the progressive deterioration of the surface properties.

Two replicates of each of the field mix (from new and existing sections) were evaluated using the procedure described above. Figure 4.8 illustrates the results comparing the performance of the four field mixes as a function of the number of load cycles. Note that the mix that had performance issues in the field did in fact show excessive deterioration when evaluated using the DFT-TWPD. The field mix that has been performing satisfactorily also showed a relatively better performance. The third mix is a field mix that has been recently placed and no issues have been reported thus far but additional performance data from the field is required before a comparison can be made to these results.

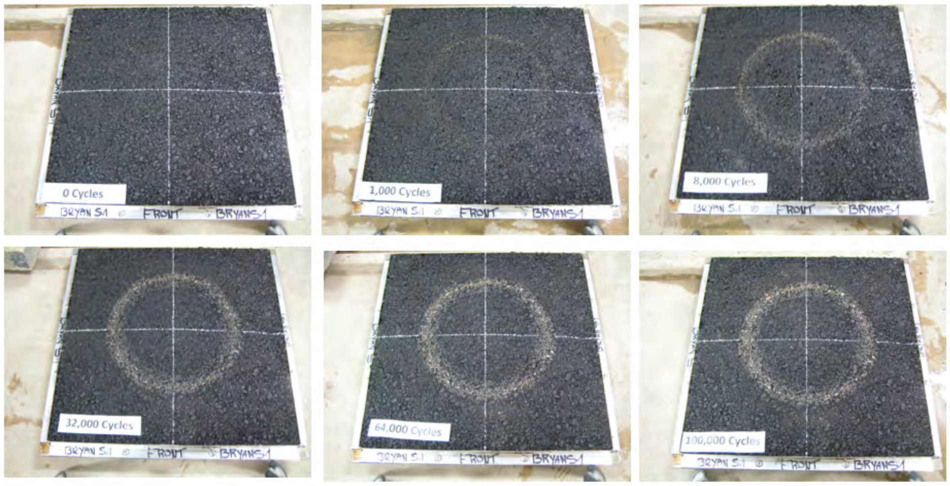

Figure 4.6. Typical progressive polishing of the surface at some of the stop points (top from left 0, 1000, 8000 and bottom form left 32000, 64000, and 100000) at which DFT measurements were carried out

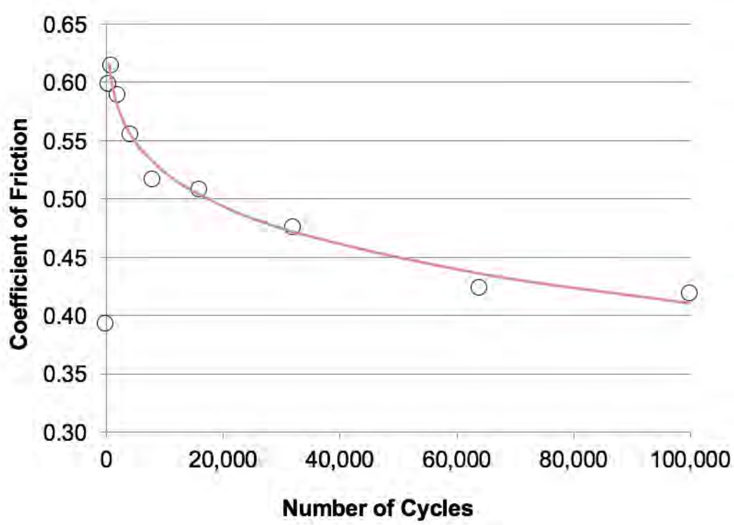

Figure 4.7. Typical DFT results for one of the mixes after different number of polishing cycles

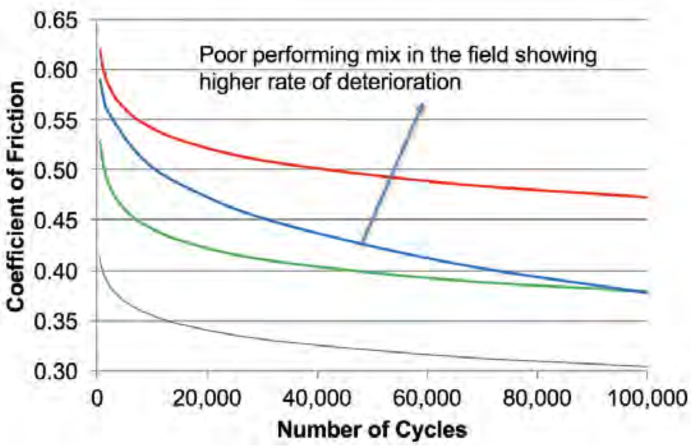

Figure 4.8. Typical for three field mixes

4.4 EVALUATION OF FIELD MIXES USING HAMBURG WHEEL TRACKING DEVICE

Three of the mixes identified in Table 4.1 were also evaluated using the Hamburg Wheel Tracking Device (HWTD). The HWTD test was conducted using two different procedures: (1) a conventional method and (2) a method that involved a 0.5 inch thick specimen over a polymer substrate. Details for this procedure are covered in a subsequent chapter; the results are summarized in Figure 4.9.

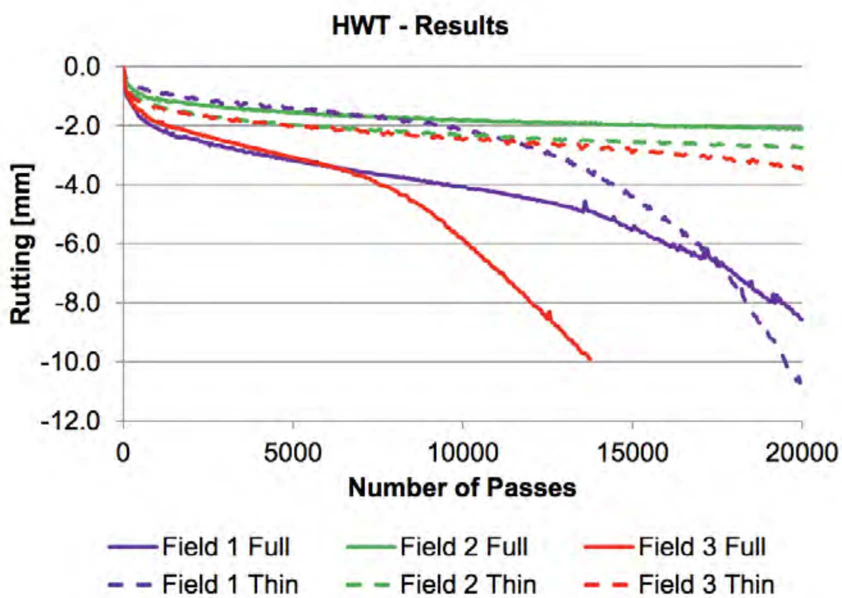

Figure 4.9. HWTT results for three of the field mixes using a regular specimen as well as a thin 0.5 inch specimen on a polymer substrate.

CHAPTER 5. INVESTIGATING PERFORMANCE OF ULTRA THIN MIXES

5.1 INTRODUCTION

In order to develop an ultra-thin asphalt mix (UTM) that can economically and functionally replace chip seals, six different candidate gradations were identified in a previous chapter based on a comprehensive review of the literature and specifications used by other state DOTs within the United States. Selection of an aggregate gradation is the first step in developing a mix design for this application. The second most important step is determining the optimum asphalt content of the mix. To this end, researchers used the current TxDOT Specification Item 347 to determine the optimum binder content for the six selected gradations. In summary, according this specification the optimum binder content is defined as the binder content at an air void content of 4%. In addition, according to TxDOT Item 347 the selected mix design must also meet the following requirements:

1. Indirect Tensile Strength
2. Overlay Test
3. Hamburg Wheel Test

As a part of this study, the aforementioned criterion for optimum binder content and the performance of the resulting mix were evaluated. In other words, the question that was explored here was, *is the optimum binder content at 4% air voids really the optimum binder content based on performance characteristics?* In order to address this question, after determining the optimum binder content for each of the six potential gradations according to the aforementioned definition, three mixes were prepared for additional performance testing. These three mixes (for each of the six gradations) were prepared: the binder contents in these three mixes were the optimum binder content (based on the above criterion), 0.5% above the optimum binder content, and 0.5% below the optimum binder content. The mixes were then subjected to the following performance evaluation tests to evaluate whether or not the criterion used to define optimum binder content accurately reflects optimal performance:

1. Hamburg Wheel Tracking Test (HWTT)

2. Modified HWTT

3. Overlay test (OT)

4. Three wheel polishing device (TWPD)

5.2 PERFORMANCE TESTS

5.2.1 Hamburg Wheel Tracking Test

The HWTT is performed to measure the rutting and moisture damage resistance of asphalt mixtures. In this study, HWTT was performed on all 18 mixes (three different binder contents for each of the six gradations). The test was performed using specimens of 5.9 inch diameter and 2.4 inches in height. In summary, asphalt mixture specimens were prepared using the Superpave Gyratory Compactor. The target air voids for the specimens was $7\% \pm 1\%$ and this was verified by measuring the bulk specific gravity of each specimen. Specimens were placed opposite each other as shown in Figure 5.1. For the testing procedure, specimens were subjected to a metal wheel weighing 158 lb that passes along the length of the specimen, as the specimen was underwater at a temperature of 50 °C. The specimens were subjected to 50 passes per minute. The deformation in the specimen was recorded each time the wheel transverses over the specimen. The specimen was considered failed after it experienced 12.5 mm of rutting. According to TxDOT specifications, the specimen must meet a certain number of passes before a rut depth of 12.5 mm occurs. For PG 76 grade binder the number of passes required is 20,000. This requirement is reduced for a PG 70 and a PG 64 binder to 15,000 and 10,000 passes, respectively.

5.2.2 Modified Hamburg Wheel Tracking Test

Ultra thin mixes (UTMs) typically have a binder content that is higher than typical dense graded mixes. As such, these mixes tend to be relatively more susceptible to rutting compared to typical dense graded mixes. However, these mixes are also intended for use in layers that are only 0.5 inch thick over an existing asphalt mixture layer. The stresses distribution within a thin layer of these mixes placed over a dense graded mix can be significantly different compared to the stress distribution when such a mix is placed as a thick layer by itself. In a conventional HWTT the thickness of the UTmix specimen is 2.4 inches according to the current standard. Since this is not the intended application thickness, a variation of the HWTT was also evaluated as a part of this study. In this variation, a

Figure 5.1. Hamburg Wheel Tracking Test Specimens in Testing Apparatus

half-inch layer of asphalt mix was applied to a Duratron polymer base. (Figure 5.2). The specimen was prepared similar to the traditional Hamburg Wheel Tracking Test specimen in the Superpave Gyratory Compactor (SGC) with the base already inside the SGC, and a tack coat applied on top of the base. Once the specimen was prepared, the test was run in the same way as the tradition HWTT.

5.2.3 Overlay Test

According to TxDOT specification Item 347, asphalt mixtures must meet an overlay test (OT) requirement of 300 cycles. In this study, the OT was conducted on all 18 mixes. The test procedure is based on Tex-248-F. Specimens were prepared using the Superpave Gyratory Compactor (SGC) at a target air void content of 7%. The specimens were then cut from the SGC specimen to meet the required shape and size for the overlay test. Figure 5.3 shows a sample specimen used in this study, set up in the testing apparatus.

Note that the testing apparatus used in this study holds the specimen vertically rather than horizontally, as is typical for the TxDOT overlay test equipment. The specimen was

Figure 5.2. Thin Asphalt Layer Applied to a Polymer Base for Modified Hamburg Wheel Tracking Test

Figure 5.3. Overlay Test Specimen in Testing Apparatus

then subjected for a maximum of 1000 cycles of triangular loading at an amplitude of 0.06 mm in tension until specimen failure. An image of a specimen that has failed by cracking is shown in Figure 5.4.

Figure 5.4. Cracked Overlay Test Specimen

5.2.4 Three wheel polishing device

The Three Wheel Polishing Device (TWPD) was used to evaluate the performance of the mix in terms of its resistance to rutting, raveling, and skid resistance. A detailed description of the test procedure used in this study has already been provided in the previous chapter.

5.3 RESULTS

Table 5.1 lists the different mixes that were evaluated using the aforementioned tests for their performance at binder contents that are slightly higher and lower than the optimum binder content (according to the volumetric criterion).

5.3.1 Hamburg Wheel Tracking Test

The research team completed the HWTT for three of the field mixtures. Although by definition the three field mixes would have passed the specification requirements, these measurements were taken to serve as a point of reference to compare the laboratory designed mixes. This was particularly important in the case of the thin HWTT specimens (Figure

Table 5.1. Mix variations evaluated for optimal performance

Mix Type	Lower Binder Content (%)	Optimal (%)	Higher Binder Content (%)
9.5 SMA Gap Graded	5.8	6.3	6.8
4.75 SMA Gap Graded	5.5	6.0	6.5
4.75 Fine Dense Graded	8.3	8.8	9.3
9.5 Fine Dense Graded	6.4	6.9	7.4
9.5 Coarse Dense Graded	6.3	6.8	7.3
4.75 Gap Graded/Open Graded	5.7	6.2	6.7

??). Figure 5.5 shows the HWTT results for three of the field mixes (using regular specimen size) included in this study. Furthermore, HWTT was completed for the six candidate gradations or mixture types at the optimum binder content. Figure 5.6 shows the HWTT results for these six candidate mixture types at their respective optimum binder contents. It is clear from the results shown in Figure 5.6 that three of the six mixture types designed in the lab performed very poorly in the HWTT whereas the other three mixes performed similar to the field mixes and met the current specification requirements. Notably, the three mixes that performed well (9.5 SMA, 9.5 coarse, and 4.75 SMA/open) also did well with the TWPD as discussed later.

5.3.2 Modified Hamburg Wheel Tracking Test

The research team conducted the modified HWTT on three of the field mixtures (Figure 5.7) as before. The HWTT was also conducted on the six candidate mixture designs at all three binder contents (optimum as well as optimum $\pm 0.5\%$ as shown in Figure 5.8 to Figure 5.10. An initial examination of the results from the thin HWTT specimens reveals the following important information:

1. In general the performance of the thin specimens for all six mixes was generally poor compared to their respective regular specimens.

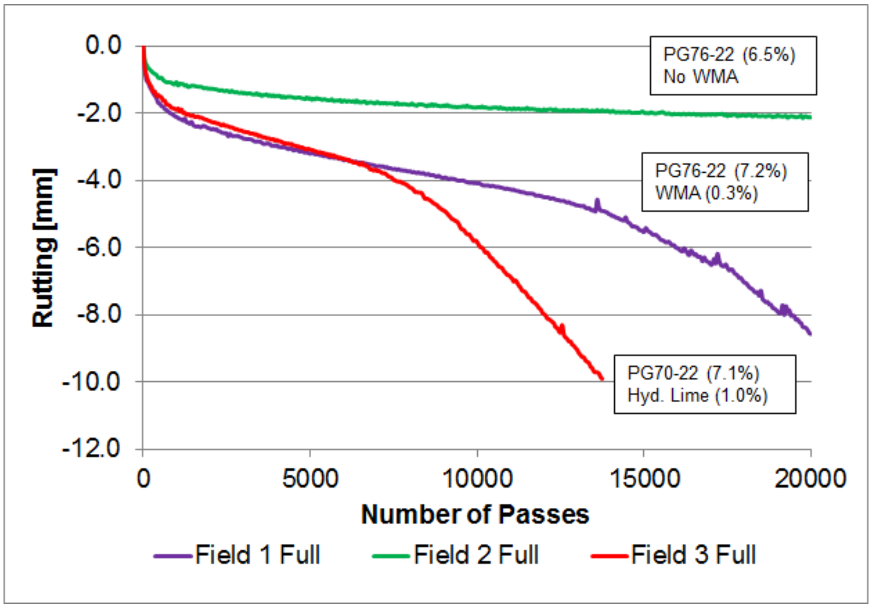

Figure 5.5. HWTT Results for the Field Mixes

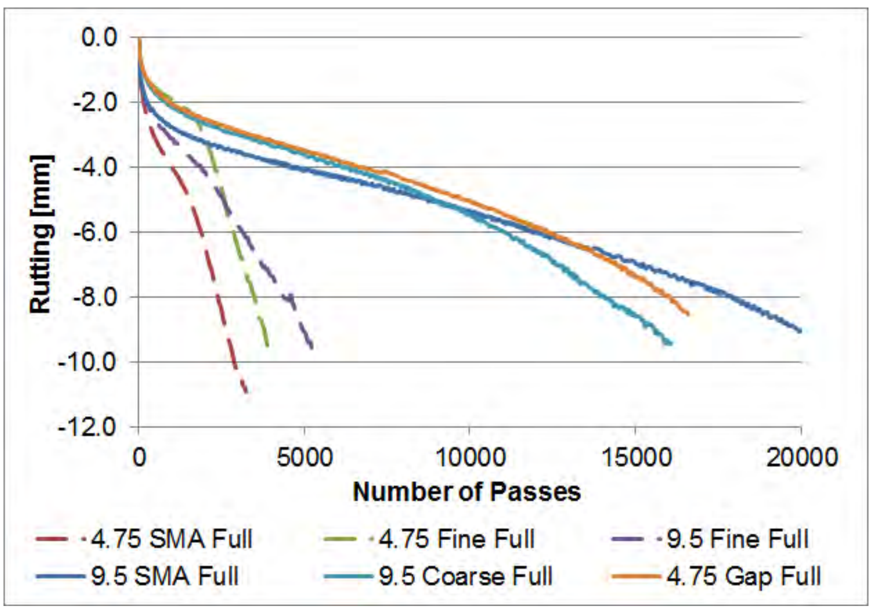

Figure 5.6. HWTT Results for the Six Different Candidate Gradations at Optimum Binder Content

2. The performance generally deteriorated at binder contents above and below the optimum.

3. At optimum binder content, three of the six mixtures that did well with the regular

HWTT specimens (9.5 SMA, 9.5 coarse, and 4.75 SMA/open) also did relatively better than the other three mixes with the thin specimens.

4. The most important observation here was that the three better performing mixes (9.5 SMA, 9.5 coarse, and 4.75 SMA/open) failed at load cyles that varied from approximately 4,500 to 6,500. This was much lower than the range observed for the three field mixes; two of these mixes experienced only 3 mm rutting and the third experienced 11 mm rutting at 20,000 cycles.

The last point above was particularly of concern, since top three laboratory mixture candidates did not perform as well as the field mixes under this test condition. This difference could be attributed to one or both of the following two reasons:

1. All three field mixes used some type of an anti-strip agent. Specifically, two of the mixes used a WMA agent that was enhanced to also serve as an anti-strip agent and the third mix used hydrated lime. For the thin specimens, two of the mixes did not show onset of moisture damage through a second inflection point in the HWTT results and third showed a very delayed onset of moisture damage (at about 12,500 cycles). Whereas, all six laboratory mixtures showed an early onset of moisture damage.

2. Two of the three field mixes used a PG 76 binder compared to the PG 70 binder used in all of the laboratory mixes. The third field mix that used a PG 70 binder also incorporated hydrated lime that could contribute to stiffening effect.

In order to investigate whether the above factors were the cause for the early failure of thin HWTT specimens, researchers conducted an additional set of tests using the three best candidate laboratory mixes. In the first round of tests, all three mixes were modified using a liquid antistrip agent at 1%. In the second round of tests, all three mixes were modified by using a PG 76-22 binder in lieu of a PG 70-22 binder. It must be noted that the mixes with the PG 76 binder were the same as the PG 70 binder with the exception of the binder grade. In other words, the mixes were not redesigned to accommodate any changes that may be due to the grade of the binder. Figures 5.11 and 5.12 present the results from these additional mixes. The comparative results between the HWTT and modified HWTT at optimum binder content for the six mixes in study are shown in the Figure 5.13. Figure 5.14 shows a summary of the modified HWTT results for the six candidate gradations. It can be observed from these figures that adding the liquid anti-strip agent was only marginally effective in improving the HWTT performance of the mixes. It is possible that the specific anti-strip agent used in this case was not effective with this particular binder-aggregate pair. On the other hand, changing the binder grade from PG 70-22 to 76-22 did substantially improve the HWTT performance of the three selected mixes. Although a combination of the additive and higher binder grade was not used in this case, it is very likely that this would further improve the HWTT performance of the mixes with thin specimens comparable to the field mixes.

In summary, based on these results, it is evident that the mixtures with more coarse aggregates performed better in the HWTT. It appears that the maximum aggregate size is less important. For example some mixtures with a 9.5 mm nominal maximum aggregate size performed well, while others did not, and the same held true for mixes with a 4.75 mm maximum nominal aggregate size.

In general, the mixes were found to have different responses under the stress state of the half inch mix layer on the polymer base when compared to the full-size specimen. For the fine mixes, the response was fairly similar, but the coarse mixtures showed a much longer life before rutting 12.5 mm. It is also important to note that the bond is critically important to the test conditions for the half-inch specimen. Without a strong bond between the asphalt mix and the polymer base, the mix will fail by stripping aggregates from the base.

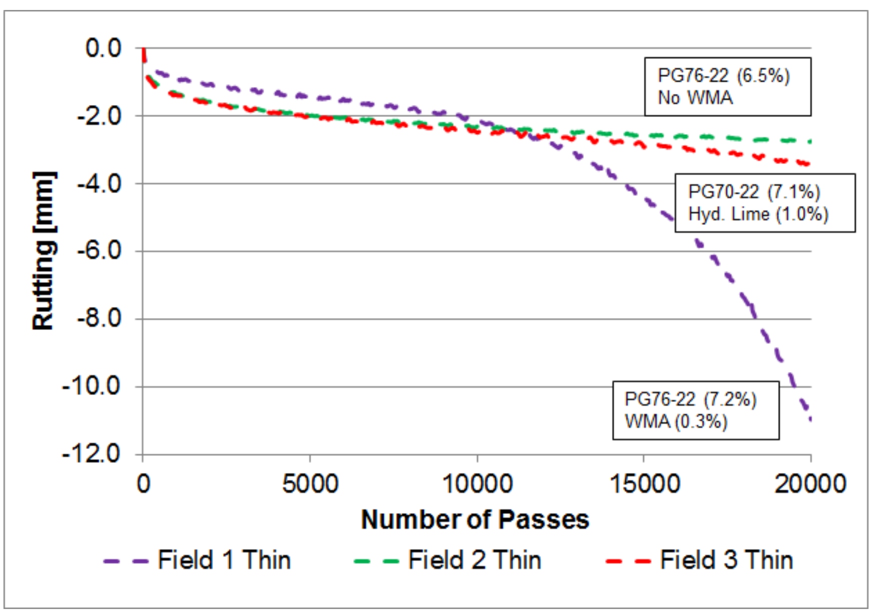

Figure 5.7. Modified HWTT Results for the Field Mixes

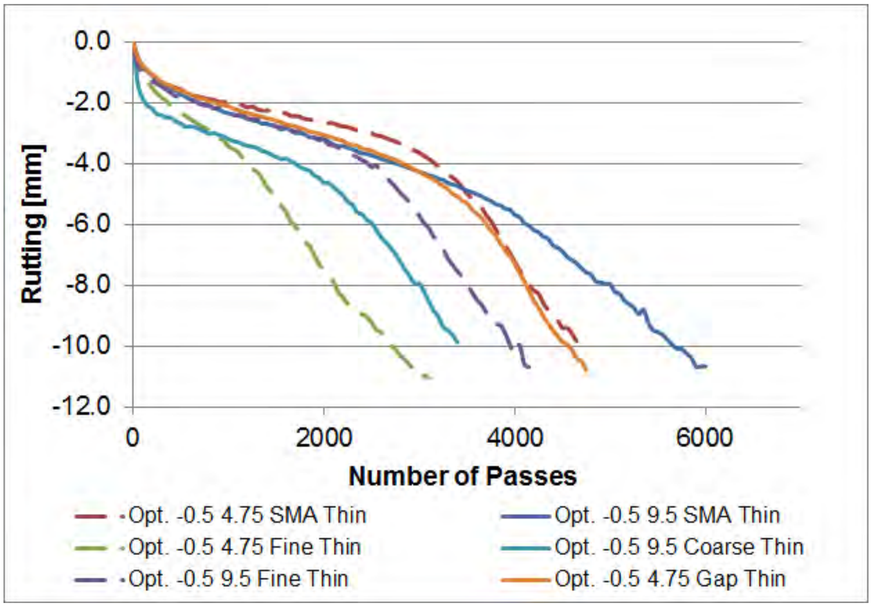

Figure 5.8. Modified HWTT Results for the Six Different Candidate Gradations at Optimum -0.5% Binder Content

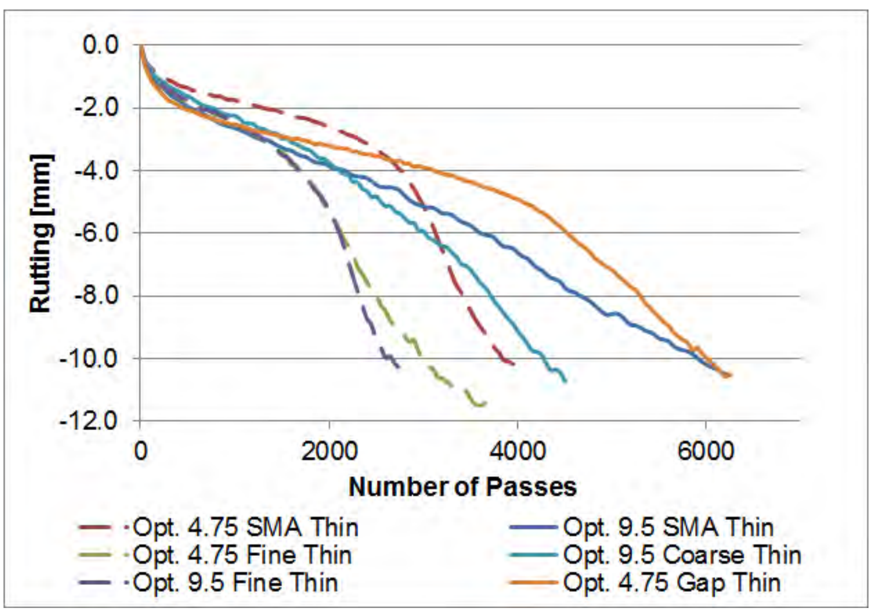

Figure 5.9. Modified HWTT Results for the Six Different Candidate Gradations at Optimum Binder Content

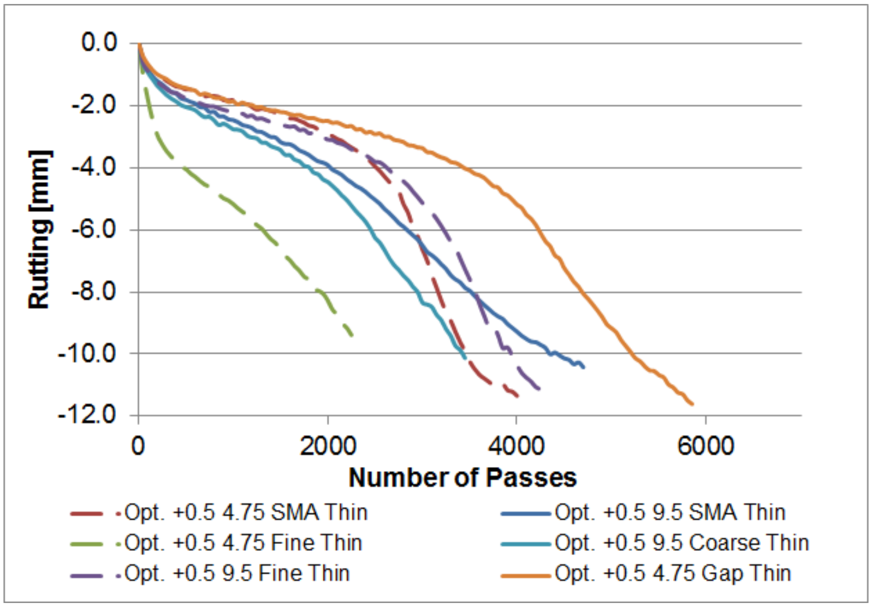

Figure 5.10. Modified HWTT Results for the Six Different Candidate Gradations at Optimum +0.5% Binder Content

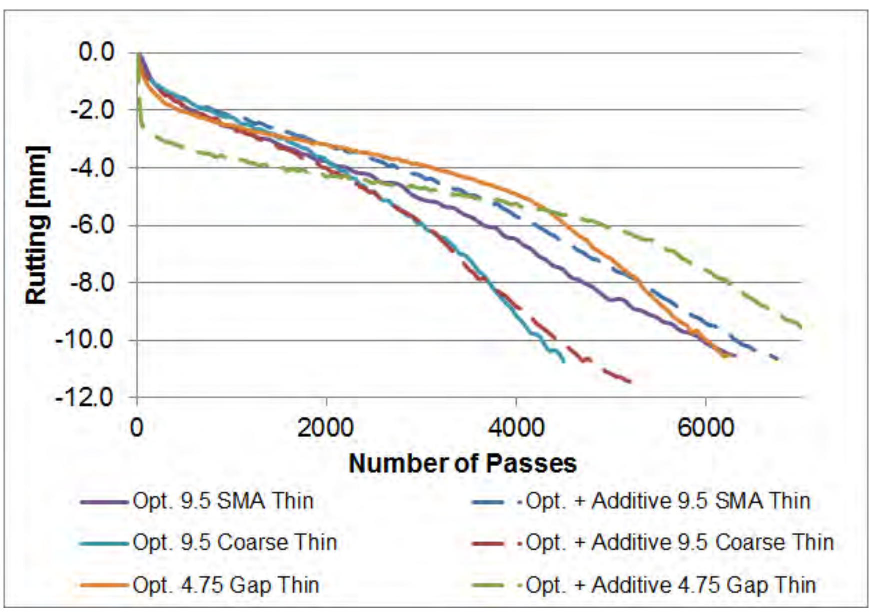

Figure 5.11. Comparison Modified HWTT Results for the Three Best Candidate Gradations at Optimum Binder Content and with Additive

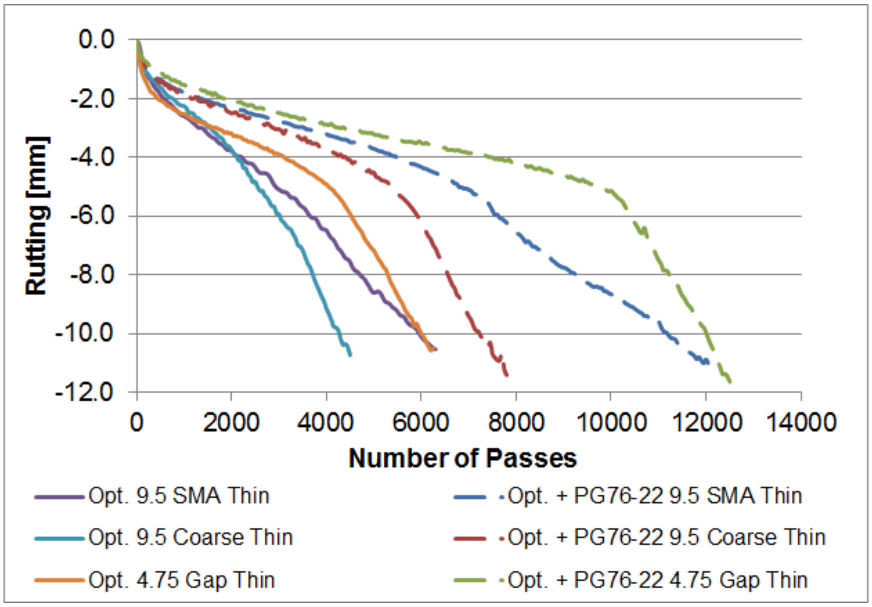

Figure 5.12. Comparison Modified HWTT Results for the Three Best Candidate Gradations at Optimum Binder Content and with High Quality Binder

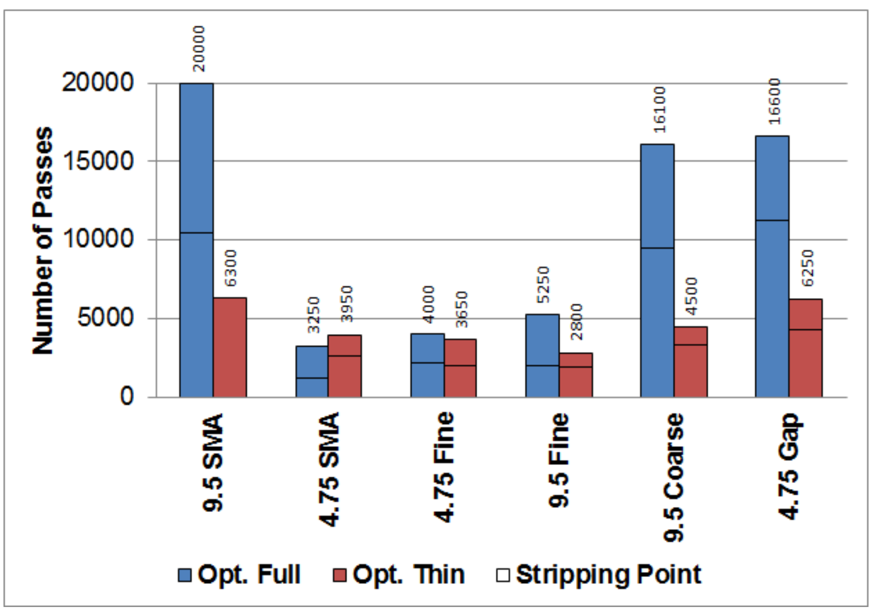

Figure 5.13. Comparison HWTT and Modified HWTT Results for the Six Candidate Gradations at Optimum Binder Content

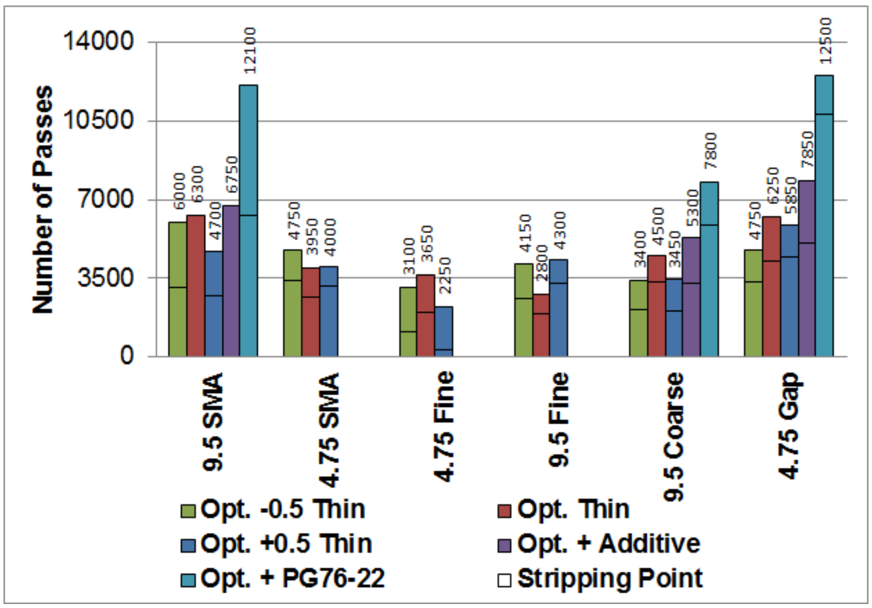

Figure 5.14. Resume of Modified HWTT Results for the Six Candidate Gradations

5.3.3 Overlay Test

The research team tested the three best candidate asphalt mixes using the overlay test (OT). The three chosen were the mixes that utilized mostly coarse aggregates (9.5 SMA, 9.5 coarse graded, and 4.75 SMA/open graded). This was based on the HWTT and TWPD performance of these mixes. Note that all three tests (HWTT, OT and TWPD) were being conducted simultaneously and the results from the HWTT and TWPD consistently and independently demonstrated that these three selected mixes were significantly better performing. Figure 5.15 shows the maximum load that each specimen endured in the overlay test. This load is always obtained on the first cycle of the test, as the specimen experienced fatigue damage throughout the test and loses its capacity to carry load as the test progresses. The results showed that at all mixes showed the best load-carrying capacity at their respective optimum binder content compared to similar mixes with more or less binder than the optimum.

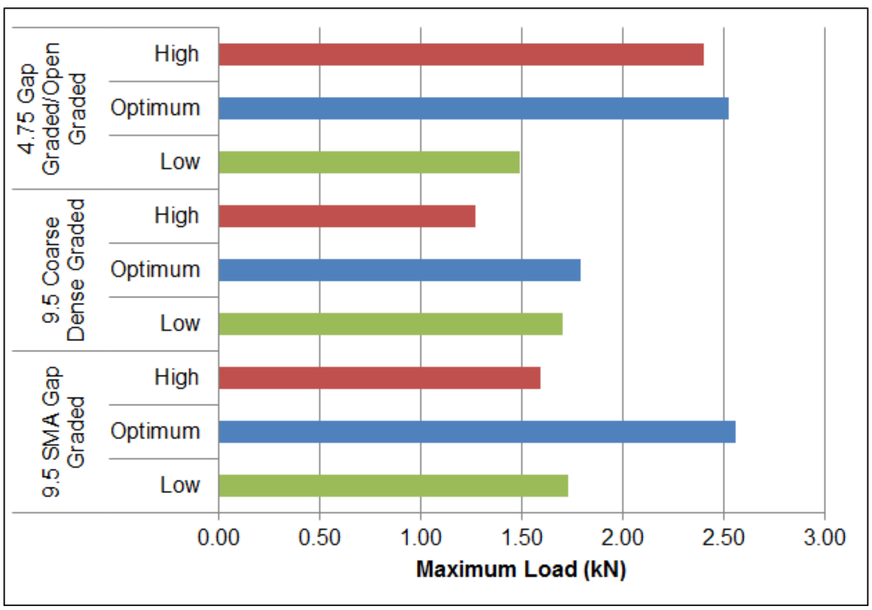

Figure 5.15. Maximum Load in Overlay Test for Coarse Mixes

Figure 5.16 shows the reduction in load from the first to last cycle in the test. It is important to note that every mix tested remained below 75% reduction in load. Typically, the percent reduction was greater at lower asphalt content; an increase in binder content corresponds with better fatigue life.

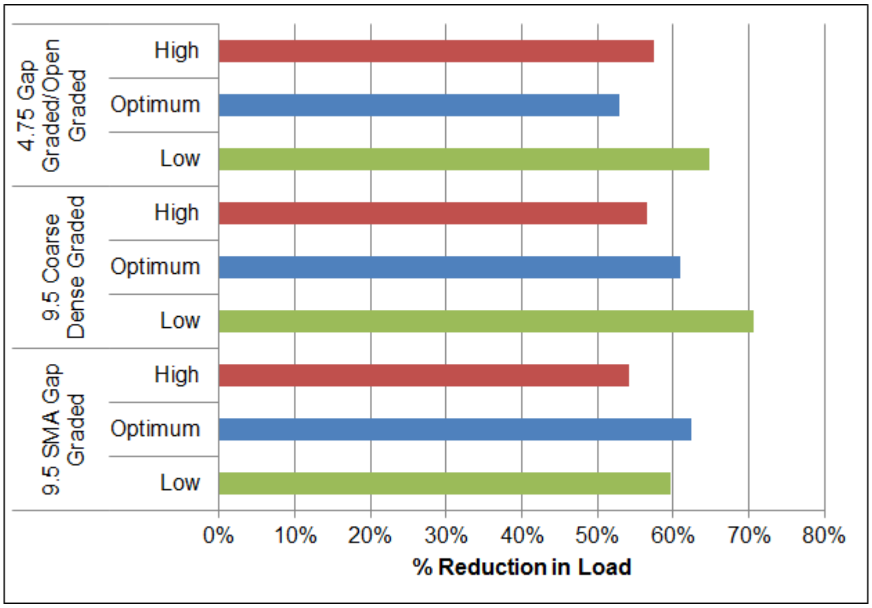

Figure 5.16. Percent Load Reduction over 1000 Cycles in Overlay Test for Coarse Mixes

5.3.4 Three wheel polishing device

The research team completed tests with the TWPD for all the field mixes, and the six mixture types developed in the laboratory at their respective optimum binder contents. Figure 5.17 shows the TWPD results for all the four field mixes.

For the six laboratory designed mixes, the performance of the mixes at their respective optimum binder contents was observed in the TWPD. If the performance was acceptable in terms of skid resistance, raveling, bleeding and rutting, then additional tests were performed at ±0.5% of the optimum binder content with the TWPD. Meanwhile, mixes that demonstrated poor performance at their optimum binder content in the TWPD were not tested at additional binder contents. Figure 5.18 to Figure 5.23 show the TWPD results for the six mixes selected at the different binder contents tested. Figure 5.24 shows the TWPD results for good candidate mixes at optimum binder content. For the coarse mixes, the best results for skid resistance (based on both the raw coefficient of friction and the change in coefficient of friction over the life of the specimen) were typically observed at the optimum binder content.

Furthermore, rutting measurements were obtained after the different set of cycles in the TWPD test. Figure 5.25 to Figure 5.28 show the rutting results for the six mixes selected at different the binder contents tested. Rutting was typically the best at the optimum binder content. For two of the three mixes, the optimum was the best, and for the third mix, rutting at the optimum, high, and low binder contents were all very close. For these two mixes, it was also observed that the performance of the mix with the high binder content was close to the performance at the optimum binder content. However, the performance at the lower binder content yielded much worse performance compared to the performance at the optimum binder content. In other words, the mixtures demonstrated to be more tolerant to an increase in the binder content rather a decrease in the binder content.

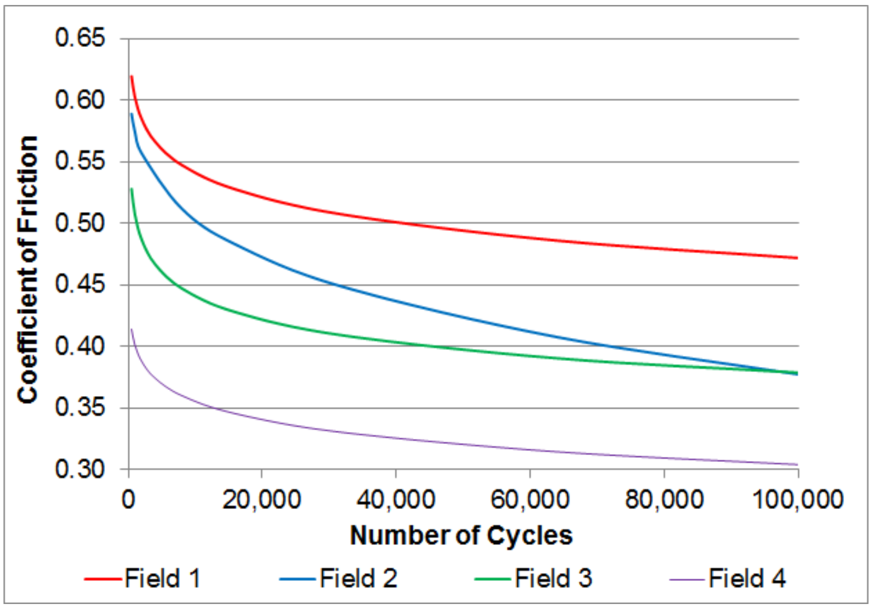

Figure 5.17. TWPD Results for Field Mixes

Finally, a visual inspection was also used to classify the performance of the mixes in the three wheel polisher over the life of the specimen from 0 to 100,000 cycles. The photos taken of each specimen can be found in Figures

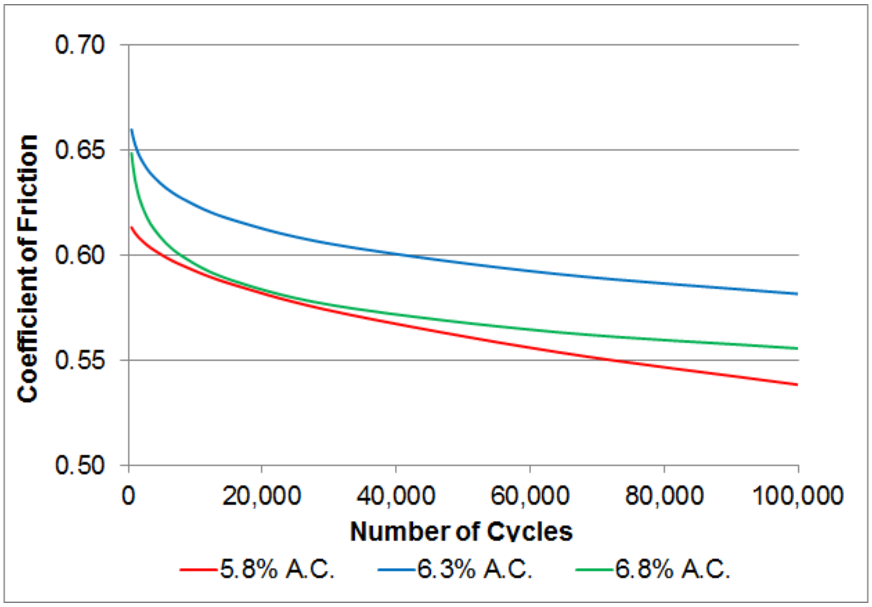

Figure 5.18. TWPD Results for 9.5 mm SMA Gap Graded Mix at Three Binder Contents

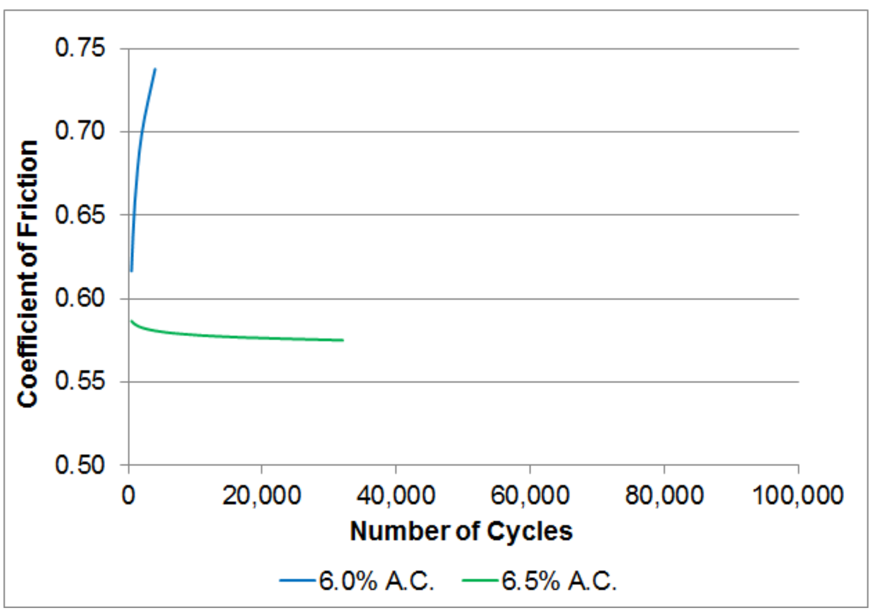

Figure 5.19. TWPD Results for 4.75 mm SMA Gap Graded Mix at Two Binder Contents

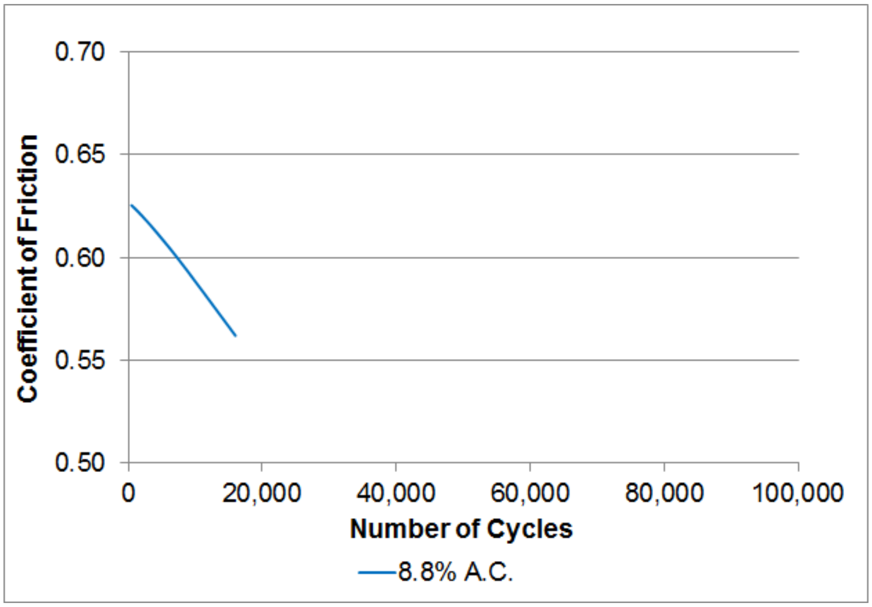

Figure 5.20. TWPD Results for 4.75 mm Fine Dense Graded Mix at One Binder Content

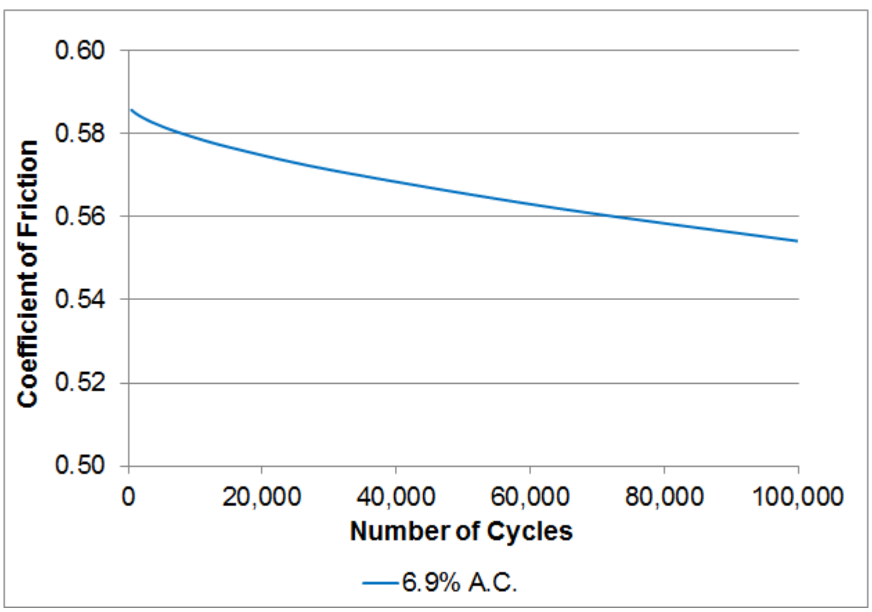

Figure 5.21. TWPD Results for 9.5 mm Fine Dense Graded Mix at One Binder Content

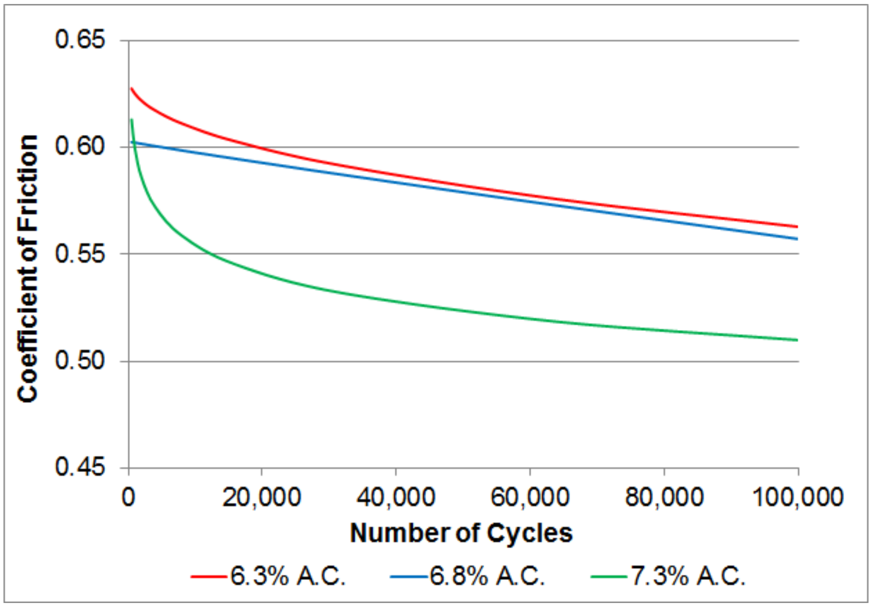

Figure 5.22. TWPD Results for 9.5 mm Coarse Dense Graded Mix at Three Binder Contents

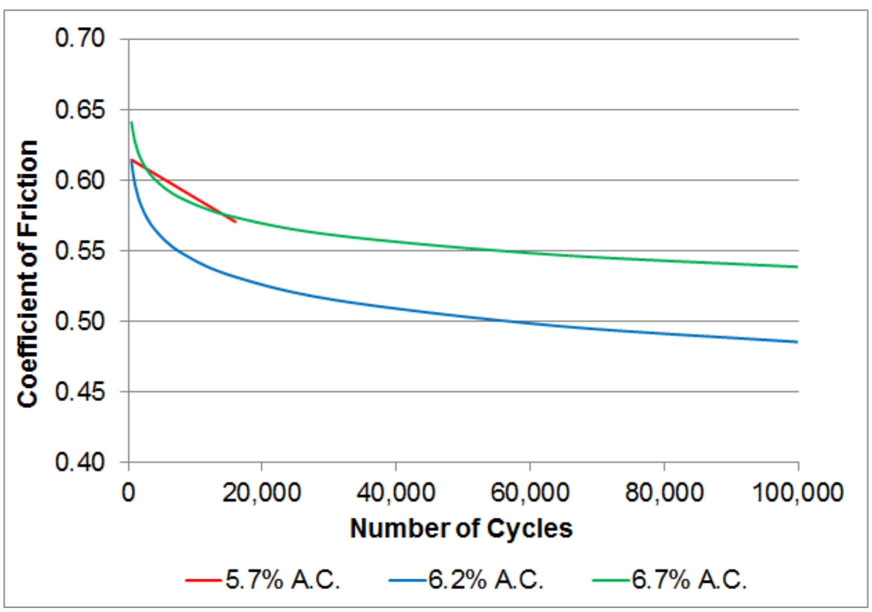

Figure 5.23. TWPD Results for 4.75 mm Gap Graded/Open Graded Mix at Three Binder Contents

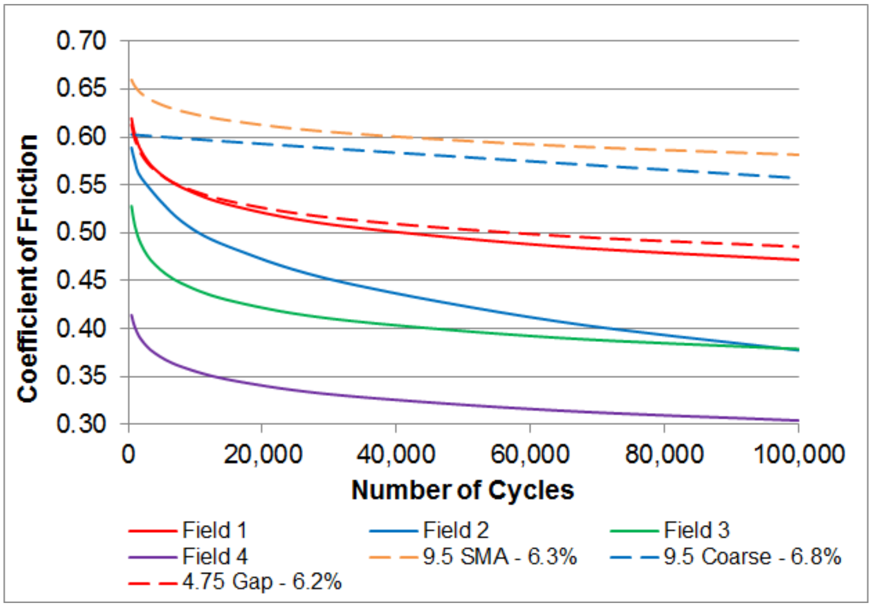

Figure 5.24. TWPD Results for Good Candidate Mixes at Optimum Binder Content

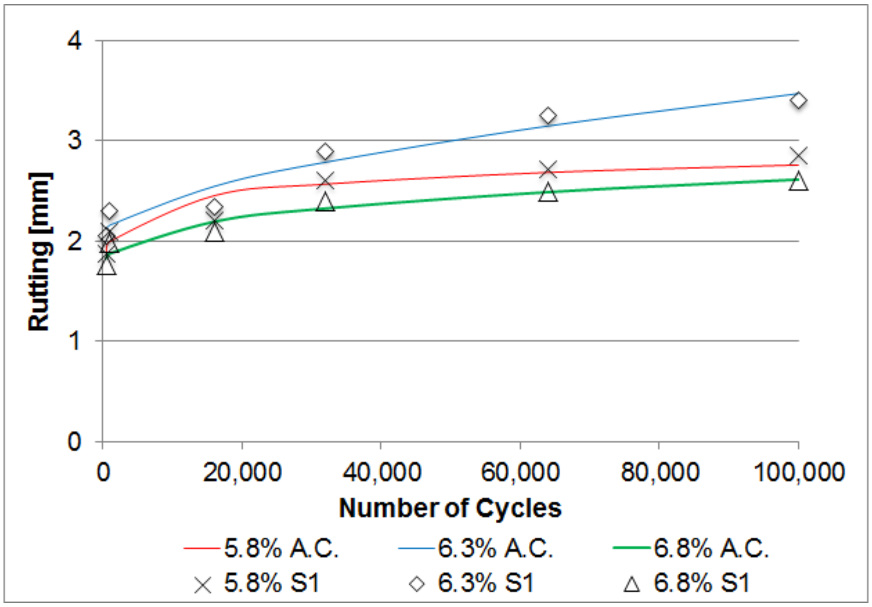

Figure 5.25. Rutting Results for 9.5 mm SMA Gap Graded Mix at 3 Binder Contents

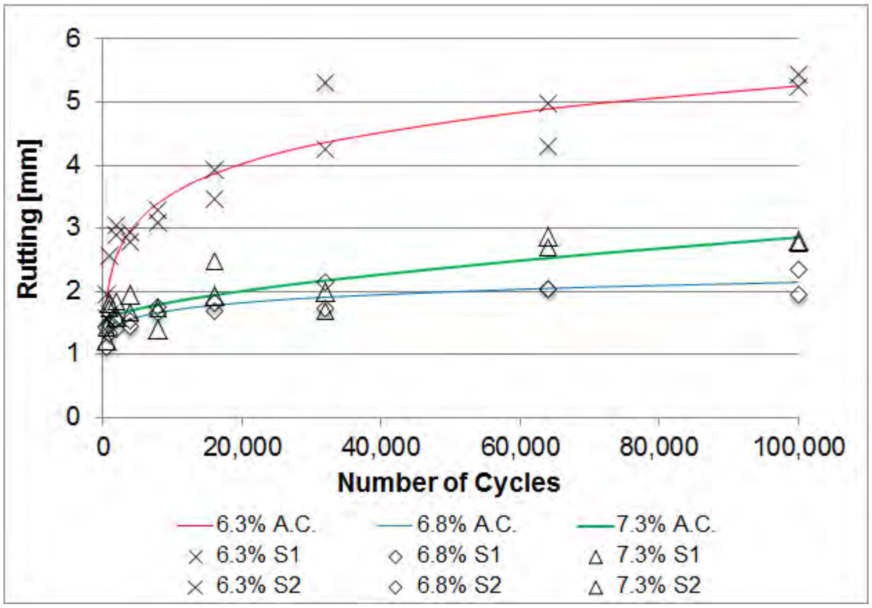

Figure 5.26. Rutting Results for 9.5 mm Coarse Dense Graded Mix at 3 Binder Contents

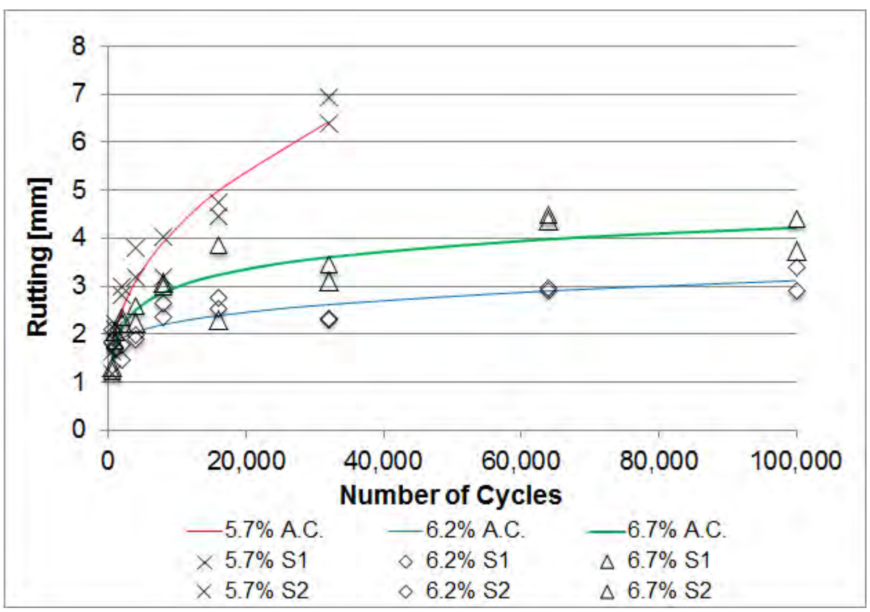

Figure 5.27. Rutting Results for 4..75 mm Gap Graded/Open Graded Mix at 3 Binder Contents

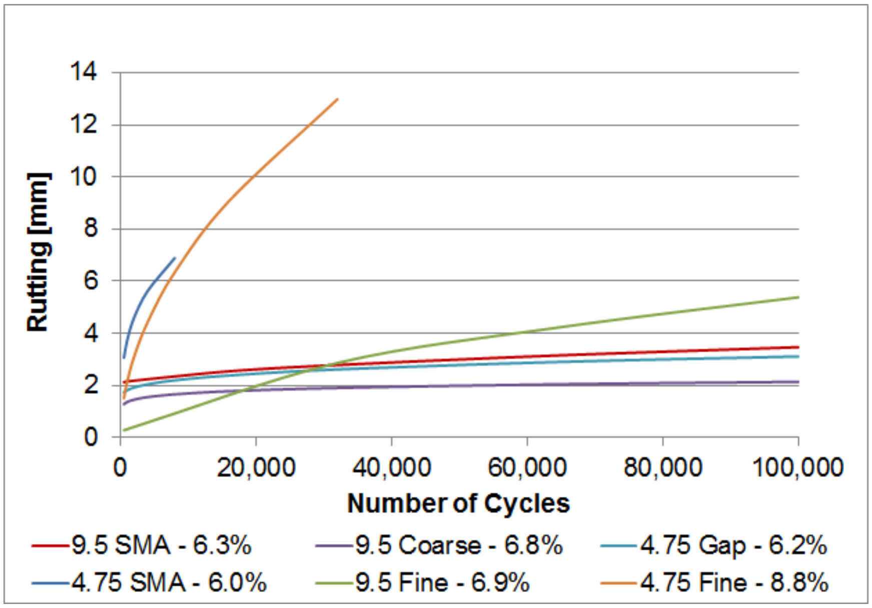

Figure 5.28. Rutting Results for the Six Different Candidate Gradations at Optimum Binder Content

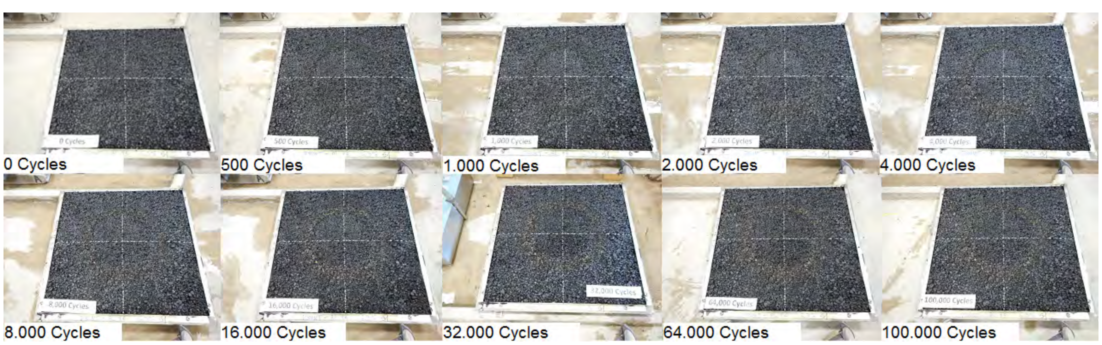

Figure 5.29. TWPD Photos for 9.5 mm SMA Gap Graded Specimen

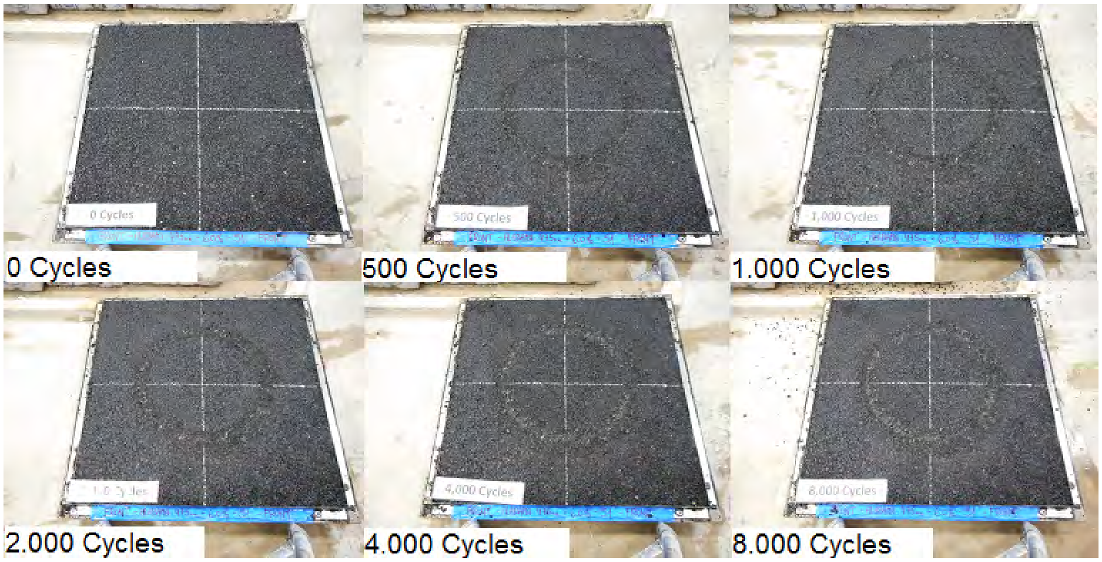

Figure 5.30. TWPD Photos for 4.75 mm SMA Gap Graded Specimen

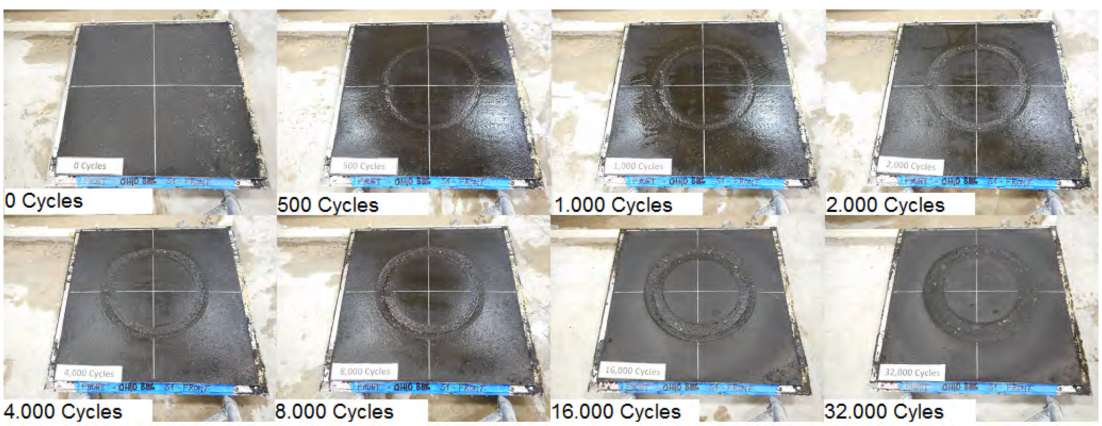

Figure 5.31. TWPD Photos for 4.75 mm Fine Dense Graded Specimen

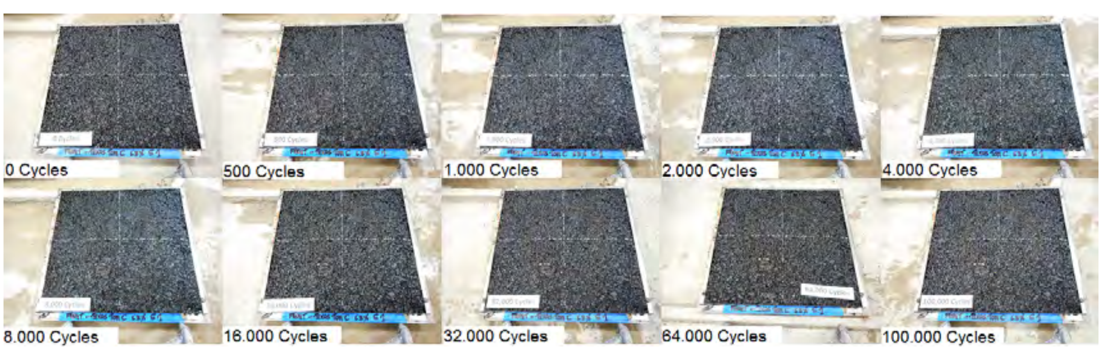

Figure 5.32. TWPD Photos for 9.5 mm Coarse Dense Graded Specimen

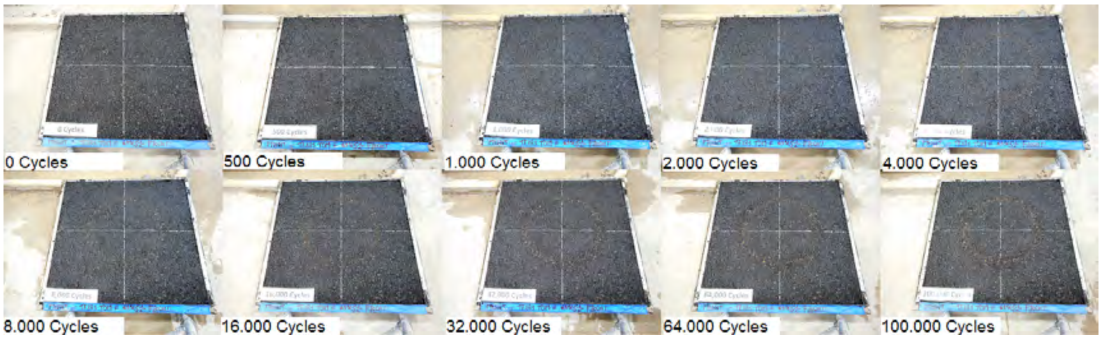

Figure 5.33. TWPD Photos for 9.5 mm Fine Dense Graded Specimen

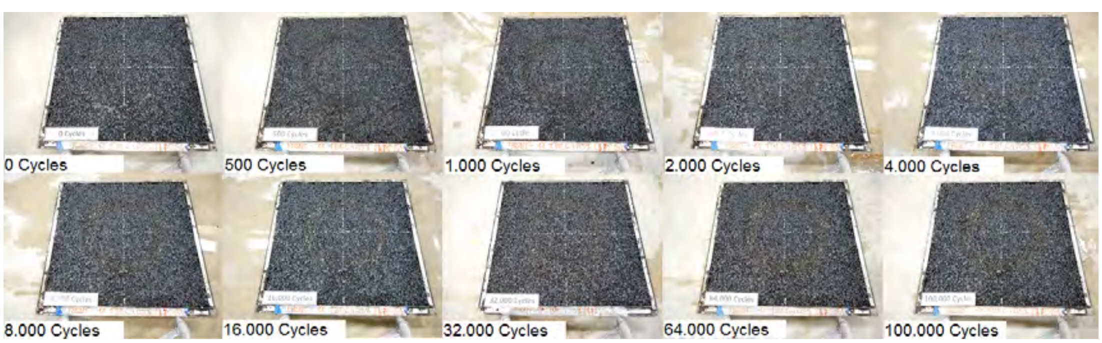

Figure 5.34. TWPD Photos for 4.75 mm Gap Graded/Open Graded Specimen

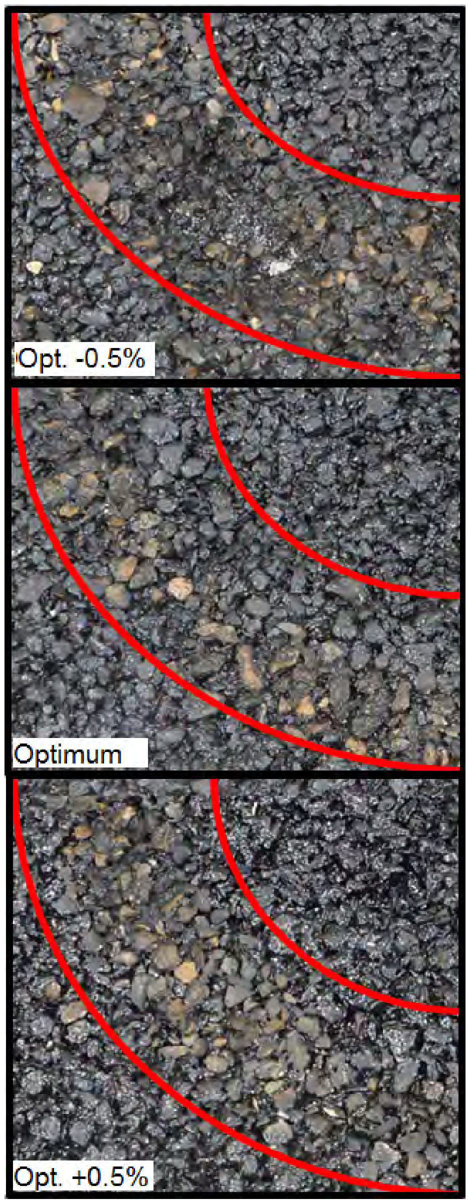

Figure 5.35. TWPD Photos for 9.5 mm SMA Gap Graded Specimen at the Last Set of Cycles

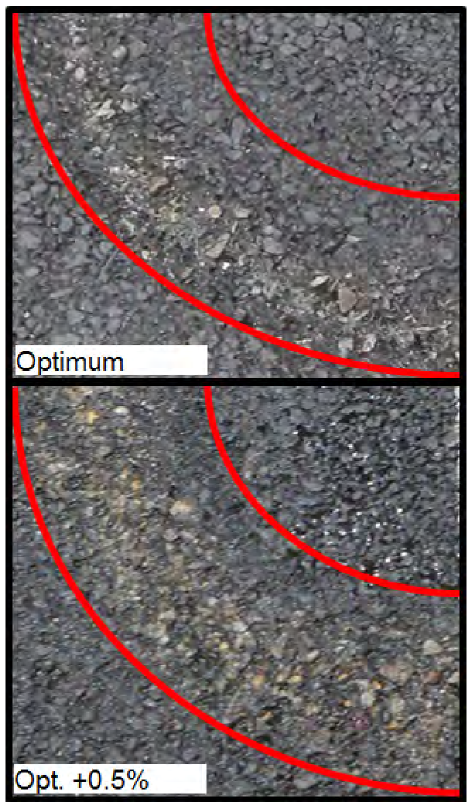

Figure 5.36. TWPD Photos for 4.75 mm Fine Dense Graded Specimen at the Last Set of Cycles

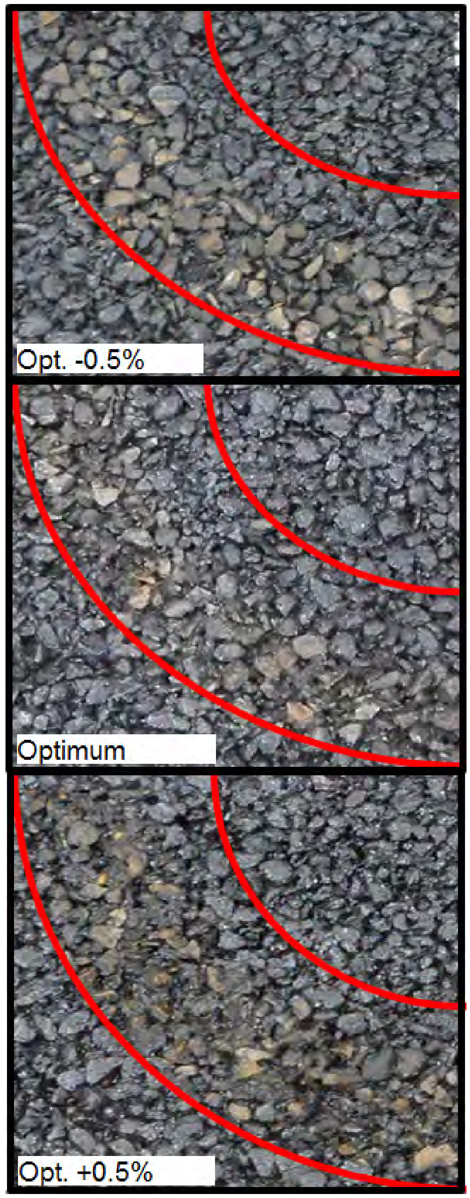

Figure 5.37. TWPD Photos for 4.75 mm Gap Graded/Open Graded Specimen at the Last Set of Cycles

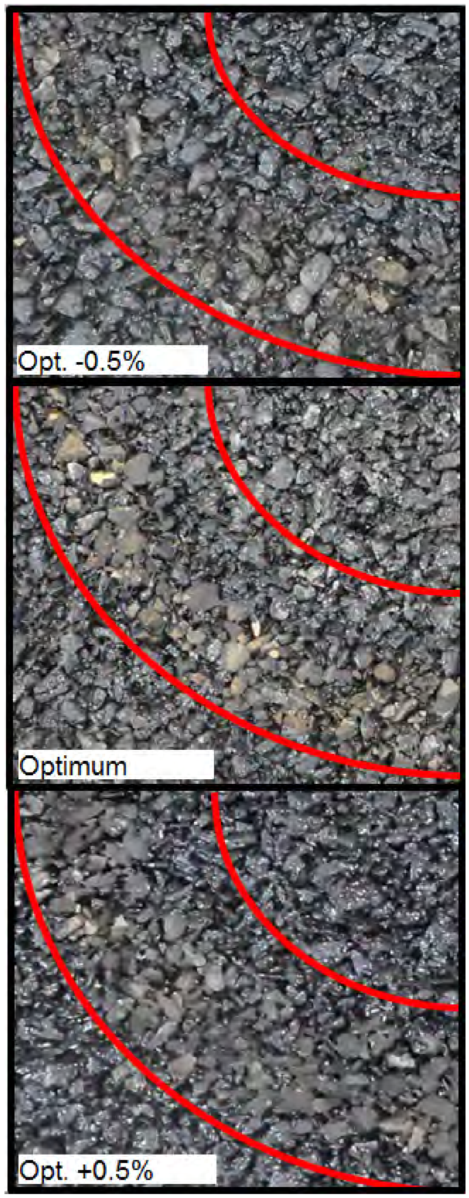

Figure 5.38. TWPD Photos for 9.5 mm Coarse Dense Graded Specimen at the Last Set of Cycles

5.4 SUMMARY

Six different mixture designs were developed based on a survey of different mixture types used all over the United States. The optimum binder content for all six designs was determined using the specifications described in Item 347 of TxDOT specifications. The performance of these six mixes was evaluated using a three wheel polishing device (TWPD), Hamburg Wheel Tracking Test (HWTT), and overlay test (OT). Results from all three tests indicate that the three coarse mixes performed substantially better than the three fine mixes irrespective of the maximum aggregate size. In addition, the optimum binder content determined using Item 347 was validated to result in optimal performance based on HWTT, OT and TWPD tests. Finally, the use of PG 76-22 binder may be preferred compared to a PG 70-22 binder. Although the latter showed comparable and similar performance to field mixes in the regular HWTT, it did not show similar performance when a thin specimen was used with the HWTT.

CHAPTER 6. SUMMARY

The main goals of this study were to: (i) explore the different possible aggregate structures that could be used to design a mix for application as an ultra thin overlay, (ii) identify and validate a volumetric mix design criterion to design such mixes using laboratory based performance indicators, (iii) identify requirements for the tack coat to be used with such mixes and ultra thin overlays, and (iv) demonstrate the life-cycle cost for such overlays compared to chip seals.

In order to achieve the aforementioned goals, a nationwide survey of aggregate structures that could potentially be used as an ultra thin overlay was conducted. Six different aggregate structures were identified and used in the remainder of this study. These mixes were used with a volumetric mix design criterion to determine the optimum binder content. Mixture specimens were prepared and performance tests at the optimum, as well as above and below this optimum content for each mix were conducted. These performance tests included Hamburg Wheel Tracking Device or HWTD, Modified Specimen HWTD, Overlay Tester, and Three Wheel Polishing Device - Direct Friction Tester or TWPD-DFT combination. Performance metrics included resistance to rutting, cracking, bleeding, and raveling while also maintaining a desirable level of skid resistance. In addition, four different field mixes were also used to benchmark the results from the performance tests. Skid resistance results from the mixes were compared to skid resistance of chip seals using data and correlations available from the existing literature for the latter.

Of the six possible aggregate structures evaluated in this study, the mixes with majority coarse aggregates behaved better than those with finer aggregates in the TWPD and HWTD tests. Three of the six candidate aggregate structures were ultimately deemed viable for use as an ultra thin overlay. Measurements of skid resistance show that mixes designed for ultra thin overlays had comparable, and in most cases better, performance when compared to equivalent DFT friction values obtained on seal coats from other studies. Although it may not be economically feasible in all cases, ultra thin can provide an alternative to seal coating with improved ride quality and noise characteristics. Finally, this study also demonstrated that the Three Wheel Polishing Device (TWPD) combined with Direct Friction Tester (DFT) is sensitive to differences in performance of the selected mixes in terms of raveling, bleeding, rutting and skid resistance and can be used on a routine basis to validate the performance of mixes designed for use in ultra thin overlays.

Recommendations from this study are condensed into a proposed specification and two standard test methods that accompany this research report. The first test method is for the use of the TWPD as a performance screening tool for design of mixes used in ultra thin overlays. The second test method is to evaluate the properties and acceptability of the tack coat used in an ultra thin overlay to bond with the existing pavement surface. Some of the aspects related to the proposed specification, such as the use of a PG70 binder, must be validated through additional field implementation studies.

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APPENDIX A.
HIGHLIGHTS FROM REVIEW OF ADDITIONAL LITERATURE RELATED TO THIN OVERLAYS

PERFORMANCE EVALUATION OF SUPERFLEX MODIFIED THIN ASPHALT OVERLAY

Problem or objective

To investigate the performance of the modified overlay mixture including high-temperature stability, moisture susceptibility and skid resistance. In order to investigate the effects of different thickness levels and structure patterns, four thin overlay sections were paved on route G321 in Guangdong, China

Application

The main advantage of this modifier(Superflex) is better cohesiveness and high-temperature Stability

Experiment and field application

N/A

Findings

15% Superflex was verified as the optimum modifier content for the minder selected in this study. The penetration, ductility, softening point and elasticity recovery rate of the mixed Superflex modified asphalt met the criterion of SBS I-D of China. In addition, viscosity satisfied the standard of modified asphalt in japan.

Other

Superflex modifier is a mixture of modified asphalt with natural dust particles. The Superflex modifier used in the study was produced in TMA Company in Indonesia.

Test setup

The wheel rutting test was used to examine the dynamic stability and the high-temperature stability of mixtures. Samples in triplicate were made to obtain friction coefficient, texture depth and water permeability so as to examine the skid resistance.

FIELD PERFORMANCE EVALUATION OF ULTRA-THIN WHITE TOPPING OVERLAY IN LOUISIANA

Problem or objective

The objective of this study is to evaluate the field performance of three in-service Ultra-Thin White topping (UTW) pavements constructed during 1999 to 2003 as a rehabilitation technology, by means of pavement management system (PMS) data.

Application

White topping overlay is used to address distress in HMA pavements such as rutting and shoving

Experiment and field application

N/A

Findings

The Pavement Performance Index (PPI) value generally decreased as the pavement age and Equivalent Single Axle Load (ESAL) increased. The pavement condition was fair, good, and fair for US167, US65, and US90 after 13.5, 9.4 and 10.2 years of service, respectively. The fair pavement condition for US 167 and US90 was mainly due to the relatively high International Roughness Index (IRI) and faulting values.

Other

Test setup

the pavement performance index (PPI) was used to represent the overall composite performance based upon longitudinal and transverse cracking, roughness, and patch data for rigid pavement. field performance of three UTW sections in Louisiana was monitored up to 13.5 years of service.

A STUDY EFFECTIVENESS OF THIN SURFACE TREATMENTS USING HAMBURG WHEEL TRACKING DEVICE (2011)

Problem or objective

The objective is to evaluate the performance of three types (1" HMA, Nova Chip and chip seal) of thin surface treatments in Hamburg Wheel-Tracking Device(HWTD) test.

Application

Thin surface treatments are applied to pavement to bring back to appropriate serviceability for road users.

Experiment and field application

N/A

Findings

pavements treated with thin surface treatments showed a high variability in the number of wheel passes to failure in HWTD test. 2 treated with Nova chip and one with 1" HMA, passed the criterion of maximum 20,000 wheel passes w/out exceeding the maximum rut depth of (20 mm). NOVA CHIP also also retarded stripping compared to control subjects. Air void was found to be a significant factor affecting the performance of thin surface treatments.

Other

N/A

Test setup

Hamburg Wheel Tracking Device following the Tex-242-F also tested for Gmb and Gmm

PERFORMANCE OF AN ANTI-ICING EPOXY OVERLAY ON ASPHALT SURFACES (2013)

Problem or objective

The primary objective was measuring the performance of an anti-icing overlay on asphalt surfaces

Application

Developed to fill the role of an anti-icing/anti-skid overlay

Experiment and field application

these overlay systems typically provide protection of the bridge deck while increasing skid resistance.

Findings

The thin-bonded overlay was shown to have a high initial MTD, which loses 13% of the overall overlay thickness after 9 months of service. Results from the BPT demonstrate that the thin-bonded overlay maintained a high level of friction with slight wear within the first year of service. All bond failures occurred within the asphalt-wearing surface. A slight decrease in chloride content was experienced after the thin-bonded overlay was installed. The overlay required regular intervals of deicing solution to be applied prior to and during winter storm events, particularly during storms with significant moisture. A decrease in the amount of deicing chemicals needed to prevent road surface icing was observed when compared with the control deck with no thin-bonded overlay. The installation cost for the overlay was slightly higher than other types of thin-bonded overlays; however, the thin-bonded overlay used in this study produced anti-icing capabilities.

Other

N/A

Test setup

Four different tests were performed before and at different times after installation to measure performance. Sand patch test, skid resistance test using portable skid tester, Bond strength, chloride content. Anti-Icing performance test

OPTIMIZED DESIGN FOR 4.75-MM NMAS SUPERPAVE MIX THIN OVERLAY (2011)

Problem or objective

The main objective of this research study was to evaluate performance of 4.75-mm NMAS Superpave mixes with varying river sand content and binder grade

Application

provide the optimized mixture design for a long-lasting ultra thin hot-mix asphalt(HMA) overlay using .4.75-mm NMAS Superpave asphalt mixture.

Experiment and field application

Can be applied in thin lifts for low- to medium-volume facilities

Findings

Rutting performance during the HWTD was aggregate specific.(effect of higher binder grade on rutting performance is inconclusive), The anti-stripping agent affected the moisture sensitivity test results and mixes without anti-stripping agent failed to meet the Tensile Strength Ratio (TSR) specified by the Kansas Department of Transportation. Optimized design combinations suggested limiting the river sand content in between 15% and 20% rather than 35% (current practice) for the Kansas 4.75-mm NMAS Superpave mixture.

Other

N/A

Test setup

AASHTO standard practice (R 35-4) AASHTO T27 AND T11, also used KDOT KT-50 HWTD(Tex-242-F), MOISTURE SUSCEPTIBILITY TEST (KT 56)

THIN WHITETOPPING FOR GREEN HIGHWAYS (2011)

Problem or objective

the objective of this study was to asses the behavior of 5-in, 6-in and 7.5-in thin whitetoppings on existing 5-in, 7-in, and 9-in AC pavements for different bonding conditions with the AC layer and existing AC moduli. The white topping responses for different temperature differentials were also assessed.

Application

can be used to reduce HEAT ISLANDS. The use of TWT will take out the factor out the warming caused by the concrete asphalt stone steel and other engineering materials that are responsible for these Heat Islands. TWT is also cost effective.

Experiment and field application

N/A

Findings

Whitetopping (TWT) has a higher albedo than Asphalt Concrete (AC). TWT needs much less maintenance than AC therefore it is cost effective. Curling stress increases with the increase of TWT thickness. AC thickness, modulus and bonding conditions does not influence curling stress. service life of TWT is mostly affected by the interface bonding conditions between TWT and AC especially for smaller TWT thickness. BONDED TWT have higher service life than unbonded ones. thickness of existing AC pavement significantly affects TWT life whereas existing AC condition does not have much effect. for UNBONDED condition, thicker TWT is recommended.

Other

N/A

Test setup

Finite Element Model, each pavement was modeled as a 3 layer pavement system. They used model meshing and model loading

PERFORMANCE OF ULTRA-THIN BITUMINOUS OVERLAYS (2014)

Problem or objective

The main objective of this study was to evaluate field performance of Ultra-Thin bonded bituminous surface (UBBS) projects

Application

to improve Roughness, rutting, transverse cracking, and fatigue cracking and the distresses in the future.

Experiment and field application

N/A

Findings

in Kansas, pavements treated with ultra thin bonded bituminous surface (UBBS) had a high variability in service life. The majority served 6 years. UBBS reduces pavement roughness, transverse and fatigue cracking one year after treatment, but consistent improvement was not observed after the UBBS treatment. A sharp drop-off in effectiveness in mitigating transverse and fatigue cracking is observed after a couple of years in service. service life, cumulative traffic and existing pavements thickness do not significantly affect the progression of distresses. This may indicate that UBBS can be used on pavements with a wide variety of thickness and traffic.

Other

N/A

Test setup

Distress data needed was obtained from the Pavement Management Information System (PMIS) database, one of the three parts of Pavement Management Systems (PMS), maintained by KDOT. Data was retrieved for rehabilitated UBBS projects in Kansas.

FLOWABLE FIBROUS CONCRETE FOR THIN CONCRETE INLAYS (2011)

Problem or objective

The main objective was to construct reasonable slab sizes and crack widths while ensuring economic feasibility.

Application

this was developed to be placed rapidly in a thin layer and provide a high cracking resistance and residual load capacity for the thin inlay system

Experiment and field application

A full-scale thin overlay project was created to demonstrate and observe the placement of this material and to monitor the cracking and bonding performance of the hardened concrete pavement.

Findings

with the aid of a slightly higher cementitious content, superplasticizer, and smaller maximum aggregate size, the mixture was workable enough to be easily constructed as a thin inlay with only external vibrations. The flowable fibrous concrete (FFC) mixture was tested in the laboratory and found to provide superior residual capacity and fracture toughness properties far above the requirements for Ultra-Thin whitetopping (UTW) design

Other

N/A

Test setup

"The initial performance was measured from full-scale inlay sections of the FFC mixture at 5 cm thick on a milled asphalt pavement. Different slab sizes ranging from 1.2 to 3.3m were constructed in the full-scale sections. The longest slab sizes produced the earliest and widest cracking at the joints, with the joints cracking before day one also residing as the largest crack widths measured at later ages. The sections predominantly exhibited good interfacial bonding between the asphalt and concrete. De-bonding was only found in locations where debris remained at the interface from insufficient milling and cleaning"

ALTERNATE USES OF EPOXY ASPHALT ON BRIDGE DECKS AND ROADWAYS (2014)

Problem or objective

This paper describes the problems faced and solved with epoxy asphalt surfacings on various projects other than the dense-graded wearing courses on orthotropic decks, and discusses the potential application epoxy asphalt in roadway pavements.

Application

Epoxy asphalt in roadway pavements

Experiment and field application

Airfield and port pavements where high strength, durability and chemical resistance are essential needs. Thin dense-graded overlays on concrete bridge decks to provide waterproofing and skid resistance. The surfacing of the San Francisco Oakland Bay Bridge in the U.S. used this system that has remained in service since 1976. Epoxy asphalt chip seals approximately 10 mm thick applied on orthotropic steel decks in the shop before installation of the deck system on the bridge for use as a long lived (up to 10 years) temporary wearing surface prior to paving. This method has been used on the orthotropic steel deck replacement of the old concrete decks of the Golden Gate Bridge in the U.S. and the Lions Gate Bridge in Canada. Either field or shop applied 25-35 mm thick dense graded first layer used as a permanent waterproofing and stiffening layer for orthotropic steel decks to be surfaced with a sacrificial wearing surface. The Ben Franklin Bridge in Philadelphia in the U.S. paved in 1984 is an example. Open graded overlays on concrete bridge decks or roadways with severe skid problems to eliminate hydroplaning. Severe skid and hydroplaning problems on an area of the San Francisco Oakland Bay Bridge were eliminated with this treatment. Long-lived wearing courses for high priority strategic roadways. Thi

Findings

Other

N/A

Test setup

different roadways in bridge decks were analyzed

DESIGN AND LABORATORY EVALUATION OF SMALL PARTICLE POROUS EPOXY ASPHALT SURFACE MIXTURE FOR ROADWAY PAVEMENTS (2014)

Problem or objective

The objective of this study is to design a small particle porous epoxy asphalt (SPPEA) mixture and evaluate in the laboratory its pavement surface related performance, including high tempera- ture stability, low temperature crack resistance, moisture resis- tance, friction, and permeability.

Application

to increase the durability of pavement surface with porous asphalt mix- tures, a small particle porous asphalt mixture modified with epoxy resin

Experiment and field application

N/A

Findings

Small particle porous asphalt mixture modified with epoxy resin can be designed to possess excellent performance desired for pavement surface functions, including permeability, friction, moisture resistance, and resistance to high temperature deformation and low temperature cracking.

Other

N/A

Test setup

N/A

THIN HMA OVERLAYS IN TEXAS: MIX DESIGN AND LABORATORY MATERIAL PROPERTY CHARACTERIZATION (2008)

Problem or objective

The overall objective of this project is to provide TxDOT with balanced design methodologies for very thin overlays that provide acceptable resistance to rutting, cracking, and wet weather skid resistance.

Application

to provide better roadways using the optimum binder and construction methods for HMA (thin overlays)

Experiment and field application

N/A

Findings

It was very problematic, in particular, for the limestone mixes to attain the 98 percent target density at 50 gyrations. Also, while some mixes barely passed the OAC verification procedure at 93+/-0.5 percent density, satisfactory results were, in almost all cases, obtained at 96+/-0.5 percent density. CAM SS 3109 specification seems to be satisfactory for the thin overlay aggregates, including the gradation characteristics. In general, high quality clean (no dust) SAC Class A aggregates with low soundness value (< 20 percent), such as the granite and sandstone, exhibited superior laboratory performance based on the Hamburg and overlay tests. Additionally, it is also proposed that such aggregates have a reasonably low WAC of preferably less than 2 percent. This low WAC helps in minimizing asphalt-binder absorption

Other

N/A

Test setup

HWTD

DESIGN AND PERFORMANCE EVALUATION OF VERY THIN OVERLAYS IN TEXAS (2009)

Problem or objective

The main objective was to overlook Performance Evolution of 5 different highways (thin overlays)

Application

N/A

Experiment and field application

US 59 (Timberland Drive) in Lufkin: there is one small area at the beggening of the project about 250 ft long where the deflections are high, and there is one bad joint near 3,000 ft from the beggening. the rest looked good. Therefore, this is a good thin overlay to use. PumPhrey Drive in Fort Worth: The overall Performance of this thin HMA overlay is very good. Loop 20 at international Drive in Laredo: The only problem with the mix was that it did not meet t he overlay tester requirement of 750 cycles (lasted 678). in this case the district decided to waiver the 750 requirement most overlay was placed at .75 inches US 281 in Marble Falls, Austin: The optimal asphalt content was found to be 7.4%, this passed both the HWTD and the overlay tester requirements. US90 San Antonio: Asphalt content of 6.8% PG 70-22 binder with 1% lime, this design lasted more than 1000 cycles in the overlay tester and rutted 6.4 mm after 15,000 passes of the Hamburg.

Findings

Other

N/A

Test setup

N/A

GEORGIA'S EVALUATION OF SURFACE TEXTURE, INTERFACE CHARACTERISTICS, AND SMOOTHNESS PROFILE OF MICROMILLED SURFACE (2009)

Problem or objective

This paper presents the scope and the findings of research for evaluating the micromilling done in conjunction with 15.6 miles of PEM overlay on I-75 south of Macon.

Application

N/A

Experiment and field application

Micromilling is designed to to produce a more uniform and smoother milled surface and finer milled surface texture than that of conventional milled surfaces. It is also estimated that the estimated cost savings for the construction project describe in the paper was $58,000 per lane mile compared to the conventional millinhg.

Findings

"Micromilling must produce the milled surface with the RVD of surface texture at a 1.6 mm milling accuracy and requiring corrective actions when the RVD exceeds 3.2 mm projects considered for this process should be carefully evaluated for suitability (the bottom layer should be in good condition) the ULIP was used for determining the RVD depths of the micromilled surfaces along the milling direction, ratios for MPD values in the perpendicular and diagonal directions to that in the milling direction varied between 1.03 and 1.45, with an average of 1.21 No slippage failure was occurred on all of the PEm surfaces of this project 7-9 months after construction "

Other

N/A

Test setup

RVD, roughness test for slippage

FULL-LANE COVERAGE MICROMILLING PAVEMENT-SURFACE QUALITY CONTROL USING EMERGING 3D LINE LASER IMAGING TECHNOLOGY (2014)

Problem or objective

This paper explores the possibility of using emerging three-dimensional (3D) line laser imaging technology to develop a full-lane quality control method that can measure Ridge-to-valley-depth (RVD), provide quality control covering a full lane, and identify problem areas.

Application

N/A

Experiment and field application

You can apply RVD when you are micromilling to have quality control and and identify problem areas.

Findings

"Results show that this method can be use, 3D range data can be used to measure RVD's with an error less than .4mm in repeated runs. Results show that the RVD's derived the 3D range data can effectively differentiate between smooth and rough -milled surface textures. In the case of the I-95 test the rough section is 4.8mm and the smooth section is only 1.1 this shows that the RVD on rough sections has a larger variation "

Other

N/A

Test setup

N/A

GUIDELINES FOR USING PRIME AND TACK COATS (2005)

Problem or objective

The objective of this study was to produce a prime and tack coat guide publication for project development and field personnel to provide decision-making guidance on how to use, when to keep and when to eliminate prime and tack coats.

Application

N/A

Experiment and field application

The purpose of tack coat is to ensure bond between the existing pavement surface and a new pavement surface.

Findings

"For optimum application rates use the formula volume of material at delivered temp = (AR*A) / (9sft/sqyd*M), where: AR= application rate at 60F in gal/sqyd of material (cutback or asphalt emulsion), A= area of test section (length * spray bar length) in sft, M= multiplier for correcting volumes to the basis of 60 degrees F as shown in tables 12 for cutback and 13 for asphalt emulsions"

Other

N/A

Test setup

N/A

PRESERVING GEORGIA PAVEMENTS WITH MICROMILLING (2014)

Problem or objective

In this research we will replace the previous friction course with the new mix called Porous European Mix by the use of micromilling

Application

This helps avoid the poor bonding between PFC and milled surfaces and the entrapment of water that penetrates through the PFC in the valleys created my milling.

Experiment and field application

N/A

Findings

"Georgia has saved over 11 million dollars and after 4-7 years of in service, both projects I-75 and I-95 have shown good performance. Variable depth micromilling provides the required surface texture with out sacrificing milled surface texture and smoothness LRP can measure both surface texture and smoothness on micromilled surfaces and can serve as a tool for quality acceptance and performance measurement."

Other

N/A

Test setup

N/A

MICROMILLING ON I-285 (2011)

Problem or objective

In this research we will replace the previous friction course with the new mix called Porous European Mix by the use of micromilling

Application

This helps avoid the poor bonding between PFC and milled surfaces and the entrapment of water that penetrates through the PFC in the valleys created my milling.

Experiment and field application

N/A

Findings

No reports were found since it is still very recent

Other

N/A

Test setup

N/A

PROJECT ON I-285 IN METROPOLITAN ATLANTA.

Problem or objective

To show the successful experiences of developing and implementing the new method of microsurfacing.

Application

Micromilling is a promising pavement preservation option for PFC's that have sound underlying pavement structures.

Experiment and field application

N/A

Findings

"The new method has an estimated savings of $4.7 millionand pavements are still in good condition the project achieved Georgia Dots surface texture and smoothness requirements with variable depth micromilling"

Other

N/A

Test setup

Acceptance testing, new performance indicator (RVD)

A SUSTAINABLE AND COST-EFFECTIVE PAVEMENT METHOD: MICROMILLING AND THIN OVERLAY (I-95) SAVANAH, GEAORGIA (2010)

Problem or objective

To show the successful experiences of developing and implementing the new method of microsurfacing

Application

Micromilling is a promising pavement preservation option for PFC's that have sound underlying pavement structures.

Experiment and field application

N/A

Findings

"The new method has an estimated savings of $5.7 million and pavements are still in good condition the project did not achieve the requirements: scabbing of the OGFC ocurredthin, weakly bonded layers remained in place- because a single milling depth had been specified"

Other

N/A

Test setup

acceptance testing, new performance indicator (RVD)

TACK COAT GUIDELINES IN THE STATE OF CALIFORNIA

Problem or objective

guidelines to get optimum tack coat mixture for the specified project.

Application

A tack coat is a very light application of asphaltic emulsion or asphalt binder to an existing pavement surface or between layers of hot mix asphalt. A tack coat is used to ensure a good bond. Some require a flush coat (fog seal and sand cover)

Experiment and field application

if applied correctly the spray can provide a great bond between an existing pavement or HMA to a new one.

Findings

the spray is best applied when the nozzles are alined correctly and they have no room for imperfections. The surface has to be extremely clean in order for it to stick to the existing pavement and act as a good interbonder

Other

N/A

Test setup

This paper does not provide test set ups.

TACK COATS FOR ASPHALT PAVING (2013)

Problem or objective

The objective of this study was to evaluate the practice of using tack coat through controlled laboratory simple shear tests and determine the optimum aplication rate.

Application

N/A

Experiment and field application

It can create better bods and interlocking between the new pavement and the existing pavements

Findings

Tests indicated that the tack coat asphalt or modified tack coat asphalt emulsions has higher shear strength values compared with the cutback asphalt: improvement in bond strength dependant on application rate, viscocity and temperature. The shear resistance at the interface increased significantly with an increaser in the application rate and decreased with an increase in temperature. the tack coat asphalt emulsion bond strength at low viscocity has slightly improved in shear strenght value compared with high viscocity.

Other

N/A

Test setup

Shear strength test.

EXPERIMENTAL INVESTIGATION OF TACK COAT FATIGUE PERFORMANCE: TOWARDS AN IMPROVED LIFETIME ASSESSMENT OF PAVEMENT STRUCTURE INTERFACES (2010)

Problem or objective

This paper focuses on investigating the bonding fatigue performance between two asphalts concrete (AC) layers

Application

N/A

Experiment and field application

improve interlocking of the tack coat and the new pavements to improve the lifetime of the roads

Findings

Results from both the oligocyclic and fatigue tests show very low scatter. Each testing temperature (10 and 20 degrees C) a power law leads to a very good corralation between applied shear stress and number of loading cycles to failure, this allowed them to to plot both the oligocyclic and the fatigue tests together and were corralated through a power law. at 10 deg. C the tack coat leads to a decrease in bonding fatigue performance, this means that at this temp., applying a tack coat improves interface fatigue shear performance

Other

N/A

Test setup

Double Shear Test (DST)

NEW PROCEDURE TO CONTROL THE TACK COAT APPLIED BETWEEN BITUMINOUS PAVEMENT LAYERS (2013)

Problem or objective

in this research a new method for analyzing the tack coat applied on site is developed, while considering correlations among the tack coat dosages used, the percentage of emulsion absorbed by the selected geotextile and the contact6 surface, and the macrotexture of the bottom layer.

Application

Optimize the amount of tack coat applied to achieve proper bonding between the pavement layers

Experiment and field application

the control device could be used to cooralate the percentage of emulsions absorved by the geotextile with the macro-texture values of the surface and the amount of emulsions in charge of the bond between layers. The correlations found in the results can be used to establish the proper amount of binder to apply according to the macro-texture of the layer and the percentage of bitumen included in the emulsion. Once the corralation is established, the control device can be used to control that the adequate emulsion previouosly calculated is finally spread on layer surface.

Findings

The percentage of emulsion absorbed by the geotextile is highly related to the surface macro-texture of the samples where the emulsion is applied. The tack coat dosage applied is another important factor related to emulsion absorbed by the geotextile. For all surface macro-texture ranges, the geotextile absorbs less emulsion for a dosage of 250 g/sqm of residual bitumen. The highest percentage of emulsion absorbed is obtained for the dosage of 500 g/sqm for the samples with lower content of surface voids, while for the samples with higher macro-texture values, the highest percentage of emulsion absorbed is obtained for the dosage of 375 g/sqm. the type of emulsion applied had minimal influence on the results, being practically ruled out for further analysis.

Other

N/A

Test setup

ophitic filler tests, bulk density and porosity tests,

INFLUENCE OF SURFACE MACRO-TEXTURE AND BINDER DOSAGE ON THE ADHESION BETWEEN BITUMINOUS PAVEMENTS LAYERS (2011)

Problem or objective

This paper studies the influence that the surface macro-texture of the layers may have on the adherence strength of a tack coat

Application

To have the optimum roughness needed for best interlocking of the tack coat and the existing macro-surface

Experiment and field application

N/A

Findings

In this paper different dosages between different bituminous mixtures were analyzed using shear tests, leading to the conclusion that the optimal application range varies from 250 to 500 g/sqm. the influence of the surface macrotexture of different types of asphalt mixtures on the bond between layers was studied. it was found that the maximum values of shear strength are obtained for a rough texture of .17 mm and a dosage of 250 g/sqm.

Other

N/A

Test setup

sand circle test (similar), bulk density of mineral dust in toluene, mineral dust voids in dry compacted samples

ACRP COMMON AIRPORT PAVEMENT MAINTENANCE PRACTICES (2011)

Problem or objective

To observe how slurry seals and micro surfacing is done in airport roadways

Application

Fine milling can improve pavement smoothness and pavement friction

Experiment and field application

smoothness is improved by milling of existing pavement features such as bumps, stepping,(faulting) at transverse cracks, and rutting. If the pavement has sufficient structural capacity, the reduction in thickness is not of concern

Findings

Surveys were done in several airports who used this type of technology and most rated the the slurry seals as very good or good performance

Other

N/A

Test setup

N/A

APPENDIX B.
DEVELOPMENT OF A DIRECT SHEAR TEST SETUP FOR TACK COAT

Development of Tack Coat Direct Shear Test Setup

EXECUTIVE SUMMARY

To improve the adhesive bonding between existing and overlay layers, a layer of tack coat is applied between the two asphalt layers. Bituminous and emulsified asphalt are the two general types of the tack coats which contractors are allowed to use in USA. The slippage due to the applied horizontal load is the most important distress, which can significantly deteriorate the service life of new placed overlay. The absence of tack coat in between the two layers lead to separation and slippage. Also, use of very strong tack coat may also lead to separation between the two layers due to brittleness at lower temperature. Slippage damages the structural integrity of the pavement, reduces the ride quality, and increase the risk of water penetration. Therefore, measuring the bonding strength provided by a tack coat needs to be evaluated and is the focus of this technical memorandum. A laboratory test setup (direct shear test) was developed for evaluating shearing strength of various tack coats. Rather than using asphalt mixtures on top and bottom, two cylindrical synthetic specimens were manufactured and tested to identify and minimize the influence of friction between synthetic specimens.

The new direct shear test method, developed in this study, was used to analyze the cohesion properties of different tack coats at different application rate, and the effect of the compaction on the final bonding strength between layers was also evaluated. Six different tack coats (PG 64-22, PG 70-22, SS-1h, CRS-2, CQS-1ht, and Ultrafuse), two different application rate (0.03 and 0.05 gal/yd^2), and two different preparation method (without and with clamp pressure) were evaluated. Application rate for emulsified tack coat are based on the residue amount which means that 0.03 gal/yd^2 and 0.05 gal/yd^2 of residues was used for evaluating emulsified tack coats.

The test results show different cohesion characteristics provided by different tack coats, application rates, and compaction pressure significantly influence bond strength and the laboratory results will be used in future tasks to identify suitable tack coat type.

INTRODUCTION

Tack coat is application of bituminous liquid asphalt or asphalt emulsion between existing layer and overlay. Poor interface shear strength between two asphalt layer is the main reason to have slippage distress in overlaid pavements. Especially where vehicles accelerate or decelerate, lack of adhesive bonding between layers results in layers' separation. Therefore, quality of tack coat as an adhesive between two layers provides a better contact and service life. Figure 1 shows a typical tack coat distribution truck.

The quality of tack coat has been studied by various researchers to find and analyze all different factors that can affect the adhesive bonding strength between two layers. Mohammad et al. [2002] used 6 different tack coats with four different rates of application at two different temperatures to examine the effect of these three factors in the final interface shear strength. Tashman et al. [2006] evaluated the effect of surface treatment, curing time, residual application rate, and coring location on bonding strength between layers for tack coat type CSS-1. Salinas et al. [2013] observed the construction factors effects on field performance of four different tack coat materials like different methods of cleaning the existing surface (broom and air blast), different paving procedure (spray paver and regular paver) and different existing layer surface conditions (smooth or milled surface). Recently, TxDOT conducted research on several trackless tack products that have come to market in Texas (TxDOT study 0-6814). The researchers recommend adopting the DSR tackiness test and track-free time test to qualify trackless tack materials. The researchers also recommend adopting the shear bond strength test. However, bond strengths from field samples were considerably lower (15–95 psi) than for lab-molded samples (100–200 psi) and varied among different overlay projects.

Figure 1 - Tack Coat Distribution truck [Tashman et al, 2006]

Although various tests have been developed to identify the quality of bond strength between two layers, the test results are typically masked by the friction provided by the aggregates of the two layers and compaction effort during construction. In general, the magnitude of frictional bond strength (induced to aggregate texture and compactive effort) is significantly higher than the shear strength provided by the tack coat, which leads to erroneous conclusions and reluctance in using it as an acceptance criterion. In addition, the friction offered by the two layers will also depend on mix types, aggregate abrasion, etc. Therefore, the evaluation results for one specific tack coat could be different based on the different textures of aggregate and aggregate skeleton. Developing a standard procedure to evaluate the quality of tack while minimizing the effect of aggregate's friction characteristic in measured shear strength seems to be necessary and is the focus of this task.

REASERCH OBJECTIVES

The objective of this task was to develop a test method that can efficiently identify quality of tack coat that is suitable for use especially for Ultra-Thin overlays.

TEST PROCEDURE

A typical direct shear test device, developed by Soil Tests, Inc., commonly used by geotechnical engineers to obtain soil shear strength was modified for use in this study. The modified device with different components is shown in Figure 2.

The modifications include: replacement of load and deformation measuring dial gauges with load cell and linear variable differential transformer (LVDT), specimen holding mold, and a data acquisition system. The horizontal shearing load (0.25 in./min.) and vertical load application system was maintained the same. To measure the applied horizontal load, load cells manufactured by Futek, Inc. were utilized. Three different load cell types were used in this study 0-50 lbs (0-23 kg), 0-500 lbs (226 kg), 0-2,000 lbs (907 kg) and 0-5,000 lbs (2,268 kg). The reason for selection of such a range was that the measured strength varied depending on the tack coat type, application rate and compaction method. A LVDT (model no Schaevitz MP-2000) was used to measure horizontal deformations.

The shear box developed is made of aluminum and has a 2 in. (50.8 mm) thick bottom plate and a 3 in. (76.2 mm) thick upper plate. It has the capability to test 4 in. (101.6 mm) as well as 6 in. (152.4 mm) diameter specimens. Figure 3 shows closer view of the developed shear box. Four leveling screws are placed on the corners of the upper plate of the shear box to provide a gap between the shearing plates. Circular solid synthetic cylindrical specimens of 4 in. (101.6mm) diameter and 2 in. (50.8 mm) thickness were used for evaluating tack coat quality. The cylinders are machined smoothly to provide a frictionless surface. The acquired data is then imported in an Excel sheet for further analysis and identification of peak failure shear strength. These specimens used instead of asphalt mixture in order to remove the effect of friction on the final results.

To perform test, 1.764 ounce of tack coat is placed in the oven at 325˚F for 2 hours to make sure that the emulsifying agent evaporated completely [AASHTO T59, Mohammad et al. 2002] from the tack coat. After two hours of baking, the color of tack coats turns completely black. Figure 4 shows the brown SS-1h before putting in the oven and its black residue which rubbed on the lower specimen's top surface uniformly. Two different residue rate of application (0.03 gal/yd^{2}and 0.05 gal/yd^2) were used to cover the top surface of lower specimen. Then, the upper specimen is immediately placed on the top of the tack coat surface.

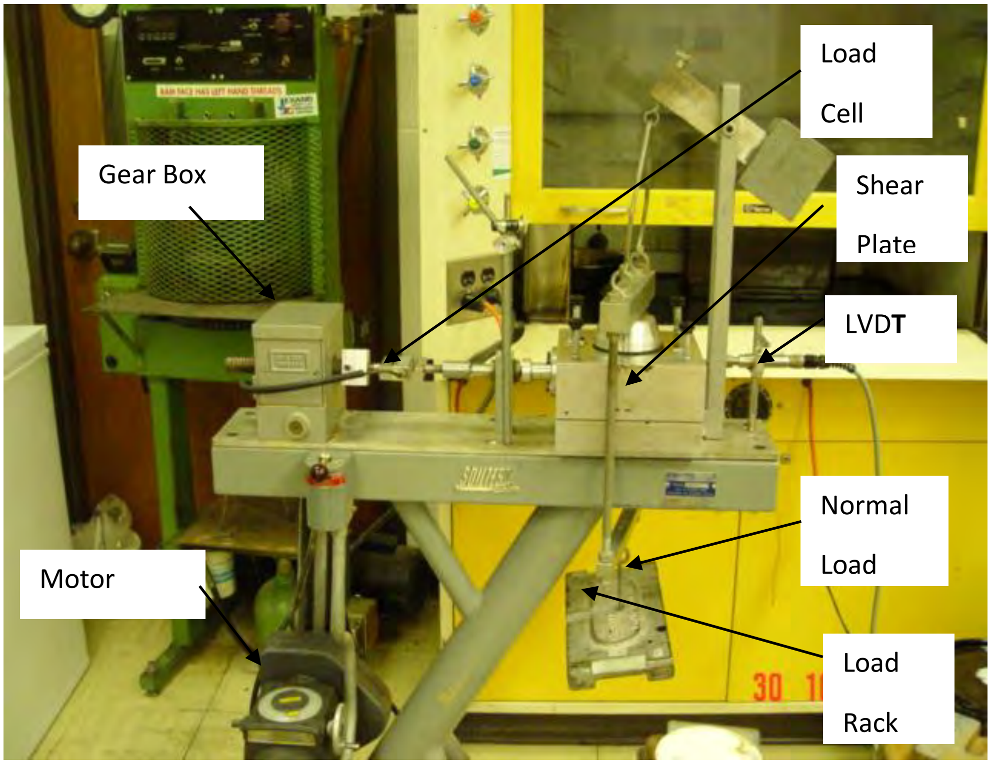


Figure 3 – UTEP Direct Shear Test Setup

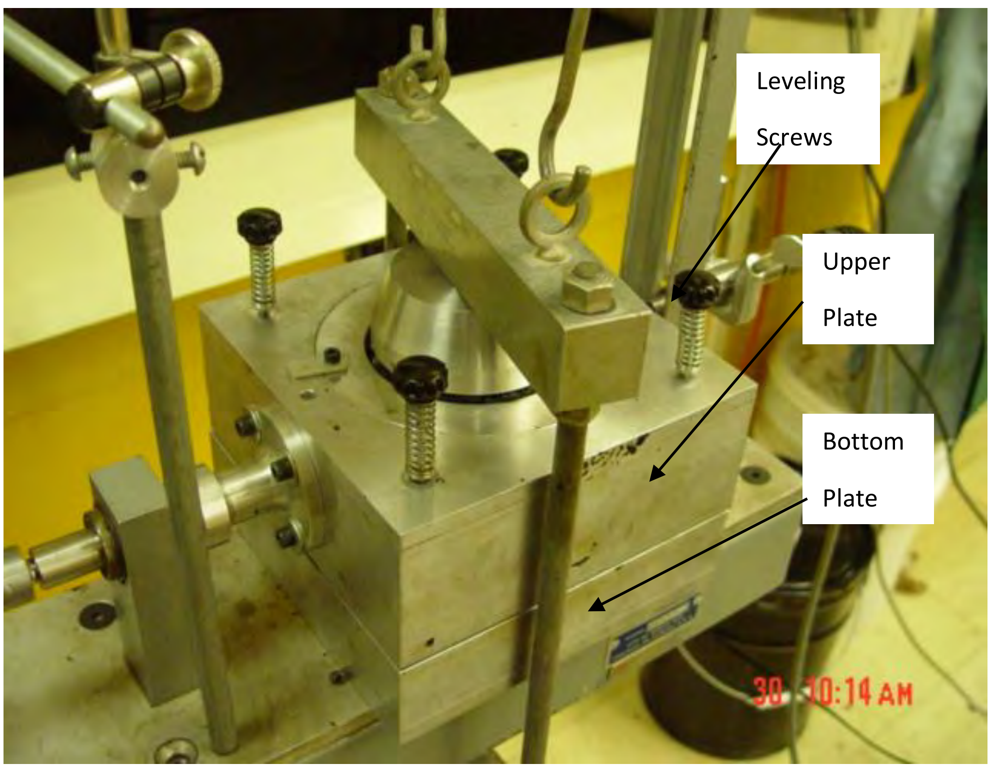


Figure 2 - Shear Box for the UTEP Direct Shear Apparatus

(a) **Brown SS-1h before baking**

(b) **Black SS-1h after baking**

Figure 4 - Influence of Baking on Color of Emulsion

In addition to tack coat application rate, two levels of compaction efforts were placed to simulate field condition. In one scenario, a 20 lbs of weight (1.5 psi) was placed on the top surface of the upper specimen (Figure 5a) and left it for three days at room temperature (77˚F). As the specimens surfaces are totally smooth and the hot tack coats are very slippery materials, some of the testing needed to be performed again due to sliding at the interface of the specimens. To mitigate slippage and simulate different compaction force, a 20 psi pressure was applied using clamp's, as shown in Figure 5b. It is assumed that application of 20 psi clamp pressure simulated compaction effort applied during construction. However, application of pressure expelled the tack coat out of the interface, which reduced the testing in some cases to only one rate of application (0.03 gal/yd^2). Any amount higher than 0.03 gal/yd^2 resulted in expulsion of tack coat material.

Direct Shear tests are typically performed by varying the normal stress, and Mohr-Coulomb failure criterion is used to obtain shear strength (ASTM D3080). For each increment of normal stress, the peak shear strength is recorded and a plot similar to the one shown in Figure 6 is developed. The normal stresses (σ) are plotted on the x-axis and the corresponding maximum shear strength (τ) is plotted on the y-axis. To identify relationship between shear and normal stress, a best fit line is generated. The τ-intercept of the best fit line is termed as cohesive strength of soil 'c', and the slope of the line is termed as the friction angle 'ϕ'.

(a) 20 lb Static Load **(b) 20 psi Static Compression**

Figure 5 – Two Methods of Simulating Field Compaction

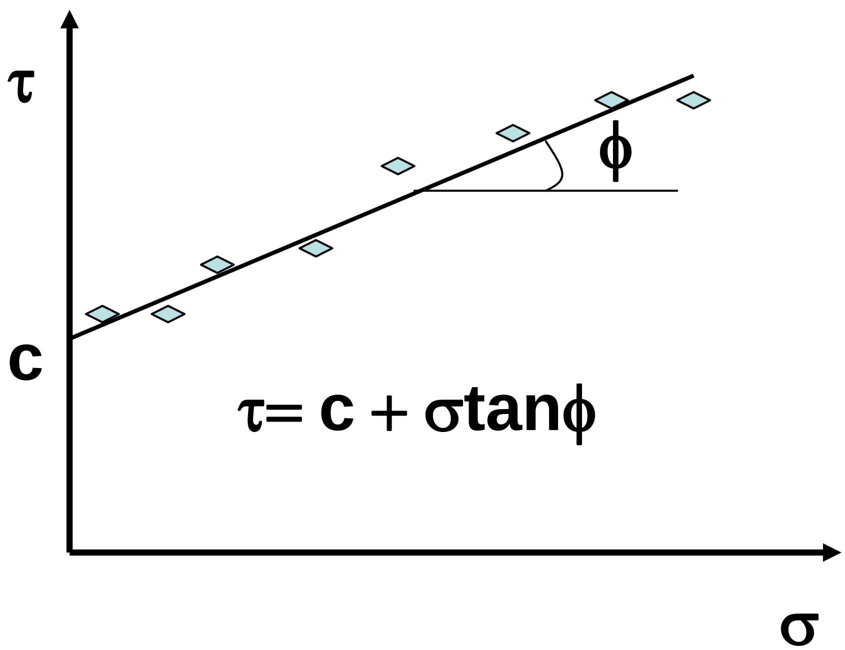


Figure 6 – Typical Results from a Series of Direct Shear Tests

To identify the cohesion as well as frictional resistance component of the shear strength, the following equation is used $\tau = c + \sigma \tan\phi$ where τ is the shear strength, c is cohesion, σ is normal stresses and ϕ is the angle of friction. In the case of tack coat testing, the c value is the cohesive strength of applied tack and $\tan\phi$ is the frictional resistance offered by the two layers.

Using specimens with very smooth surfaces, the frictional resistance by two layer will be negligible and the generated fit line is anticipated to be almost horizontal, thus, the acquired angle of friction would be very small. In this way, the results obtained from this test will provide cohesive strength of the tack coat without the influence of frictional component.

For evaluation of test setup, seven tack coat types commonly used in Texas were selected: two emulsions (SS-1H, CRS-2), two performance-graded asphalt binder (PG64-22, PG70-22) and three trackless tack coats (Trackless A, B, and C). Trackless A (CQS-1HT) is an emulsion, which has brown to black color and pH of 2.1-4. Trackless B (NTSS) is anionic and having a 0-20 penetration base asphalt. Trackless C (Ultra-fuse) is modified tack by blending stiff base binder with specialized additives and polymers. The emulsions SS-1H, CRS-2, Trackless A and Trackless B were recovered through the method of AASHTO T59 (ASTM D6934) before testing to evaluate residual properties.

RESULTS AND DISCUSSION

In order to minimize the effect of the friction on the direct shear test results, the synthetic specimens should have smooth surface. To make sure that the surfaces are smooth enough, the direct shear test was done with the specimens without any tack coat material. The test results showed significant increase in failure load with increase in normal stresses indicating that the interface of two layers is not frictionless. To minimize the friction, the synthetic specimens were machined further and a similar test was performed and the second set of results indicated reduction in friction. After second machining, the variation in maximum shear load for three different normal loads (18, 36, and 72 lbs) was less than 6 lbs (0.5 psi failure shear stress), as shown in Figure 7. This means that the surfaces of the specimens are very smooth and the contribution of the friction to the final results is minimal. Therefore, the results of the tests with tack coat materials would be only related to the cohesion of the tack coat materials based on their type, rate of application, and compaction pressure.

Assuming that the normal stress as the only variable, in direct shear testing of two layer of asphalt mixture with tack coat in between, the maximum shear stress (shear stress at the failure point) increases with increase in normal stress. This is because of the increased friction level results in higher amount of normal stress. For instance, as it can be seen at Figure 8, for SS-1h with 0.05 gal/yd^2 rate of application with 1.5 psi of compaction pressure, the maximum shear stress (shear stress at the failure) is almost equal for three normal stresses (18, 36, and 72 lbs) suggesting that the surface was smooth enough to almost remove the effect of friction on the results and obtained angle of friction would be very small.

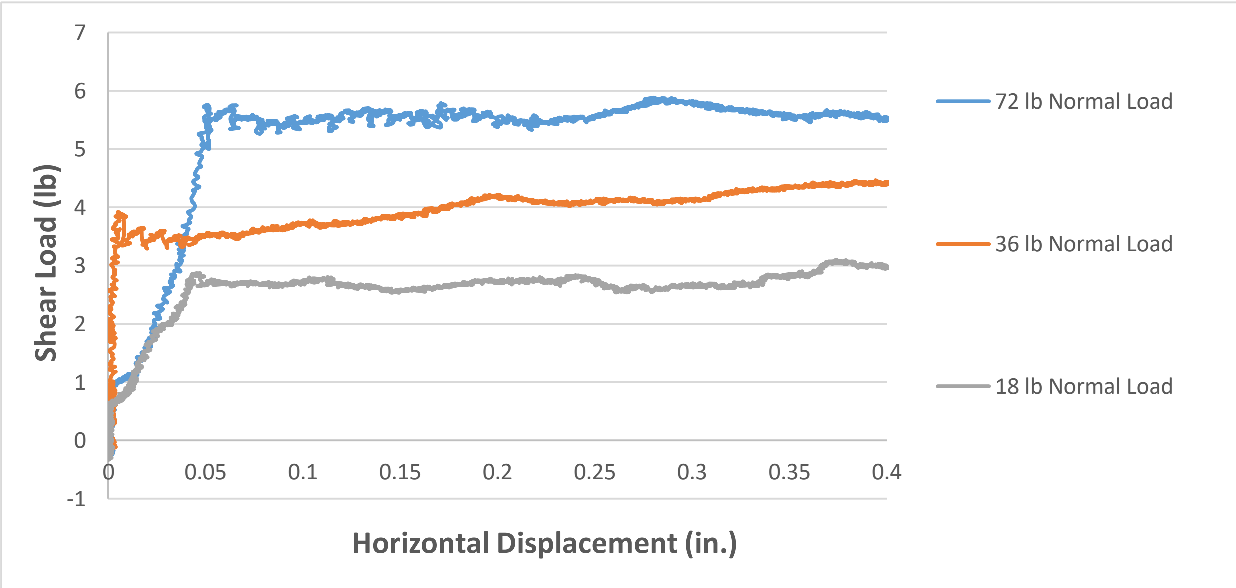


Figure 7 - Shear Load - Horizontal Displacement for Direct Shear Tests of Specimens with Very Smooth Surfaces without Tack Coats

The test results on various tack coat types, application rates, and compaction efforts are included in Tables 1 and 2. The test results for compaction pressure of 1.5 psi are included in Table 1 for different application rates while Table 2 includes influence of different compaction pressures at only one application rate of 0.03 gal/yd^2. The test results suggest that the increase in compaction effort enhances the shear strength and increase in application rate reduces the shear strength with few exceptions. The loss in strength at 0.05 gal/yd^2 can be attributed to creation of a thin

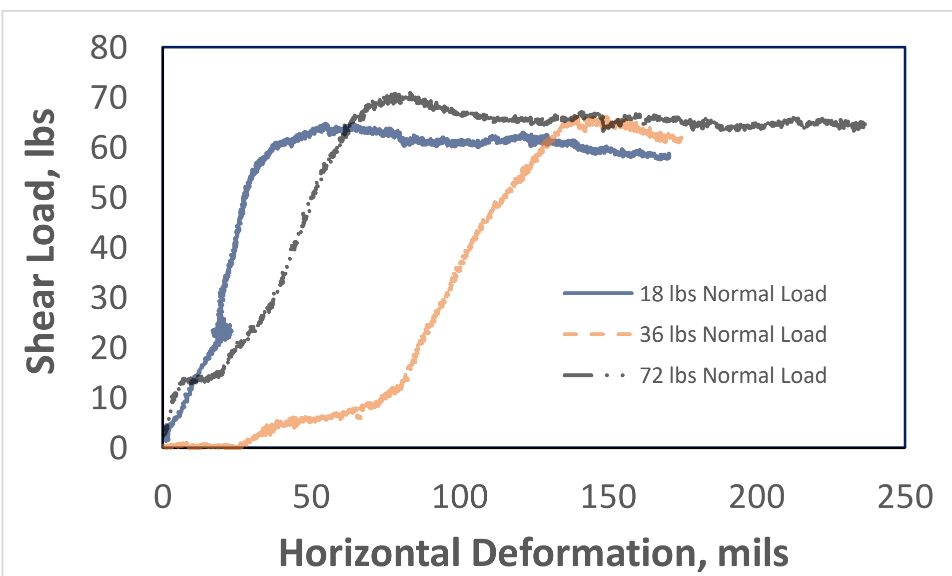


Figure 8 – Typical Shear Load - Horizontal Displacement Obtained from Direct Shear Tests

film which acts as a lubricant or can be attributed to the fact that the synthetic specimens have minimal pores and it doesn't allow the infiltration of emulsion as one would expect in the field due to porosity inherently present in the asphalt concrete mixtures.

The test results presented in Table 1 indicate that the CRS-2 has the lowest shear strength in comparison to other tack coat types while Trackless C (Ultra-fuse) has the highest shear strength. The test results also indicate that the cohesion values varied from 1.5 psi (for CRS-2) to 207 (for Trackless C) while friction angle varied from 2.7 (for CRS-2) to 36.4 (Trackless B) degrees. Although there is a change in the friction angle, the influence of friction angle is minimal on measured shear strength.

Table 1 – Test Results for Different Application Rates and 1.5 psi of Compaction Pressure (without clamping)

Tack Coat	0.05 gal/yd^2		0.03 gal/yd^2	
	Cohesion (psi)	ϕ (°)	Cohesion (psi)	ϕ (°)
SS-1H	5.0	7.0	8.1	3.0
CRS-2	1.5	2.9	2.4	2.7
PG64-22	11.0	13.0	15.4	17.0
PG70-22	18.7	15.0	24.1	12.0
CQS-1HT (Trackless A)	13.3	1.0	16.4	8.0
NTSS (Trackless B)	Not Tested	Not Tested	123.32	36.4
Ultra-fuse (Trackless C)	Not Tested	Not Tested	206.76	32.2

Table 2 – Test Results with 0.03 gal/yd^2 Application Rate and Different Compaction Pressures

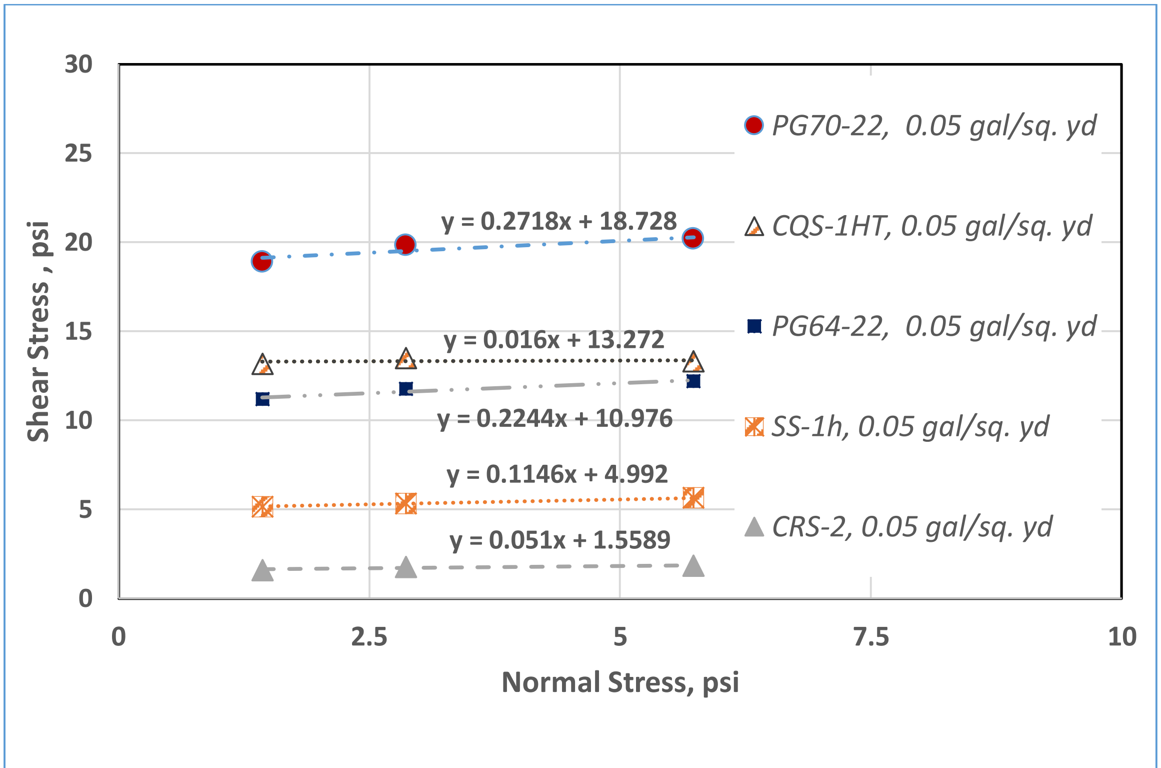
Tack Coat	Without Clamping (1.5 psi)		Clamping (20 psi)	
	Cohesion (psi)	ϕ (°)	Cohesion (psi)	ϕ (°)
SS-1H	8.1	3.0	13.7	7.0
CRS-2	2.4	2.7	4.9	11.0
PG64-22	15.4	17.0	22.7	15.0
PG70-22	24.1	12.0	24.0	7.0
CQS-1HT (Trackless A)	16.4	8.0	26.0	15.0
NTSS (Trackless B)	123.32	36.4	128.4	35.6
Ultra-fuse (Trackless C)	206.76	32.2	217.5	29.5

The test results are also summarized in Figures 10 through 13 to better explain the influence of application rates and compaction pressure. Since Trackless B (NTSS) and C (Ultra-fuse) had significantly higher shear strength, the test results are separately presented in Figures 12 and 13. As expected, the cohesion provided by the asphalt binder (PG 64 and PG 70) is higher than the emulsions (CRS-2 and SS-1). The only emulsion CQS-1HT provided cohesive strengths similar to that of PG 64-22. Further exploration of the CQS-1HT, identified the tack coat to be trackless tack coat.

On comparing influence of application rate (Figures 10), it can be identified that the higher application rate negatively influenced shear or cohesive strength for all tack coat types. Since synthetic specimens were used, there are no pores that can be filled by the tack coat. Therefore, it is proposed to use only 0.03 gal/yd2 for evaluating quality of tack coat. However, the test results clearly evaluate the quality of tack coat in terms of cohesive or shear strength and difference between poor or good quality tack coat can be identified using this test setup.

The second set of tests were performed by increasing compression pressure from 1.5 psi to 20 psi and the results are shown in Figures 11. The test results indicate that the effect of compaction on the cohesion value is significant for weaker tack coats (tack coats with lower cohesion values). For instance, CRS-2 cohesive strength increased from 1.5 psi to 5 psi (more than 3 times) with increase in pressure from 1.5 to 20 psi. However, the similar influence was not found in stronger tack coats. For instance, PG 70-22 cohesive strength (24 psi) remained the same at the two pressure levels. On the other hand the improvement for PG6 4-22, and CQS-1HT are 50%, and 45%, respectively. This means that compaction is an important factor on final characteristics of the interface layer especially when the cohesion value of the tack coat material is lower. Thus, suggesting that the enhancement in shear strength provided by compaction effort is minimal for good quality or stronger tack coats while significantly increases shear strength provided by weaker tack coats.

The Trackless B (NTSS) and C (Ultra-fuse) tack coats test results are included in Figures 12 and 13. These two tack coat types performed significantly different than the remaining ones. The Trackless C track coat increased the shear strength between 5 to 10 times in comparison to other tack coat types. The Trackless C (Ultra-fuse) tack coat exhibited shear strengths more than 200 psi while Trackless B (NTSS) exhibited strength in excess 120 psi. Additionally, the strength exhibited by Trackless C may have been even higher because a failure in terms of peak shear strength was not observed (Figure 13) similar to the one observed in Figure 8. The test was stopped after horizontal deformation reached more than 0.12 in. The test results also show that increase in shear strength includes both cohesion as well as frictional components. The friction angles or more than 30 ° were measured for Trackless B and C tack coats. Thus, the increase in normal stress increased the shear strength. Although frictional component increased, the magnitude of friction component is less than 5 psi (for 30 ° frictional angle and normal load of 72 lbs) in comparison to cohesion component of 120 or 200 psi. Since Trackless B and C tack coats are proprietary materials, the reasons for increase in frictional components could not be identified. Additional frequency sweep and elastic recovery tests were performed to better characterize the behavior of tack coats.



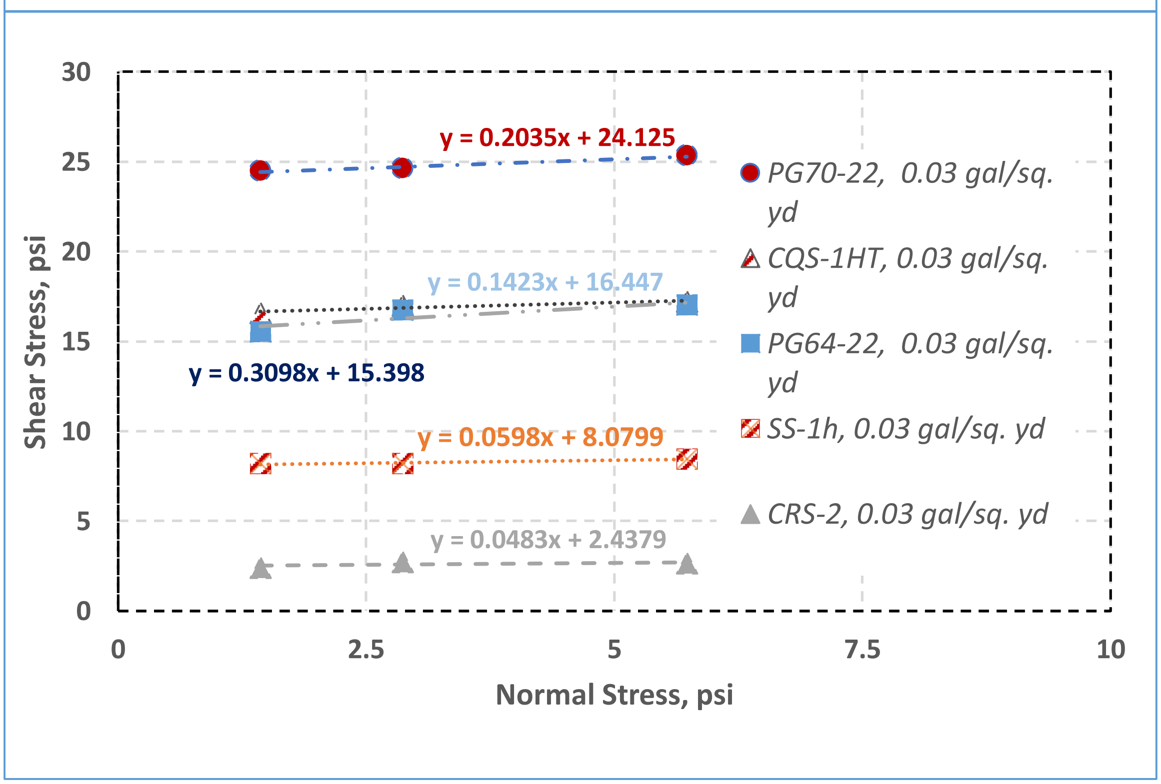


Figure 10 - Failure Envelopes for 1.5 psi of Compaction Pressure

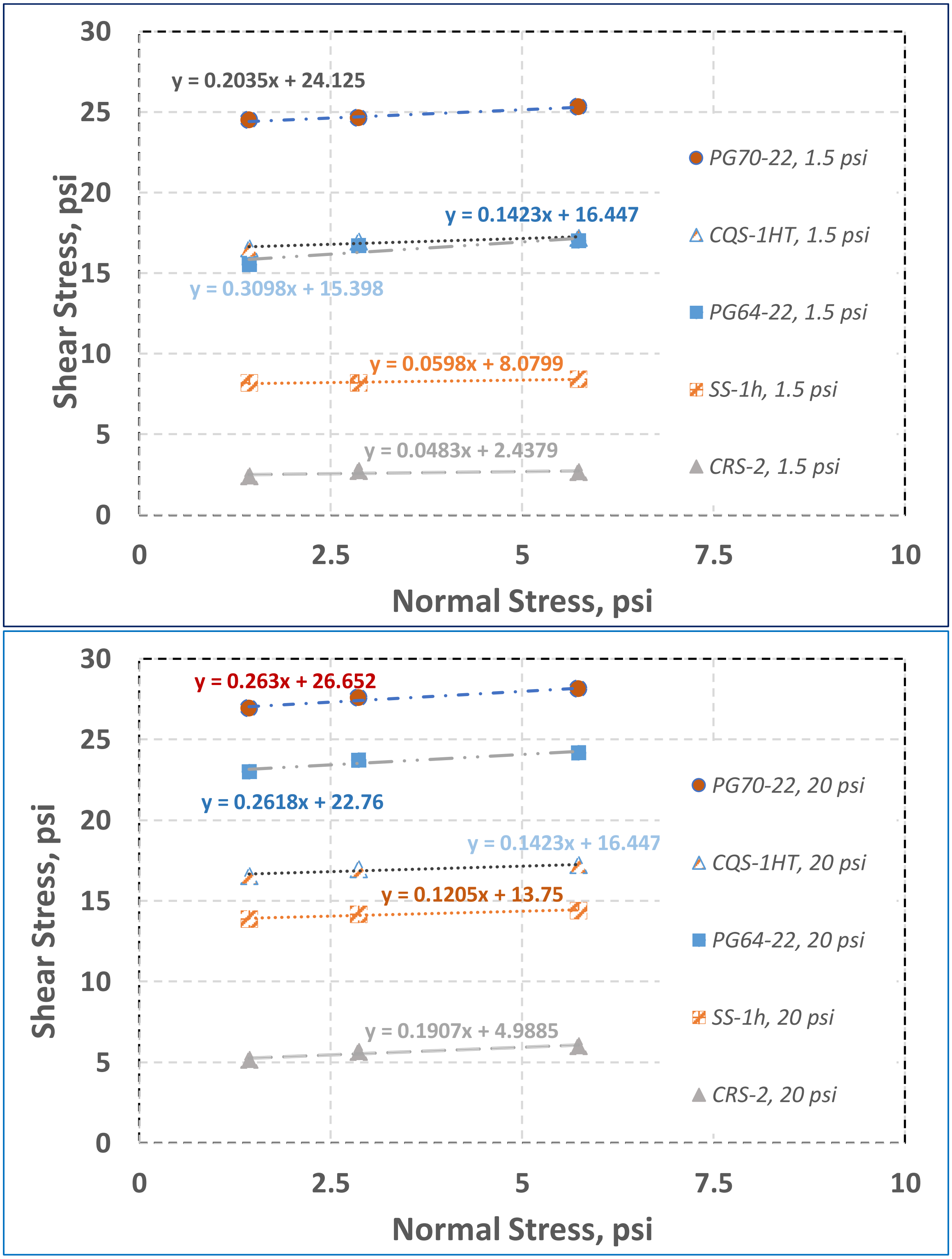


Figure 11 - Failure Envelopes for Application rate of 0.03 gal/yd^2

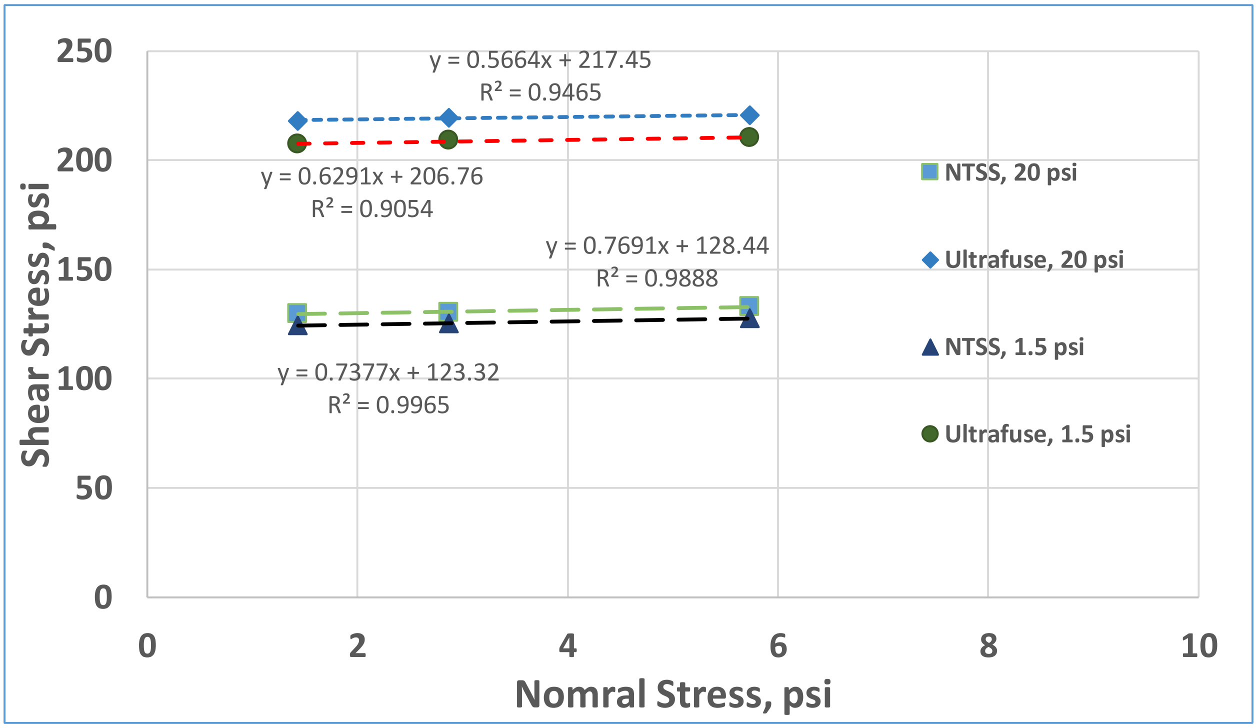


Figure 12 – Trackless B and C Tack Coat Test Results with 0.03 gal/yd² Rate of Application

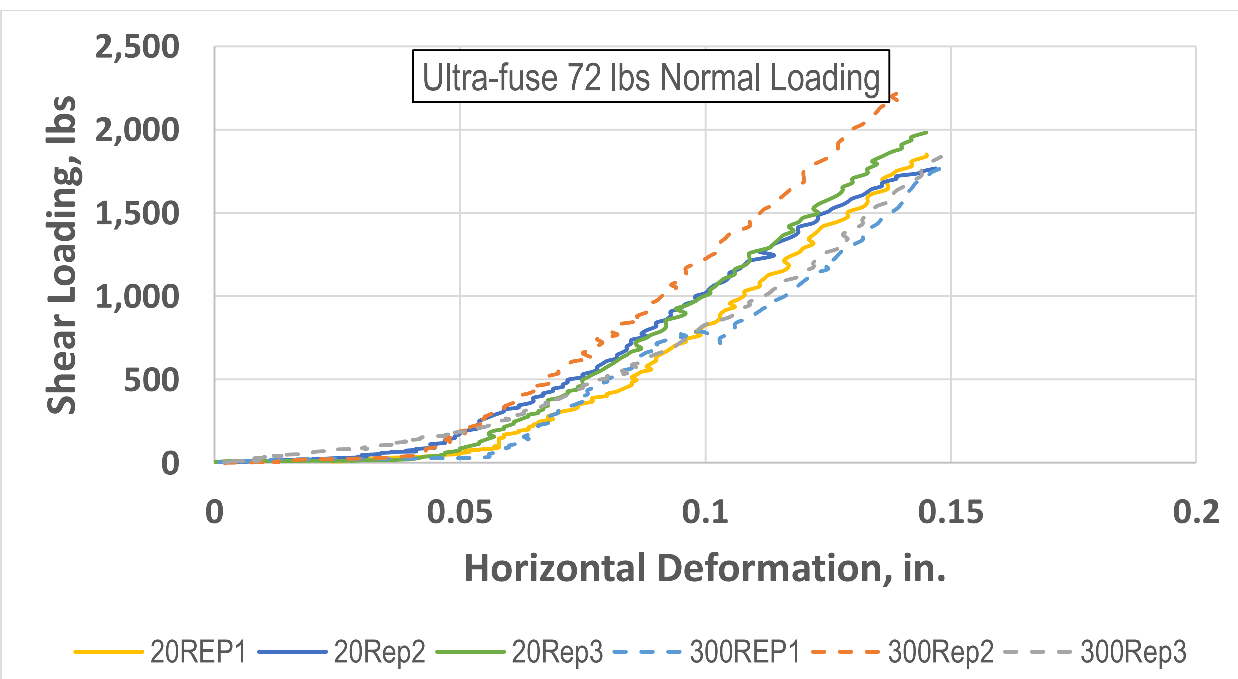


Figure 13 – Trackless B and C Tack Coat Load and Deformation Test Results with 0.03 gal/yd² Rate of Application

DSR Test Results

The frequency sweep tests were carried out using dynamic shear rheometer (DSR) equipment. For testing, 25 mm plate and gap of 1 mm were used while performing tests at 60, 80°C while 8 mm plate and gap of 2 mm were selected for testing at remainder of the test temperatures (4, 28, and 46 °C. The purpose of the tests was to develop a master curve at 25 °C temperature using the time temperature superposition principle (TTSP).

The test results are summarized in Figure 14. The master curve indicate that Trackless B and C tack coats had significantly higher complex modulus in comparison to other tack coat types at higher frequency or lower temperatures. The CRS-2 tack coat had lowest complex modulus at all frequencies. If a ranking is developed, as per the cohesion values from direct shear test (lowest to highest), the ranking is CRS-2, SS-1H, PG 64-22, Trackless A, PG 70-22, Trackless B, and Trackless C. The complex modulus values will provide similar rankings at 0.1 Hz frequency suggesting that direct shear test results are able to differentiate between different tack coat types. Additionally, Trackless A tack coat type has higher complex modulus at lower frequency (or higher loading time) but increase in frequency (or lower loading time) didn't increase in complex modulus suggesting that it is less temperature susceptible in comparison to other tack coat types. Overall, the test results suggest that Trackless A (CQS-1HT) is better in comparison to other tested tack coat types.

CRS-2 and was applied in shifting single curve of each temperature to a smooth master curve at reduced frequency at specified reference temperature. Recently, there are several references about the functions of modeling dynamic modulus master curves and shift factors, some of them were listed here (16-19). In this study, Christensen-Anderson-Marasteanu (CAM) model, as shown in Equation 1, was used for the master curve construction. Equation 2 is the function of modeling the phase angle at specific temperature to reference temperature. Modified kealble shift function as Equation 3 was implemented to determine the shift factor from the specific temperature to the reference temperature.

Elastic Recovery Tests

The elastic recovery test was performed based on the speciation of Tex-539-C which specified the testing temperature is 10°C (50°F). The test results are included in Table 3 and suggests that only PG 64-22 and PG 70-22 met the specifications as per ITEM 300. However, the other tack coat types are not expected to meet elastic recovery requirements.

Although more testing is needed before it can be used as a acceptance criterion, the cohesion of more than 15 psi, as per direct shear tests, should be an acceptable tack coat. Additionally, the testing on mixes was performed as well using Trackless A tack coat as well and performance matched with the field performance. Therefore, 15 psi of cohesion limit should be a minimum criterion. In terms of maximum limit, the rheological testing at lower temperatures is needed before it can be specified.

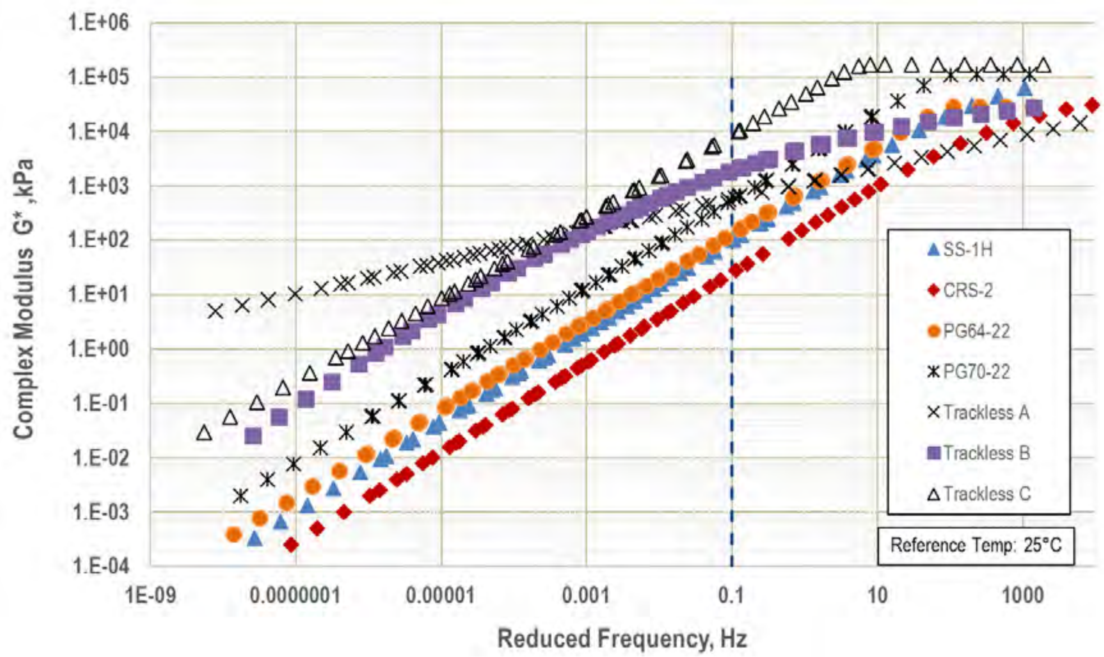


Figure 14 – Master Curve of Tack Coats Tested Using DSR

TABLE 3. Elastic Recovery Test Results.

Tack coat	Test Temp (°C)	Rep1 (cm)	Rep2 (cm)	Rep3 (cm)	Recovery (%)
CRS-2	10	2.5	2.5	3	Fail
SS-1h	10	9.8	10	10	Fail
PG64-22	10	17.5	17.2	17	14
PG70-22	10	16.8	17	17	15
Trackless A	10	13.5	14	-	Fail
Trackless B	10	2.5	3	-	Fail
Trackless C	10	0	0	0	Fail

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- AASHTO T59: Standard Method of Test for Emulsified Asphalts

- ASTM D3080: Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions

APPENDIX C.
GUIDELINES FOR MICROMILLING AND TACK COAT APPLICATION

Micro-Milling and Tack Coat Application Guidelines

Executive Summary

Increase in construction cost and decrease in revenue has lead various state highway agencies to place thinner overlays for enhancing the ride quality. Although economical, there are two issues that needs to be evaluated to materialize the benefits of thinner overlays. One is the depth of milling and another one is bonding between existing and newly placed thinner layer. Typically, overlay is placed by milling the existing surface. This extra step creates uneven surface and provides better bonding between the two layers. However, use of conventional milling drums will lead to reflection of grooves on the thinner overlaid surface due to repeated traffic load. Therefore, recently developed micro-milling technique needs to be used that reduces depth of the milled surface.

The bonding between existing and overlaid layers is achieved by spraying tack coat on top of the surface layer. The reduced overlay thickness will increase magnitude of horizontal and shear stresses in the tack coat layer. Therefore, micro-milling depth should be deep enough to make sure that the required bonding strength is met.

Teeth material, teeth spacing and grade averaging accuracy are the main specifications of a micro milling machine. There are also different methods to measure the uniformity and smoothness of a surface texture which has to be satisfied for the micro milled surface to be acceptable. Therefore, the purpose of micro milling specifications is to create surface roughness that meets bonding strength and reduces the milling depth to minimize reflection of grooves on the overlaid surface.

Introduction

Poor bonding between existing layer and overlay results in premature failure of overlays. The traffic induced horizontal and shear stress between two layers are the most common reasons for deterioration. Slippage between the two layers commonly occurs at areas where the traffic accelerate, decelerate, or turn sharply, resulting in tears or half-moon shape deformations in the direction of the traffic [West *et al*. 2005,Hasiba 2012]. Lack of inerfaec bonding (due to moisture or poor tack coat placement practices) between adjacent layers also causes premature fatigue. Adhesive interface bonding strength between two layers is essential for longevity of pavement [Hasiba 2012]. Surface texture and condition, tack coat materials and application rate, placement temperature, curing time, and test methods are the main factors which several experimental or numerical studies have been done to investigate their influence on the bonding strength between the existing and the new layer.

A common technique to enhance bonding characteristics between two layer is the removal of the upper portion of the existing layer and placement of new layer on top (mill and Overlay) [Kandhal *et al*. 1989]. Pavement milling is a process that removes the surface of the pavement using milling machine. Milling machine uses a large rotary drum equipped with carbide tipped teeth to cut and grind the asphalt concrete layer. The milling process produces surface with higher roughness of the existing layer, thus, creating more contact area between two layers, which provides better bonding between the layers. Milling also removes the shallow distresses from the surface of existing layer [Pavement Interactive 2011].

Although milling improves bonding, the surface roughness created is not suitable for thinner overlays because the depth of roughness is either close to or more than the thickness of thinner layers. Therefore, micro milling technique has been developed that reduces the depth of milling by adjusting the depth and spacing of cutting teeth in comparison to conventional milling. Micro milling removes old deteriorated asphalt surface and provides adequate bonding strength to the new overlay. It also restores ride and levels the existing asphalt surface which eases the placement and compaction of the overlay [Los Angeles County Department of Public Works 2012]. The teeth spacing of a micro milling drum (1/4 inch) is about 2.5 times smaller than a conventional drum (5/8 inch) [Bassard 2015]. The increase in number pf cutting teeth in comparison with the conventional drum produces a smaller ridge-to-valley (RVD) depth which results in a surface with a significantly finer and more uniform texture [Pavement Interactive 2011].

Figure 1 - Conventional (standard) Drum (left) and Micro-milling Drum (right) [Bassard 2015]

Micro milling advantages

Micro milling has three distinct advantages in comparison with the conventional milling method and are as follows:

1- The milled surface with the conventional drum could be exposed to the traffic during the pavement construction for a very short time because the higher RVD will lead to raveling, driver nuisance (noise and breaking of windshield due to loose aggregate) in a very short time. On the other hand, the new micro milling technology creates fine and uniform asphalt surface that can be temporarily used as an alternative to the existing layer and yet aggressive enough to provide improved skid resistance [FHWA 2015]. A previous study conducted at Department of Construction management at the University of Houston evaluated the use of a milling machine to enhance pavement texture and its effect on skid improvement. The results show that surface milled with finer pattern exhibits improved skid resistance [Gao *et al.* 2015].

2- Since conventional milling produces large RVD, there is a risk for the overlay to reflect the milled shape on its surface as very thin layer will compact under traffic loads. It also increases the risk of surface delamination of the overlay after being exposed to the traffic.

The use of micro milling drums minimizes the distress formation especially when placing ultra-thin overlays [Lai *et al* 2009].

3- In case of using open-graded asphalt mix for the overlay, the large RVD results in water entrapment at the valleys of the milled surface with the conventional milling method [Lai *et al* 2009]. Water entrapment may causes severe damages like the stripping of the asphalt pavement and potholes [Kandhal *et al*. 1989].

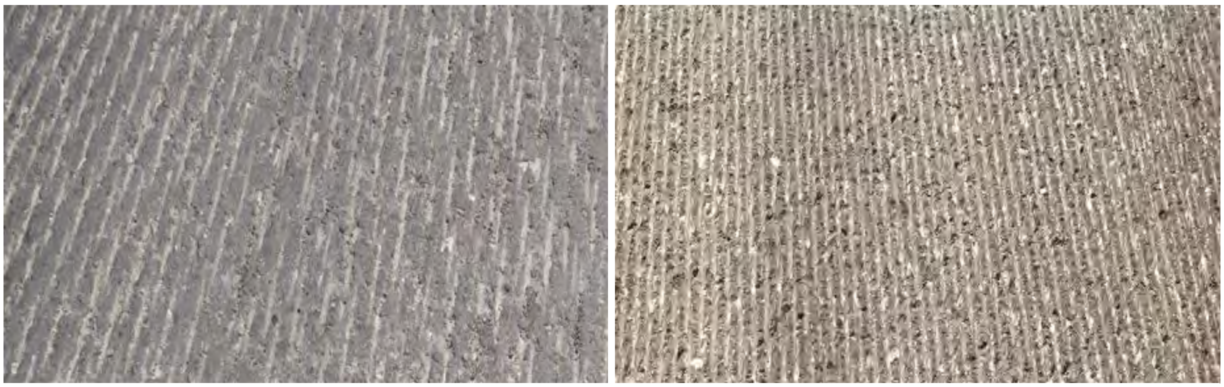

Figure 2 - Conventionally Milled Surface (left) and Micro-milled Surface (right) [Bassard 2015]

Micro-milling Specification

Some of the specifications which have to be considered for the micro milling are related to the micro milling machine. Teeth material, spacing, elevation accuracy and grade averaging accuracy are the most important topics in this regard. On the other hand, the quality (uniformity and smoothness) of the micro milled surface is another criteria that makes sure that the desired surface has been created. There are different standards and methods to specify the uniformity and smoothness of a surface texture. The RVD, mean texture depth (MTD), and mean profile depth (MPD) are commonly used methods to measure the uniformity and smoothness of the micro milled surface texture. Following is the review of each of these criteria:

- **Teeth Material, Spacing and Elevation Accuracy**: According to Los Angeles County Department of Public Works, the micro milling drum teeth has to be tungsten-carbide-tipped spaced less than 1/4 inches apart on center [Los Angeles County Department of Public Works 2012]. Texas Department of Transportation (TXDOT) accepts the carbide or equivalent material for the tip of the teeth with a maximum tooth spacing of 5/8 inches [TXDOT 2004]. Michigan Department of Transportation (MDOT) specifies that the milling drum with a minimum of 3 wraps of carbide teeth spaced no greater than 3/16 inch [Michigan DOT, 2010]. According to Vermont Agency of Transportation, the micro milling drum has to be equipped with carbide or PCD (polycrystalline diamond) tipped teeth with a maximum tooth spacing of 8 mm (0.3125 inch) axial distance between the tips of each tooth [Vermont Agency of Transportation]. Kansas Department of Transportation (KSDOT) defines minimum of 60 teeth per foot as micro milling drum [Kansas DOT 2007]. There is a general agreement in literature about the teeth elevation accuracy of the micro milling drum. Los Angeles Department of County Works, TXDOT, Alabama Department of Transportation (ALDOT), and Georgia Department of Transportation (GDOT) propose tooth elevation accuracy to be 1/16th of an inch [Los Angeles County Department of Public Works 2012, Texas DOT 2004, Alabama DOT 2014, Georgia DOT 2006]. According to Michigan Department of Transportation and Vermont Agency of Transportation, the tooth holder blocks are required to be uniform such that variations in the cutting radius shall be less than 0.03 inches and 0.02 inches, respectively [Michigan DOT 2010, Vermont Agency of Transportation 2011].

- **Grade Averaging Accuracy:** Micro milled surface is required to be precisely leveled. Therefore, the micro milling machine has to be equipped with grade and slope control to make sure that the desired grades and slopes will be acheived. Micro milling machine needs to have an automatic grade averaging control system to control the longitudinal profile and transverse cross-slope [Michigan DOT 2010, Vermont Agency of Transportation 2011, Alabama DOT 2014]. Texas Department of Transportation and Georgia Department of Transportation specifies that the grade and slope control has to be operated from string line or ski and based on mechanical or sonic operation [Georgia DOT 2006, Texas DOT 2004].

- **Uniformity and Smoothness of the Surface Texture:** Micro milling drum can be used for removing of 0 to 2 inches of asphalt surface. After micro milling process, the surface texture of the milled surface needs to be evaluated to make sure that the surface texture is uniform and smooth enough. There are several methods for the surface texture measurement and are summarized in the following paragraphs:

  - The volumetric sand patch method, according to ASTM E 956, has been used for the texture measurement for very long time. In this method, the MTD of the surface is calculated based on the area that a known amount of sand or glass spheres could cover after spreading over the smooth surface [China and James 2012, Fisco 2009, ASTM E 965 2001]. Virginia Department of Transportation states that the maximum MTD for a micro milled surface should be less than 0.08 in. (2.0 mm) to be left open to traffic (Virginia DOT 2004, Mokarem 2006). This method is time consuming and it requires traffic control for longer period of time.

  - MPD is another way to specify the surface texture. Several laser-based devices have been developed to determine MPD. Circular Texture Meter (CTM) is the most popular device which different department and agencies use for measuring the texture of the pavement (In TxDOT Special Provision No. 354, Planning and Texturizing Pavement, has the specification for the RVD of the surface but it does not specify the method to measure MPD. It specifies to the pavement producing a final pavement surface with transverse pattern of 0.2 in. center to center of each strike area with difference no greater than 1/16 in. in RVD measurement of the final milled surface. Construct a uniform finish free from gouges and ridges that does not vary more than 1/8 inch in width of the cut). This device uses laser to calculate the MPD [Fisco 2009, ASTM E2157 2001]. The National Center for Asphalt Technology (NCAT) propose to use CTM for surface texture measurement [Lai *et al* 2009, Smit *et al* 2007]. There are also several other different brands of laser profilers that can be used for surface texture measurement. The Georgia department of Transportation uses the Laser Road Profiler (LRP) as a part of its quality assurance process and specifies that the indices for the surface smoothness should be less 825mm/km and no greater than 900mm/km [Lai *et al* 2009, Georgia DOT 2006]. These devices can perform the surface texture measurement without significantly influencing traffic flow. [China and James 2012].Most of these devices also gives the user MTD to compare with the measured MPD.

- The RVD is the most common method for measuring the uniformity of the surface texture in which there is a limitation for ridge to valley depth of the milled surface to satisfy the texture uniformity. The Texas Department of Transportation, the Georgia Department Of transportation, the Vermont agency of Transportation, the Los Angeles County Department of Public Work, and the Michigan Department of Transportation are some of the departments and agencies that state that if the depth of RVD exceeds more than 1/8 inches (3.2 mm) then the underlying layer needs to be removed and replaced [Texas DOT 2004, Georgia DOT 2006, Vermont Agency of Transportation 2011, Los Angeles County Department of Public Works 2012, Michigan DOT 2010]. Therefore, the micro milling machine should be capable of removing the asphalt surface to a tolerance of 1/8 inches. There are relationships to calculate RVD based on the MPD measured by CTM or some of other laser profiler devices [Lai *et al* 2009].

Different department and agencies stipulate specifications for the micro milling machine and micro milled surface to approve a micro milling job and they are in general agreement about micro milling specifications between them. Based on the field evaluation, new guidelines will be proposed to be implemented by TxDOT.

Tack Coat Application Guidelines

Based on the investigation conducted by the International Bitumen Emulsion Federation (IBEF) in 1999, cationic emulsions are most commonly used with some use of anionic emulsion [Romasnchi 2009]. The tack coat application rate generally ranges from 0.026 to 0.088 gal/yd^2

(0.12 to 0.4 l/m^2) which can be reduced to less than 0.02 gal/yd^2 (0.09 l/m^2) by adding polymer to the tack coat [West 2005, Romanschi 2009, Mohammad 2001]. The literature review didn't identify changes or improvement to the current guidelines suggested by Texas Department of Transportation (Online Manual on Surface Preparation). Therefore, it is not included in the technical memorandum. If new information on tack coat application guide becomes available or modifications to the existing guidelines are needed (based on field evaluation), the existing tack coat application guideline of TxDOT will be modified accordingly.

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APPENDIX D.
LIFE CYCLE COST ANALYSIS FOR COMPARISON BETWEEN CHIP SEAL AND ULTRA-THIN OVERLAY

Life Cycle Cost Analysis for Comparison between Chip Seal/Seal Coat and Ultra-Thin Overlay

Executive Summary

Seal coat/Chip sealing is commonly used pavement preservation method to improve the ride quality and skid resistance. However, the service life of seal coat is 3 to 5 years and it requires crack sealing in between. To further extend service life, TxDOT and other highway agencies have promoted Ultra-Thin overlays (UTO) especially in the urban environment to minimize traffic disruption. Although UTO extended the service life, the life cycle cost analysis has not been conducted to identify benefits of UTO. This report includes: a brief introduction of each method, their construction steps, and life cycle costs associated with each preservation technique. In the end, an excel file has been developed to perform the life cycle costs analysis for future projects.

Seal Coat

Seal Coat is a pavement surface treatment method to provide a smooth surface. Seal Coat, also known as a chip sealing, is a layer of asphalt binder covered with chips (crushed uniform aggregates) on top of an existing pavement [1]. Chip seal actually uses all materials that we have in asphalt mixture, but, in this method, the materials are added separately. A layer of hot asphalt is sprayed on the existing asphalt surface and a layer of uniform crushed aggregates is immediately distributed on top of the hot asphalt [2]. Chip sealing increases the service life of the pavement by preventing water and air from penetrating the pavement, sealing very small crack, tightening the raveled aggregate, and reducing the aging effect. It also improves the skid resistance of the surface [2].

Figure 1 - Seal Coat Surface Treatment [3]

Asphalt cements, asphalt emulsion, and cutbacks are three different types of asphalt that are traditionally used in chip seal projects. According to ITEM 300 of TxDOT Standard Specifications, list of all different asphalts that can be used for surface treatment are: AC-5, AC-10, AC-5 w/2% SBR, AC-10 w/2% SBR, AC-15P, AC-15P, AC-15- 5TR, HFRS-2, MS-2, CRS-2, CRS-2H, HFRS-2P, CRS-2P, Asphalt-Rubber Types II and III [2]. The type of asphalt is selected based on the available aggregate type, pavement general surface condition, and expected traffic. To check the detailed category and specification of the asphalt oils for the chip sealing, TxDot Seal Coat and Surface Treatment Manual has been developed.

Lime stone and sand stone are commonly used in seal coat projects. Aggregates should be uniformaly graded (usually 3/8 in.) because smaller size will be fully covered and bigger size will not fully covered.

There are two different methods to calculate the application rate of asphalt and aggregate for each specific project in TxDOT (as per Seal Coat and Surface Treatment manual): modified Kearby design method, and McLeod design method. These two methods can be used to calculate the application rate of the asphalt oil and aggregates based on the aggregate particle size, unit weight, void, and absorption and also traffic volume, existing pavement condition and general weather condition [2].

Generally, asphalt should be able to cover 70 percent of the aggregates surfaces. The range for the asphalt application rate is between 0.15 gal per square yard and 0.55 gal per square yard.

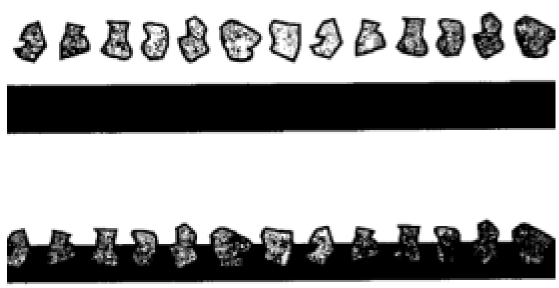


Figure 2 - Asphalt and Aggregate Interaction [4]

For aggregate application rate, generally speaking, there should be about 90 percent of coverage over the surface and the thickness of the layer would be equal to just one aggregate size.

Following are the construction steps for a chip seal projects [5]:

- Cleaning the surface
- Spraying the binder over the asphalt surface
- Distributing the chips over the oiled surface
- Embedding the aggregates by using rubber-tired roller
- Sweeping the surface to clean the loose aggregates

Cleaning Pavement Surface

The first step at chip seal surface treatment construction would be cleaning the surface to make sure that the dust, loose sand, and stone or debris will not decrease the bonding strength between binder and existing pavement. Road sweeper can be used to clean the pavement surface [6].

Figure 3 - Road Sweepers for Cleaning Pavement Surface [6]

Spraying the Binder

To spray the asphalt over the pavement evenly, truck mounted emulsion sprayer shall be used. The equipment applies asphalt over the surface. Any inconsistency in asphalt application over the pavement surface will cause serious problem in future. Less material in comparison to the calculated rate will results in very loose bonding between aggregate and surface. More material in comparison to desired application rate would be waste of material and also covers the aggregate completely which may cause slippery surface.

Truck mounted sprayer and using sprayer tank and tractor are two different methods to distribute asphalt over the pavement surface [7].

Figure 4 - Truck Mounted Sprayers for Oil distribution over the Pavement Surface [7]

Spread the Aggregates

After spraying the seal coat, the aggregate spreader is used to distribute the aggregate over the pavement surface. The spreader has to be checked to make sure that it spreads the aggregates evenly. It is better to use the equipment to spread the aggregate over a few square yard every day before starting the work to make sure that aggregate covers the surface evenly [8].

Figure 5 - Aggregate Spreader Distributes Aggregates Over the Coated Surface [8]

Rolling the Surface

To make sure that the aggregates are embedded in the seal coat, the surface has to be rolled with rubber tire rollers to minimize loose aggregates that can damage user's vehicles, especially the windshield, and may cause accidents [9].

Figure 6 - Rubber Tire Roller for Embedding Aggregates [9]

Sweeping Loose Aggregates

This part would be just like cleaning at the first step of the construction. Sweeping loose aggregates from the chipped surface is very important step for safety reason. Because this loose material can cause the wind shield damage for the passing cars and cause possible injuries or car accidents.

Crack Sealing

In order to maintain the serviceability of the pavement and filling small crack, crack sealing is performed every 2 to 3 years between the seal coat applications. Crack sealing is a simple manual method in which technicians use specific materials to seal the cracks. As the service life of chip sealing is between 6 to 10 years, 2 to 3 times of crack sealing is needed between two chip sealing preservation.

Ultra-Thin overlay

Ultra-thin overlay is a preservation method to address functional problems (ride quality, noise level, and skid resistance) of the pavement and prevent small cracks at the pavement surface to propagate downward and cause further structural problems. Ultra-thin overlay with around 0.5 in. thickness does not have any structural effect on fatigue or rutting service life of the pavement, but it prevents small distresses from further increase [14,15].

Asphalt mixture used for ultra-thin overlay has a very small Nominal Maximum Aggregate Size (NMAS). Small NMAS results in very high aggregate surface. There is a direct relationship between aggregate surface and binder content in asphalt mixture. Thus, the binder content of the mixture for ultra-thin overlay would be high. Since the binder content is a main factor in asphalt mixture material cost, the cost for asphalt mixture at ultra-thin overlay project would be higher than normal well graded asphalt mixtures [14,15].

Ultra-thin overlay is a fill and mill operation in which about 0.5 in. of the pavement surface would be milled and then an especially designed asphalt mixture will be placed on top. Construction steps for ultra-thin overlay preservation is: milling pavement surface with milling machine, cleaning the surface with road sweeper, spraying tack coat over the pavement surface, paving with asphalt paver, and compacting with drum roller.

Pavement Milling

Pavement milling can be used to remove the surface layer of a pavement which has small distresses and needs to be preserved. Using micro milling machine, the determined thickness of the pavement layer (0.5 in for ultra-thin overlay preservation) could be removed and a leveled surface could be achieved. Milling machine uses an automatic grade control to make sure that final surface is leveled in both longitudinal and transverse directions [16]. Accurate leveling and providing Reclaimed Asphalt Pavement (RAP) are the most important advantageous of milling asphalt surface before overlaying [3]. Following is schematic view of a milling machine and a truck which can be used in an overlay project to mill the pavement and transport RAP form the construction site to stockpiling site [17].

Cleaning Pavement Surface

After pavement milling the pavement surface needs to be cleaned to remove all the dust and loos aggregates. Clean surface results in a better bonding strength between milled surface and HMA overlay. Road sweepers have to be used to clean the surface until there is no loos aggregate or dust on pavement surface.

Tack Coat Spraying

Bonding strength between milled surface and HMA overlay has a deterministic role in overlaying service life. Especially when we have an ultra-thin thickness overlay, deboning stress between two layers can separate two layers and decrease the serviceability of the pavement. Vehicles’ braking, decreasing or increasing speed can cause a major deboning stress between two layers and cause slippage of the overlay on top of the existing layer. Spraying tack coat over the existing surface before overlaying improves the bonding strength between two layers significantly and help overlay to not to slide over the existing layer. Based on the project specification, different types of tack coats can be used in overlaying project. But, generally speaking, by decreasing the overlay thickness the importance of tack coat cohesive characteristics increases. TxDOT online manual for asphalt overlay suggests warm polymer modified asphalt emulsion for thin and ultra-thin overlay [5]. Truck mounted asphalt distributers can be used to spray the tack coat over the existing pavement layer.

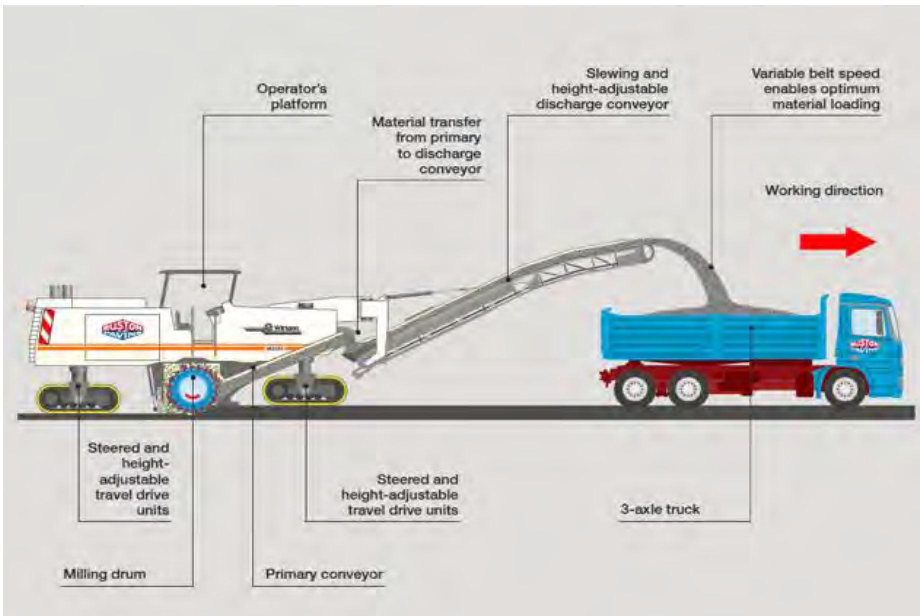


Figure 7 - Asphalt Milling Operation [17]

Paving the Overlay

According to TxDOT online manual for nonstructural overlaying, a hot mixed paving mixture has to be applied immediately after spraying the tack coat over the existing surface [18]. It worth to mention that paving a thin and ultra-thin layer of asphalt mixture is more difficult in compare to thicker layers. The paver screed level has to be controlled accurately. The paver speed would be higher in thin lift which makes the controlling process difficult. Especially for ultra-thin overlay, as the NMAS of the aggregates is more than half of the layer thickness, the HMA may tear under the paver screed [18].

Compaction

Compaction of the thin and ultra-thin overlays after paving is very important step which has a deterministic effect on overlay service life. Decreasing the thickness of the overlay, the sensitivity of the layer to vibratory compaction increases. For an ultra-thin overlay, vibratory compaction may result in aggregate breaking. It also may decrease the bonding between overlay and existing layer [5].

Having very thin lift, the paver speed would be higher. On the other hand, thinner lift cool quicker than a thick asphalt lift. So, regarding these two difference between thick and thin asphalt lift, planning the number and time scheduling of rollers is very important in overlaying construction.

Figure 8 - Asphalt Paver [19]

Figure 9 - Compaction of Asphalt Overlay [20]

Seal Coat Life Cycle Cost Excel File

This part explains how to use the provided excel file to perform Life Cycle Cost Analysis (LCCA) of the pavement preservation technique using chip sealing and crack sealing. Usually after 10 years of the initial pavement construction, a pavement preservation method needs to be used to prevent the small cracks or other distresses to grow and endanger pavement structure and serviceability. Seal Coat is a common method that can be used when there is not any major distress. The service life of the seal coat is around 6 to 10 years. It means that 2 or 3 times of chip sealing needs to done during the service life of the pavement. In order to maintain the serviceability and preventing small cracks to grow, crack sealing also needs to be done every 2 to 3 years in between two chip sealing preservations. To analyze the life cycle cost of the pavement preservation using chip sealing and crack sealing, an excel file has been created. In this excel file, all the variables can be changed based on each specific project. The excel file has 6 sheets which are explained in the following subsections.

General Guide

This sheet has some general information about the chip sealing and crack sealing. It also includes instructions to use the file properly. References are also included in this sheet.

Brief Technical Information

This sheet provides general data about pavement and preservation service life. In this part, some basic estimations about the service life of seal coat and crack sealing is provided. Based on each specific projects, experts decide about the preservation time and service life. But these estimations can be used for general cost analysis.

Each construction step is introduced separately. This information can help user to become familiar with the construction process and use the excel file properly.

Reading “General Guide” and “Brief Technical Information” sheets thoroughly, user can understand how to use excel sheets and put the information and numbers in assigned cells to analyze the life cycle cost.

Data Input

Based on each specific project, general pavement information and preservation schedule has to be entered in this page. Pavement length, number of lanes and ADT would be based on the project specs and will be used to calculate the total cost of the project. Pavement service life is based on the pavement design. Usually pavement service life is around 30 years. After around 10 years of pavement initial construction, chip sealing needs to be done to prevent small cracks growth and increase skid resistance. As service life of the chip sealing is between 6 to 10 years, usually 2 or 3 times of chip sealing would be needed during pavement service life. Number of years after initial pavement construction for which each time of chip sealing has to be done have to be put in assigned cells. Crack sealing needs to be done every 2 to 3 years between two consequent chip sealing. The productivity of the crack sealing depends on the amount of the cracks and crew size. Traffic data for highways in Texas State can be found in TxDOT official website-statewide mapping [10]. The general information related to the project is included in Table 1.

Table 1 – General Project Information for Seal Coat

Project Name	US0067-KG
Project location	El Paso Texas
Control Section	010407
Project LENGTH	10
Number of lanes	6
Average ADT	350006
Highway Type	Suburban Divided Freeway
Pavement Service life	30 years (Assumed)
Chip Sealing	Three times of chip sealing after 10, 18, and 26 years of pavement initial construction (assumed)
Crack Sealing	Every 3 years between two chip sealing (assumed)
Productivity	1 mile lane per day for chip sealing and 2 mile lane per day for crack sealing (assumed)

Note1: Data for highways in Texas can be found in TxDOT official [10] website (statewide mapping)

Note2: AADT and ADT assumed to equal

Cleaning Pavement Surface

Rental cost of the road sweeper and its operational cost are included in the costs for sweeping the road. RSMeans can be used to find the rental and operational costs of the road sweepers. Using annual indexes, costs for any specific year can be included in any specific year and can be converted to present cost. The productivity of road sweepers are usually around 0.5 to 1 mile per day. It is worth mentioning that as the productivity of road sweepers are usually less than other equipment in chip sealing projects, two or three road sweepers need to be used to keep the productivity of other equipment at their highest levels. Based on the RSMeans 2013, the cost of cleaning pavement surface is calculated as shown in Table 2.

Seal Spraying

Cost in this step of construction can be divided in to three main part: 1) cost of seal coat material, 2) cost of material transportation to the construction site, and 3) cost of the spraying material over the surface. Using the excel sheet and entering the costs for each of these main parts, the total cost for seal coating will be calculated. TxDOT average low bid unit price and RSMeans reference book can be used to find the aggregate and equipment costs respectively.

Table 2 – Cost of Cleaning Pavement Surface

Road Sweeper, self-propelled, 8 feet wide, 90.H.P.	
Rent per day	$575
Hourly operation cost	$39.85
Index in 2013	201.2
Index in 2016	207.2
Present cost for rent	$592.15
Present hourly operational cost	$41.04
Present daily operational cost	$328.32 (assuming 8 hours of work per day)
Total Cost for cleaning pavement surface per day at 2016 based on RSMeans cost indexes	$920.47
Road sweeper productivity	0.6 mile lane per day
Cost of cleaning per square yard = (total cost per day)/(productivity*1760*4)	$0.28 per square yard

The type and application rate of the seal spraying material has major effect on the final cost of this step. Polymer modified material which increase the service life of seal coating are costly in comparison to traditional binders. Seal coat application rate and aggregate type and size are dependent on each other. It is important to adjust these three variables together to decrease costs.

Productivity of this step is highly dependent on the transportation of the seal spraying material to the site and number of truck that are available. Thus, the distance between seal coat providing plant to the construction site is one of the variables that needs to be considered in cost analysis. Having all other parameters under control, the productivity of trailer mounted asphalt distributers with 8 feet width is usually more than 1-mile lane per day. The detailed cost of seal coating is included in Table 3.

Aggregate Spreading

From the cost point of view, this step, just like seal spraying, has three main part: 1) material (uniform crushed aggregate), 2) transportation, and 3) aggregate spreading. Aggregate has to be crushed and be uniformly graded. Crushed uniform aggregate with average size of 3/8 inch is what usually would be used in chip sealing. So, aggregate cost would be a little higher than cost of normal well graded aggregates. TxDOT average low bid unit price and RSMeans reference book can be used to find the aggregate and equipment costs respectively. Aggregate type and rate of application are related to the pavement surface and most importantly, to the type of seal coating agent. It should be noted that based on the ionic characteristics of the materials, some of the aggregate and seal coating agents are not compatible and should not be used together. The distance between aggregate providing plant and construction site should be considered in cost estimations.

Productivity of this step is dependent to the rhythm of providing aggregate at the construction site but assuming all other variables under control, aggregate spreaders usually have the highest productivity and can be deterministic variable in estimating the total productivity of the whole equipment and crew. The detailed cost of aggregate spreading is included in Table 4.

Rolling

Aggregate spreader just lays the aggregates over the surface. To embed aggregates into the seal coating agents, tire roller compactors are typically used. Rollers, in comparison to other equipment in seal coating projects, have smaller width and usually more than one roller needs to be used to keep the productivity in a reasonable range. Productivity for one roller is usually around 0.5 to 1-mile lane per day. Based on the RSMeans 2013, the total cost of rolling is included in Table 5.

Table 3 – Cost of Seal Spraying

Seal coat material price	$3.0 per gallon for AC-5 or AC-10 (Tx DOT average low bid unit price)
Application rate	0.25 Gallon per square yard
Seal coat material cost == material price X application rate 3 X 0.25 =	$0.75 per square yard
Asphalt Distributer, trailer mounted	3000 Gallon, 38 H.P. Diesel
Rent per day	$355
Hourly operation cost	$11.4
Index in 2013	201.2
Index in 2016	207.2
Present cost for rent	$365.58
Present hourly operational cost	$11.74
Present daily operational cost	$93.92 (assuming 8 hours of work per day)
Total cost for asphalt distributer per day at 2016 based on RSMeans cost indexes	$459.5
Productivity of asphalt distributer with 3000 gallon capacity	1 mile lane per day
Cost of asphalt distributer per square yard = (total cost per day)/(productivity *1760*4)=	$0.0652 per square yard
Cost of seal coating per square yard = (material cost + transportation cost + asphalt distributer cost=	$0.82 per square yard

Note:

-Transportation cost per gallon = (trucking cost per mile x transportation distance)/(truck capacity(m^3) X 264)

-Transportation cost per square yard = Transportation cost per gallon X seal coat application rate

-As the material price above is the final price of the material at the construction site, the transportation cost is zero in this case

Table 4 – Cost of Spreading Aggregate

Aggregate price	$30 per ton for uniform crushed aggregate
Application rate	25 pound per square yard
Aggregate Cost =(price per ton X application rate)/ (2000)=	$0.375 per square yard
Transportation cost per pound =(trucking cost per mile X trucking distance)/ (truck capacity(ton) X 2000)=(10 X 10)/(10 X 2000)=	$0.005 per pound
Transportation cost per square yard =transportation cost per pound X application rate= 0.005 X 25=	$0.125 per square yard
Aggregate Spreader, self-propelled 187 H.P.	
Rent per day	$690
Hourly operations cost	$53.20
Index in 2013	201.2
Index in2016	207.2
Present cost for rent	$710.57
Present hourly operational cost	$54.78
Present daily operational cost	$438.24 (assuming 8 hours of work per day)
Total cost for aggregate spreader per day at 2016	$1148.81
Productivity of aggregate spreader	1 mile lane per day
Cost of aggregate spreader per square yard ==(total cost per day)/(productivity*1760*4)=	$0.1631 per square yard
Cost of aggregate spreading per square yard = (material cost + transportation cost + aggregate spreader cost=	$0.66 per square yard

Table 5 – Cost of Rolling Seal Coat Aggregate

Pneumatic Tire Roller 120 H.P.	
Rent per day	$545
Hourly operation cost	$24.15
Index in 2013	201.2
Index in 2016	207.2
Present cost for rent	$561.25
Present hourly operational cost	$24.87
Present daily operational cost	$198.96 (assuming 8 hours of work per day)
Total cost for rolling per day at 2016 based on RSMeans cost indexes	$760.21
Tire roller productivity	0.5 mile lane per day
Cost of rolling per square yard	$0.22 per square yard

Sweeping Loose Aggregate

Even after rolling there are some loose aggregate which shall be removed from asphalt surface because loose aggregates can damage passing cars, especially their wind shields. Road sweepers broom the surface to remove the loose aggregates. Productivity of road sweepers are usually between 0.5 mile to 1 mile. Detailed calculation for sweeping loose aggregate cost is the same as cleaning pavement surface cost. Based on the RSMeans 2013, The total cost of sweeping is included in Table 6.

Table 6 – Cost of Sweeping Loose Aggregates

Road Sweeper, self-propelled	8 feet wide, 90.H.P.
Rent per day	$575
Hourly operation cost	$39.85
Index in 2013	201.2
Index in 2016	207.2
Present cost for rent	$562.15
Present hourly operational cost	$41.04
Present daily operational cost	$328.32 (assuming 8 hours of work per day)
Total cost of road sweeper per day at 2016 based on RSMeans cost indexes	$920.47
Road sweeper productivity	0.6 mile lane per day
Cost of road sweeping = (total cost per day)/(productivity*1760*4)=	$0.22

Crack Sealing

Based on the serviceability and amount of small cracks at the pavement surface and to arrest crack growth, every 2 to 3 years between two chip sealing, surface cracks needs to be sealed. Crack sealing has to be done by expert crew to make sure all cracks will be sealed properly. The amount of the cracks for each pavement needs to be checked by visual inspection to predict the cost, but doing the crack sealing every 2 to 3 years, the amount of the cracks sealing would be usually less than 2 feet per square yard. Assuming 1 foot of crack per square yard and 1$ cost per foot length of the crack, the cost of the crack sealing per square yard would be 1$, as shown in Table 7.

Table 7 – Cost of Crack Sealing

Crack sealing cost = (foot length of cracks in square yard X crack sealing cost per foot)= 1 X 1=	$1 per square yard

Road User Cost

Road user cost depends on delay caused by construction for users. For very small ADT, the road user cost would be zero. By increasing ADT, traffic and delay caused by closing a lane for construction would be higher and the user cost increases. For a very large ADT, road user cost can be even more than all other construction costs. Road user cost unit is dollar/day per mile for one lane closed in one direction. For example, if road user cost is $100/day per mile it means that closing one mile-lane in one direction of the road for a day costs 100 dollar. As it is obvious, by increasing productivity of the construction, road user cost can be decreased. In fact, for a highway with very large ADT, it would be better to have as much productivity as it is possible to decrease the costs of the project.

Table 8 – Estimated Road User Cost

Six lane rural interstate arterial with 15 percent truck (ADT of 45000)	$200 / day per mile [11]
Six lane rural interstate arterial with 15 percent truck (ADT of 90000)	$5,900 / day per mile [11]
Six lane rural interstate arterial with 15 percent truck (ADT of 135000)	$23,400/ day per mile [11]

Note: Checking these three numbers, we can have two important results:

1- Road user cost does not increase linearly. In fact, increasing user cost at first level of increasing the ADT is very slow (200$/day per mile for the first 45000 increase in ADT). But going to the larger range of the ADT, increasing the user cost happens very fast (17500$/day per mile for the third 45000 increase in ADT).

2- Road user cost would be negligible for a relatively not large ADT (0.0284$/day per square yard for ADT of 45000). But for a very large ADT, road user cost would be the main cost of the project (3.3238$/day per square yard for ADT of 135000). In fact, for a highway with a very large ADT productivity of the construction would be the main item to determine the construction costs.

3- TxDOT official website (statewide mapping) provides traffic data for highways in Texas state. This excel file uses average AADT which is assumed to be equal to the mean of AADT at 2015 and AADT at 2035. For future use of this excel file, average ADT can be fined based on the new numbers provided by TxDOT official website [10].

Final Calculation

Based on the provided and calculated data in previous sheets of excel file, total cost of each time of chip sealing and crack sealing can be calculated at this page. Total cost of the preservation per square yard can also be found at this page.

Table 9 – Total Cost of Seal Coat

Costs of chip sealing for one time is equal to summation of all the costs calculated in previous pages for chip sealing	$2.16 per square yard
Number of chip sealing	Assumed to be 3 times (included in the general information sheet)
Net Present Value of 3 Seal Coat Applications	$12.52 per square yard
Cost of crack sealing for one time calculated at the crack sealing sheet	$1.01 per square yard
Crack sealing total cost during the pavement service life	$5.54 per square yard
Total Cost	**$18.06**

Note: The formula for calculating net present value is [21]: Net Present Value = Current Cost X [$(1+i)^n$] Where I is the discount rate (4% percent at this study) and n=number of years from initial construction.

Assumptions used at this example:

- we assumed that US0067-KG is highway that constructed in 2015 and has 30 years of service life.

- Based on very small ADT, road user cost for this highway is zero

- productivity of one mile lane per day assumed for the construction crew and equipment.

Note: All the prices and costs for materials, equipment, and road users are from

- TxDOT average low bid unit price

- RSMeans2013

- Daniels, G., Ellis, D. R., and W. R. Stockton, Techniques for Manually Estimating Road User Costs Associated with Construction Projects. 1999.

Ultra-thin Overlay Life Cycle Cost Excel File

This part explains how to use the excel file to analyze the life cycle cost of the ultra-thin overlay preservation method. As mentioned before, usually after about 10 years of initial construction, a pavement preservation technique needs to be performed to improve pavement ride quality and to minimize small distresses from growing to become major issue. Ultra-thin overlay service life is between 8 to 10 years. This means that 2 or 3 times of overlaying will be needed during regular pavement service life. Ultra-thin overlay life cycle cost excel file has 11 sheets. Working on an example, excel file can be fully understood in the following sections.

General Guide

This sheet has some general information about ultra-thin overlay method. It also instructions to use the file properly. References are also included in this sheet.

Brief Technical Information

This sheet provides general data about pavement and preservation service life. In this part, some basic estimations about the service life of ultra-thin overlay provided. Based on each specific projects, experts have to decide about the preservation time and service life, but these estimations can be used for general cost analysis.

Each construction step is introduced separately. This information can help users to become familiar with the construction process and use the excel file properly.

Reading “General Guide” and “Brief Technical Information” sheets thoroughly, user can understand how to use excel sheets and put the information and numbers in assigned cells to analyze the life cycle cost.

Data Input

Based on each specific project, general pavement information and preservation schedule has to be imported in this page. Pavement length, number of lanes and ADT would be based on the project specs and will be used to calculate the total cost of the project. Pavement service life is based on the pavement design. Usually pavement service life is around 30 years. After around 10 years of pavement initial construction, ultra-thin overlaying needs to be done to prevent small cracks growth, improve ride quality and increase skid resistance. As service life of the ultra-thin overlay is between 8 to 10 years, usually 2 or 3 times of overlaying would be needed during pavement service life. Number of years after initial pavement construction for which each time of overlaying has to be done have to be put in assigned cells. Traffic data for highways in Texas state can be found in TxDOT official website-statewide mapping [10]. The general project information is included in Table 10.

Pavement Milling

Pavement milling has two main parts: 1) Milling machine will be used to remove 0.5 inch of the pavement surface, and 2) trucks will be used to transport and stockpile RAP. Milling machine productivity assumed to be 0.5 mile per lane per day. The detailed pavement milling cost is included in Table 11.

Table 10 - General Project Information for Ultra-Thin Overlay

Project Name	US0067-KG
Project location	El Paso Texas
Control Section	010407
Project LENGTH	10
Number of lanes	6
Average ADT	350006
Highway Type	Suburban Divided Freeway
Pavement Service life	30 years (Assumed)
Chip Sealing	Three times of chip sealing after 10, 18, and 26 years of pavement initial construction (assumed)
Crack Sealing	Every 3 years between two chip sealing (assumed)
Productivity	1 mile lane per day for chip sealing and 2 mile lane per day for crack sealing (assumed)

Note1: data for highways in Texas can be found in TxDOT official website (statewide mapping).

Note2: AADT and ADT assumed to equal.

Note3: Highway traffic data from TxDOT official website-statewide mapping [10]

Table 11 – Cost of Milling Existing Pavement Surface

Large Scale Milling Machine	500 KW
Rent per day	$2,500
Hourly operation cost	$100
Daily operational cost	$800 (assuming 8 hours of work per day)
Total daily cost for milling machine	$3,300
Milling machine productivity	0.5 mile lane per day
Cost of cleaning per square yard = (total cost per day)/(productivity*1760*4)=	$0.9375 per square yard
Transportation cost per pound = (trucking cost per mile X trucking distance)/ (truck capacity(ton) X 2000)= (10 X 10)/(10 X 2000)=	$0.005 per pound
Transportation cost per square yard = (transportation cost per pound) X (milled RAP per square yard) X (1.2)= 0.005 X 50 X 1.2=	$0.3 per square yard

Note: The number 1.2 in the above line is a stockpiling cost factor

Cleaning Pavement Surface

Please see the Cleaning Pavement Service at Chip Sealing Life Cycle Cost Excel File section.

Tack Coat Spraying

Please see the Seal Coating at Chip Sealing Life Cycle Cost Excel File section.

Overlay Paving

This step has three main parts: 1) material (very small NMAS asphalt mixture), 2) transportation, and 3) paving. Due to very small thickness of the overlay, NMAS of the aggregate has to be also very small. This means that the amount of asphalt binder in the hot mix asphalt will be higher in comparison to conventional dense graded asphalt mixture. Thus, the unit price of the asphalt mixture that can be used in ultra-thin overlay would be higher than unit price of conventional asphalt mixture. TxDOT average low bid unit price and RSMeans reference book can be used to find the asphalt mixture and equipment costs respectively. Asphalt mixture rate of application can be calculated based on the overlay thickness and asphalt mixture approximate density.

Productivity of this step is dependent to the rhythm of providing asphalt mixture at the construction site but assuming all other variables under control, especially for ultra-thin overlay, asphalt paver usually having the highest productivity and can be a deterministic variable in estimating the total productivity of the whole equipment and crew. The cost of paving is included in Table 12.

Compaction

As the thickness of overlay in this method is very small, it is better to use static rolling because vibratory rolling can crush the aggregates and the cost is included in Table 13.

Table 12 – Cost of Paving Ultra-Thin Overlay

Asphalt mixture price	$120 per ton for very small NMAS asphalt mixture
Application rate	50 pound per square yard
Asphalt mixture cost == (price per ton X application rate)/ (2000)= (90 X 50)/(2000)=	$2.25 per square yard
Transportation cost per pound = (trucking cost per mile X trucking distance)/ (truck capacity (ton) X 2000)= (10 X 10)/(10 X 2000)=	$0.005 per pound
Transportation cost per square yard transportation cost per pound X application rate= 0.005 X 50=	$0.25 per square yard
Drum Roller	125 H.P.
Rent per day	$680
Hourly operation cost	$31
Index in 2013	201.2
Index in 2016	207.2
Present cost for rent	$700.27
Present hourly operational cost	$31.97
Present daily operational cost	$255.76 (assuming 8 hours of work per day)
Total cost for compaction per day at 2016 based on RSMeans cost indexes	$956.03
Productivity of roller	5 mile lane per day
Cost of roller per square yard (total cost per day)/(productivity*1760*4)=	$0.2716 per square yard

Table 13 – Cost of Compacting Ultra-Thin Overlay

Drum Roller 125 H.P.	
Rent per day	$680
Hourly operation cost	$31
Index in 2013	201.2
Index in2016	207.2
Present cost for rent	$700.27
Present hourly operational cost	$31.97
Present daily operational cost	$255.76 (assuming 8 hours of work per day)
Total cost for compaction per day at 2016 based on RSMeans cost indexes	$956.03
Productivity of roller	5 mile lane per day
Cost of roller per square yard ==(total cost per day)/(productivity*1760*4)=	$0.2716 per square yard

Road User Cost

Please see the Road User Cost at the Chip Sealing Life Cycle Cost Excel File section.

Final Calculation

Based on the provided and calculated data in previous sheets of excel file, total cost of each time of ultra-thin overlay can be calculated as per Table 14.

Table 14 – Total Cost of Ultra-Thin Overlay

Costs of ultra-thin overlay for one time is equal to summation of all the cost calculated in previous pages for chip sealing	$26.55 per square yard

Note:

1-The formula for calculating net present value is [21]: 21]:

2-Net Present Value = Current Cost X [(i+i)^n]

3-Where I is the discount rate (4% percent at this study) and n=number of years from initial construction.

Costs of ultra-thin overlay for one time is equal to summation of all the cost calculated in previous pages for chip sealing= $4.5 per square yard.

Assumptions used at this example:
- we assumed that US0067-KG is highway that constructed in 2015 and has 30 years of service life.
- Based on very small ADT, road user cost for this highway is zero
- productivity of one-mile lane per day assumed for the construction crew and equipment.

Note: All the prices and costs for materials, equipment, and road users are from

APPENDIX E.
TEX-XXXX DIRECT SHEAR TEST PROCEDURE FOR TACK COATS

Tex-XXX-F, Tack Coat Shear Strength Measurement Test

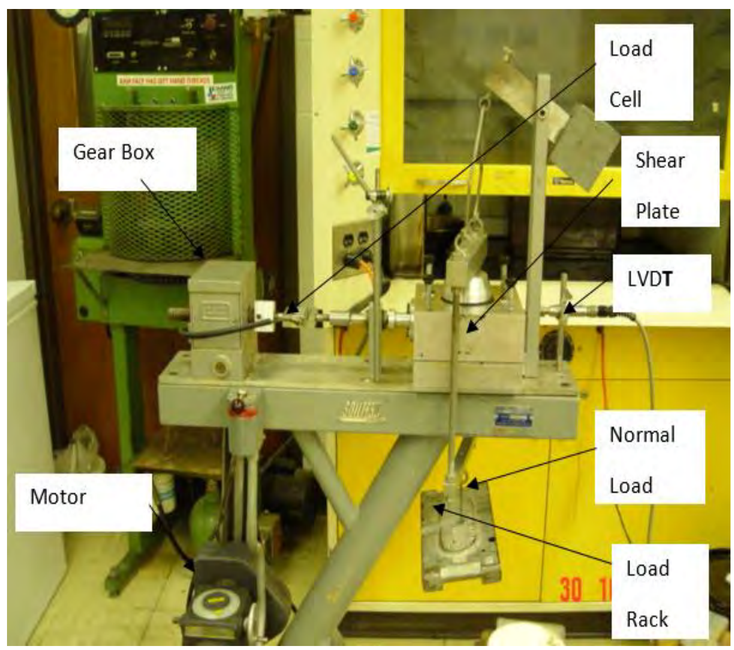
Overview
Effective Date: January 2018

Use this test method to evaluate the shear resistant properties of tack coat in laboratory by using modified direct shear test device.

Units of Measurement
The values given in parentheses (if provided) are not standard. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

Apparatus
Use the following apparatus:

- A direct shearing device with capability of applying loading rate of 0.25 in./min
- Scale, 3,000 g weighing with 0.1 g graduation.
- Air-drafted oven, which can reach temperature to 482°F (250°C).
- A 20 lbs. steel cylinder.
- Small scoop which has handle can resist 302°F (150°C) in the oven.
- Several 1, 15, and 20 lbs. weights.
- Thermal grove which can resistant high temperature around 302°F (150°C).



Shear Strength Test Setup

Materials
- Circular solid synthetic cylindrical (4in. diameter and 2 in. height) machined specimens
- Normal loading weights
- Tack coat

Procedure

Follow these steps to prepare the testing apparatus for use and to perform the tack coat shear strength test.

Preparing Tack Coat Pull Off Device for Use	
Preparing Apparatus	
Step	**Action**
1	Clean the synthetic 4 in. diameter (2 in. thickness) specimens by using wipe paper.
2	Put the can which has tack coat residue in the oven at specific temperature according to the viscosity of the residue binder for at least 30 min. until the tack coat becoming liquid stage.
3	Use glass rod to stir the tack to get uniform residue.
4	Put the synthetic specimens in another air-drafted oven at 125°F for 10 min. and put the specimen on the scale, then drop around 0.063 oz. tack residue on the specimen. Use scoop spread the residue on the specimen surface evenly. Then put another specimen on coated one. This step should be finished in 3 mins to avoid the binder to be cold.
5	Put the 20 lbs weight on the top of prepared synthetic specimen for 3 days at laboratory temperature.
Performing Laboratory Test	
6	Set gear speed of direct shear test (DST) device at 0.25 in. /min.
7	Turn on the computer and open the data acquisition system. Put the specimen in the DST mold, make sure the sitting is appropriate. Then put the specified weight (18, 36, or 72 lbs.) as normal loading on the load rack.
8	Put the LVDT on the frame, and zero the readings on the computer screen.
9	Turn on the DST gear control and start the data recording on the screen at the same time.
10	Stop the test when the shear strength vs LVDT displacement curve on the screen have peak.
11	Repeat the steps of 7 to 10 to finish all the direct shear test with different normal loading levels. For each normal loading level, there are three replicates prepared for the test.
12	Follow the next section to calculate the cohesion and friction angle.

Figure 2. Curing Condition for synthetic white specimens.

Calculations

Calculate the cohesion and friction angle based on the Mohr Circle Principle developed in soil mechanics. To identify the cohesion as well as frictional resistance component of the shear strength, the following equation is used $\tau = c + \sigma \tan\phi$ where τ is the shear strength, c is cohesion, σ is normal stresses and ϕ is the angle of friction. In the case of tack coat testing, the c value is the cohesive strength of applied tack and $\tan\phi$ is the frictional resistance offered by the two layers, as shown in figure 3. Figure 4 demonstrates an example of direct shear test with tack coat.

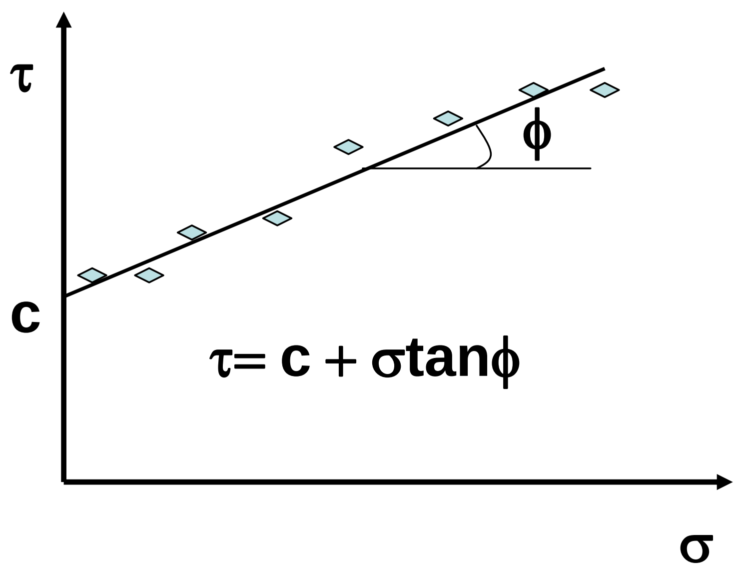


Figure 3. Schematic Mohr Circle Principle applying in tack coat DST test.

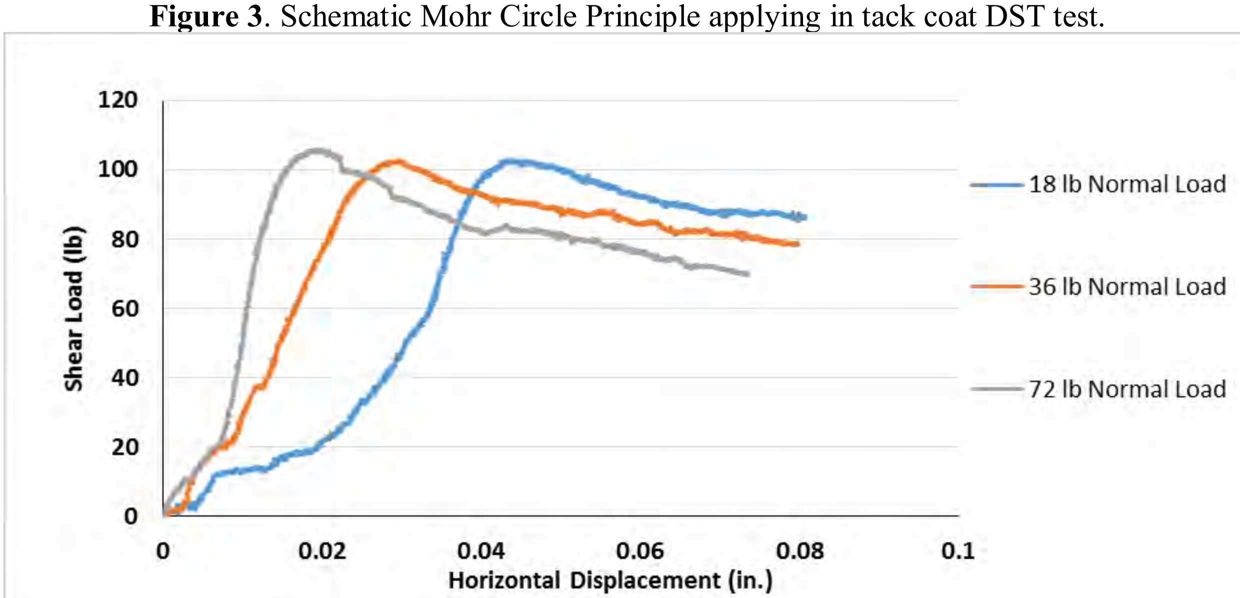


Figure 4. Typical Tack coat DST Test Results

Analysis Example

The following part is to illustrate an analysis example of direct shear test with tack coat step by step. The constitutive model developed from one study titled as "Characterization of Asphalt Concrete Layer Interfaces" is applied in this analysis. The data in figure 4 is shown herein.

Step 1

Open the raw data "XXX.cvs" file from spreadsheet, and depict the strength vs. horizontal displacement curve in a figure, such as Figure 4.

Step 2

Use spreadsheet function of *maximum* to find the peak strength from each single curve and typed the strength value in below table:

XXX, 0.03 gal/sq. yd	**Normal Loading (lb)**	**18**	**36**	**72**
	Shear Strength (lb)	102.9	103.2	106.0

Note: The non-bold data are input value, same as other tables.

Step 3

Calculate the shear stress by using shear strength to divide the specimen cross area ($S=\pi(r)^2$), the normal stress is achieved by using normal loading to divide the specimen across area. Then the following result can be calculated:

XXX, 0.03 gal/sq. yd	**Normal Stress (σ)**	1.4	2.8	5.7
	Shear Stress (τ)	1.6	1.7	1.8

Step 4

Plot the shear stress vs. normal stress curve in the spreadsheet and using the linear trend line function to do the correlation between these two parameters ($y=a+b*x$). Where y is shear stress τ, a is the cohesion value-C and b is the friction factor which is a tangent function of friction angle-ϕ. In this case, the following equation of $y=8.0799+0.0598x$ was gotten from the spreadsheet chart, and then the cohesion was 8.0799 psi and the friction angle was Arc tan (0.0598) = 3 °.

Step 5

Use the constitute model shown in below figure to characterize the direct shear test curve and the abscissa is replaced from shear displacement by shear strain which was calculated by using the strain according to the peak shear strength to divide the diameter of specimen.

Step 6

ANOVA analysis needs to be performed to verify the repeatability of the direct shear test and report cohesion strength and friction angle.

APPENDIX F.
TEX-XXXX THREE WHEEL POLISHING DEVICE - DIRECT FRICTION TEST TO EVALUATE PERFORMANCE OF MIXES USED AS AN ULTRA-THIN OVERLAY

Test Procedure for Polishing Resistance of Asphalt Surfaces Using a Three Wheel Polishing Device

TxDOT Designation: XXXXX

Effective Date: XXXXXX

1. SCOPE

1.1 This procedure simulates the influence of traffic on the performance of bituminous mixtures related to aggregate polishing, raveling, bleeding, rutting, and adhesion between bituminous pavements layers.

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 *Polish Test Device (PTD)* – a device (such as shown in Figure 1) designed to use pneumatic rubber tires attached to a turntable tracking a 12 in. ± 0.1 in. (mm) diameter circle over a bituminous test specimen matching the measurement path of the Dynamic Friction Tester (DFT) and Ciruclar Texture Meter (CTM) testing devices.

Figure 1 *- PolishTest Device (PTD)*
(left: overall view of the device; right: closer view of the wheels)

2.1.1 Pneumatic rubber tires of 8 in. diameter x 3 in. width (203.2 x 76.2 mm) at an inflation pressure for each tire of 50 ± 1 psi (344.7 ± 6.9 kPa).

2.1.2 A total overhead load applied by adding two circular steel plates on top of the turntable of

91 ± 5 lb. (405 ± 22 N).

2.1.3 A turntable capable of rotating at a constant speed of 60 ± 2 rpm.

2.2 *Spray System* – a water pool with a circulating system (i.e., water pump) and a pipe system capable of spraying water on top of the specimen during the test.

2.2.1 The water pool temperature must be maintained at 74 ± 4 °F (23.5 ± 2 °C).

2.3 *Wheel Cycle Counter* – a non-mechanical contacting system (usually a laser) capable of counting each wheel cycle passing over the test specimen.

2.3.1 Couple the signal from this counter with an automatic cut off system programmed using a digital controller to immediately stop the equipment at any required number of cycles.

2.4 *Specimen Mounting System* – a stiff metal base mounted rigidly to the equipment in order to place the specimen.

2.4.1 The mounting system must be level and restrict shifting of the specimen during testing to 0.1 inches (2.5 mm) in any direction.

2.5 *Dynamic Friction Tester (DFT)* – a portable device used for measuring pavement friction as a function of speed in an underwater condition. This device is comprised of a measuring unit and a control unit. A computer is required to record the data.

2.5.1 The size of the measuring unit (Figure 2) shall be 21-1/4 x 23-1/4 x 15 in. (540 x 590 x 380 mm) and weigh 37 lbs. (16.8 kg). It shall contain a 13.75 in. x (349.2 mm) diameter disc that rotates horizontally at a specified speed of 49.7 mph (80 kmph) before being lowered onto a wetted test surface for measurement of friction.

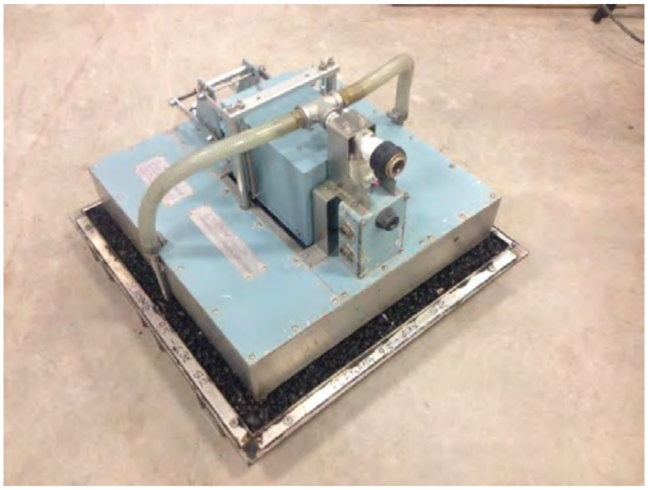


Figure 2 *–Dynamic Friction Tester (DFT) Measuring Unit (Data Acquisition Unit and Computer Not Shown)*

2.5.2 Three spring-loaded rubbers "sliders" shall be attached to the DFT measuring unit. The standard rubber for the slider assembly is synthetic rubber.

2.5.3 The control or data acquisition unit must be capable of capturing data and providing the relationship between the coefficient of friction versus speed from 0 to 49.7 mph (0 to 80 kmph). Three friction measurements are to be used at 12.4, 24.9, and 37.3 mph (20, 40, and 60 kmph).

2.5.4 The measuring unit and control unit shall be powered by 12V DC (i.e., a normal car size battery).

2.5.5 Refer to the manufacturer's specifications for equipment calibration and accuracy.

2.6 *Aluminum Specimen Mold* – a mold fabricated on top of an aluminum base plate 22 in. (558.8 mm) long x 22 in. (558.8 mm) wide x xx in. thick (Figure 3). The mold walls shall be provided with xx in. thick removable aluminum angles that create a 20 ± 0.2 in. (508 ± 5 mm) x 20 ± 0.2 in. (508 ± 5 mm) square on the aluminum base plate. The depth of the aluminum angle depends on the desired bituminous specimen thickness to be tested; usually 0.5 to 1.0 in. (12.7 to 25.5 mm). The aluminum angles shall be bolted on the top and around the edges of the base plate to serve as a mold to contain the bituminous mix during compaction.

2.7 *Oven* – capable of maintaining a temperature of at least 325 ± 5°F (163 ± 3°C).

2.8 *Manual Roller Compactor* – a manual compaction tool that consists of a roller drum of 10.0 in. (254.0 mm) working width, 9.0 in. (228.6 mm) diameter, and 60 lb. (27.2 kg) weight or similar.

2.9 *Rut Depth Gauge* – an instrument capable of measuring the rut depth created by the pneumatic rubber tires within 0.0004 in. (0.01 mm) over a minimum depth of 0.8 in. (20 mm) along the wheel track.

2.10 *Spirit Level* – a 24 in. (610 mm) long instrument capable of measuring the level of the surface of the bituminous slab specimen.

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3. MATERIALS

3.1 *Bituminous Mix* – Use mix as specified per the pertinent TxDOT Specification Items in the applicable project plans. For lab-produced mixtures, combine aggregates and prepare the laboratory mixture as described in Tex-205-F. For plant-produced mixtures, sample the mixture in accordance with Tex-222-F.

4. PROCEDURE

4.1 *Laboratory-Molded Specimens:* Prepare two molded specimens in accordance with Section 4.1 for each mixture design to be used for testing.

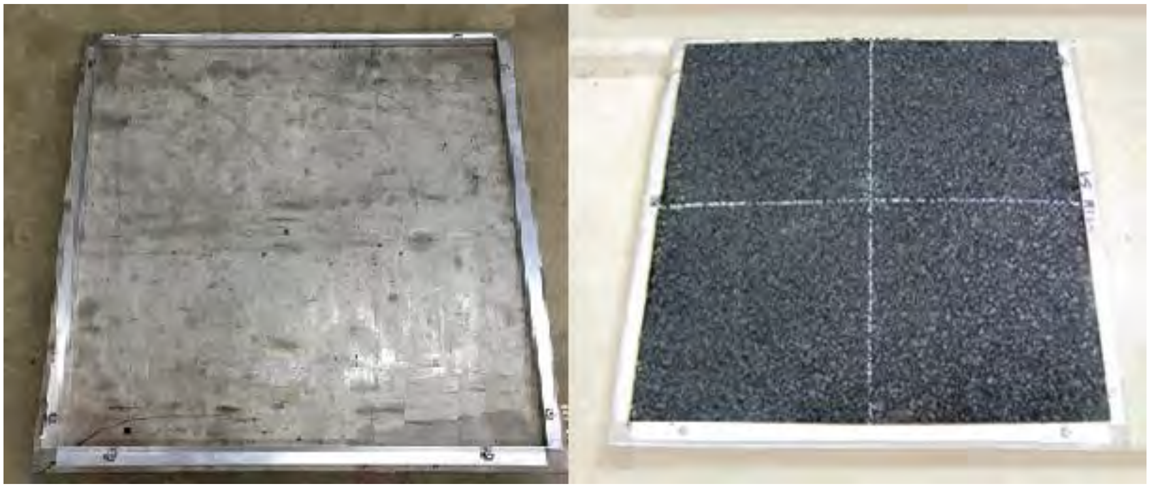

***Figure 3** – PTD Aluminum Mold and HMA Slab Specimen*

4.2 For lab-produced mixtures, perform the following:

4.2.1 Wash the aggregates and dry overnight inside the oven at 302 ± 5°F (150 ± 3°C) to ensure that the moisture is removed before mixing with the asphalt binder.

4.2.2 Heat the asphalt binder inside the oven using Table 1 below based on the PG asphalt binder in accordance with TxDOT Tex-241-F.

***Table 1** – Mixing, Compaction, and Curing Temperature*

Asphalt	Temperature °F (°C)		
Grade	Mixing	Compaction	Curing
PG 64-22	290 (143)	250 (121)	250 (121)
PG 70-22	300 (149)	275 (135)	275 (135)
PG 76-22	325 (163)	300 (149)	300 (149)

Note 1 – The time must be sufficient to provide an appropriate workability and viscosity to properly coat the aggregates.

4.2.3 Use mixture weights for laboratory-molded specimens that achieve the density requirement between 7000 and 7800 g. Mix the asphalt binder and aggregates at the temperature listed in Table 1 above using Test Procedure Tex-205-F. Density of test specimens must be 93 ± 1%, except for Permeable Friction Course (PFC) mixtures.

Note 2 – All additives must be used if the mixture design requires.

4.2.4 Place the loose asphalt mixture inside the oven for two hours at the appropriate temperature listed in Table 1 based on the PG of the asphalt binder

Note 3 - This process simulates the short-term aging during mixing and transportation in the field.

4.2.5 After the asphalt mixture is heated for two hours inside the oven, remix until all the aggregates are coated by the asphalt binder.

4.2.6 Apply a uniform coat of CRS-2P or equivalent tack coat to the base and inside edges of the mold to create a bond between the bituminous mix and the mold. The tack coat application rate shall be between 0.08 and 0.10 gal. of residual asphalt per square yard of surface area.

4.2.7 Weigh the amount of loose hot mix, which when compacted to the target volume results in the target density. Place and spread the loose hot mix over the tack coat covered mold.

4.2.8 Compact the mix manually, using the manual roller compactor, at the appropriate temperature shown in Table 1 based on the PG of the asphalt binder in accordance with Tex-241-F until the top of the compacted mix is even with the top of the mold edges.

4.2.9 Allow the mix to cool to 160°F (71°C) before testing with the PTD.

4.3 *Mounting and Testing Specimens in the PTD:*

4.3.1 Place and center the laboratory-molded specimen into the PTD.

Note 4 – Set the PTD with the correct pneumatic tire pressure, overhead load, water pool temperature, and speed of rotation.

4.3.2 Turn on the water spray system to provide water in an amount to wash away all abraded particles from the surface of the specimen during the entire test.

4.3.3 Lower the PTD turntable until the pneumatic tires rest on top of the specimen.

Note 5 – Position the PTD turntable in the center of the slab. After the designated number of cycles, remove the specimen for testing with the DFT ensuring the same location is used in order to match the wheel path in both the PTD and DFT. Mark the edges of the DFT on the surface of the mix to achieve this.

4.3.4 Program the PTD to a designated number of cycles (Table 2).

Note 6 – The PTD is equipped with an automatic cut off that can be programmed to stop the equipment at any required number of cycles.

Table 2 *– Designated number of cycles for thePTD test*

Stop Point	Cycles Applied	Cumulative Cycles
1	500	500
2	500	1000
3	1000	2000
4	2000	4000
5	4000	8000
6	8000	16000
7	16000	32000
8	32000	64000
9	36000	100000

4.3.5 Start the test using the wheel cycle counter provided with the PTD. At each Stop Point, record the number of cumulative cycles, remove the slab specimen for testing with the DFT, and measure for rutting.

4.3.6 Inspect the PTD pneumatic tires after each stop point to ensure that the wear in the tires is consistent. Replace all tires after every six slab specimens tested.

4.3.7 Repeat the PTD test from Section 4.2.1 to 4.2.6 on the second slab specimen.

4.4 *Mounting and Testing Specimens in the DFT:*

4.4.1 Place the laboratory specimen under the DFT and ensure that it is centered and leveled.

Note 7 – The specimen must be tested at the beginning (0 cycles applied in the PTD) and after each stop point based on the designated number of cycles (Table 2) applied using the PTD.

4.4.2 Open the water valve to provide the sufficient amount of water to gently rinse the surface as the test is being conducted (approximately one gallon every five mintues).

4.4.3 Program the DFT to a terminal speed of 49.7 mph (80 kmph).

4.4.4 Start the test using the software provided with the equipment. The DFT automatically starts the test when the device has achieved the target speed of 49.7 mph (80 km/h).

Note 9 – During the test, make sure that the slab specimen, placed under the DFT, is level to avoid any contact of the rubber slider pads with the slab specimen surface during the time the DFT base plate is achieving the target speed.

4.4.5 Record the average of the three coefficients of friction measured at 12.4 mph (20 km/h), 24.8 mph (40 km/h), and 37.3 mph (60 km/h).

Note 8 – The DFT output data provides the relationship between the coefficient of friction versus the speed from 0 to 49.7 mph (80 km/h) (e.g. Figure 4). The average of the three coefficients of friction measured at 12.4 mph (20 km/h), 24.8 mph (40 km/h), and 37.3 mph (60 km/h) is reported for each test.

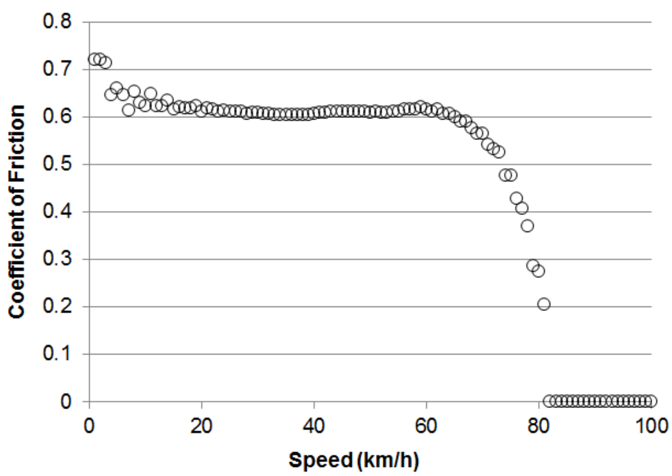

***Figure 4** – Typical DFT Output Data*

Check the DFT rubber slider pads after three measurements for consistent wear. Replace after every 45 measurements.

Using the second slab specimen, repeat the DFT test from Section 4.3.1 to 4.3.6 for three replicate friction measurements.

4.5 *Testing Specimens with the Rut Depth Gauge:*

4.5.1 Place the rut depth gauge in three different random locations on top of the wheel path in the slab specimen.

4.5.2 Record the average of the three rutting measurements at the beginning (0 cycles applied in the PTD) and after the designated number of cycles (Table 2) applied using the PTD.

5. REPORT

5.1 Report the following for each slab specimen:

- slab specimen type;
- slab specimen thickness;
- coefficient of friction at 0, 500, 1000, 2000, 4000, 8000, 16000, 32000, 64000, and 100000 passes (when available);
- rut depth at 0, 500, 1000, 2000, 4000, 8000, 16000, 32000, 64000, and 100000 passes (when available);
- number of cycles to failure;
- additional comments.

APPENDIX G.
ITEM-XXXX ULTRA THIN OVERLAY MIXES

Item XXX

Ultra Thin Overlay Mixes

1. DESCRIPTION

Construct a thin surface course composed of a compacted mixture of aggregate and asphalt binder mixed hot in a mixing plant. Produce a thin surface course with a lift thickness of 1/2 in.

2. MATERIALS

Furnish uncontaminated materials of uniform quality that meet the requirements of the plans and specifications.

Notify the Engineer of all material sources and before changing any material source or formulation. The Engineer will verify that the specification requirements are met when the Contractor makes a source or formulation change, and may require a new laboratory mixture design, trial batch, or both. The Engineer may sample and test project materials at any time during the project to verify specification compliance in accordance with Item 6, "Control of Materials."

2.1. **Aggregate.** Furnish aggregates from sources that conform to the requirements shown in Table 1 and as specified in this Section. Aggregate requirements in this Section, including those shown in Table 1, may be modified or eliminated when shown on the plans. Additional aggregate requirements may be specified when shown on the plans. Provide aggregate stockpiles that meet the definitions in this Section for coarse, intermediate, or fine aggregate. Do not use reclaimed asphalt pavement (RAP) or recycled asphalt shingles (RAS). Supply aggregates that meet the definitions in Tex-100-E for crushed gravel or crushed stone. The Engineer will designate the plant or the quarry as the sampling location. Provide samples from materials produced for the project. The Engineer will establish the Surface Aggregate Classification (SAC) and perform Los Angeles abrasion, magnesium sulfate soundness, and Micro-Deval tests. Perform all other aggregate quality tests listed in Table 1. Document all test results on the mixture design report. The Engineer may perform tests on independent or split samples to verify Contractor test results. Stockpile aggregates for each source and type separately. Determine aggregate gradations for mixture design and production testing based on the washed sieve analysis given in Tex-200-F, Part II.

2.1.1. **Coarse Aggregate.** Coarse aggregate stockpiles must have no more than 20% material passing the No. 8 sieve. Aggregates from sources listed in the Department's *Bituminous Rated Source Quality Catalog* (BRSQC) are preapproved for use. Use only the rated values for hot-mix listed in the BRSQC. Rated values for surface treatment (ST) do not apply to coarse aggregate sources used in hot-mix asphalt.

For sources not listed on the Department's BRSQC:
- build an individual stockpile for each material;
- request the Department test the stockpile for specification compliance; and
- once approved, do not add material to the stockpile unless otherwise approved.

Provide aggregate from non-listed sources only when tested by the Engineer and approved before use. Allow 30 calendar days for the Engineer to sample, test, and report results for non-listed sources.

2.1.1.1. **Blending Class A and Class B Aggregates.** Coarse aggregate stockpiles should consist of only Class A aggregates.

2.1.1.2. **Micro-Deval Abrasion.** The Engineer will perform a minimum of one Micro-Deval abrasion test in accordance with Tex-461-A for each coarse aggregate source used in the mixture design that has a Rated Source Soundness Magnesium (RSSM) loss value greater than 15 as listed in the BRSQC. The Engineer will perform testing before the start of production and may perform additional testing at any time during production. The Engineer may obtain the coarse aggregate samples from each coarse aggregate source or may require the Contractor to obtain the samples. The Engineer may waive all Micro-Deval testing based on a satisfactory test history of the same aggregate source.

The Engineer will estimate the magnesium sulfate soundness loss for each coarse aggregate source, when tested, using the following formula:

$$Mg_{est.} = (RSSM)(MD_{act.}/RSMD)$$

where:
Mg_{est} = magnesium sulfate soundness loss
MD_{act} = actual Micro-Deval percent loss
RSMD = Rated Source Micro-Deval

When the estimated magnesium sulfate soundness loss is greater than the maximum magnesium sulfate soundness loss specified, the coarse aggregate source will not be allowed for use unless otherwise approved. The Engineer will consult the Geotechnical, Soils, and Aggregates Branch of the Construction Division, and additional testing may be required before granting approval.

2.1.2. **Fine Aggregate.** Fine aggregates consist of manufactured sands and screenings. Natural sands are not allowed in any mixture. Fine aggregate stockpiles must meet the gradation requirements in Table 2. Supply fine aggregates that are free from organic impurities. The Engineer may test the fine aggregate in accordance with Tex-408-A to verify the material is free from organic impurities. Use fine aggregate from coarse aggregate sources that meet the requirements shown in Table 1 unless otherwise approved.

Test the stockpile if 10% or more of the stockpile is retained on the No. 4 sieve and verify that it meets the requirements shown in Table 1 for crushed face count (Tex-460-A) and flat and elongated particles (Tex-280-F).

2.2. **Mineral Filler.** Mineral filler consists of finely divided mineral matter such as agricultural lime, crusher fines, hydrated lime, or fly ash. Mineral filler is allowed unless otherwise shown on the plans. Use no more than 2% hydrated lime unless otherwise shown on the plans. Test all mineral fillers except hydrated lime and fly ash in accordance with Tex-107-E to ensure specification compliance. The plans may require or disallow specific mineral fillers. Provide mineral filler, when used, that:

- is sufficiently dry, free-flowing, and free from clumps and foreign matter as determined by the Engineer;
- does not exceed 3% linear shrinkage when tested in accordance with Tex-107-E; and
- meets the gradation requirements in Table 3.

2.3. **Baghouse Fines.** Fines collected by the baghouse or other dust-collecting equipment may be reintroduced into the mixing drum.

Table 1
Aggregate Quality Requirements

Property	Test Method	Requirement
Coarse Aggregate		
SAC	Tex-499-A (AQMP)	A[1]
Deleterious material, %, Max	Tex-217-F, Part I	1.5
Decantation, %, Max	Tex-217-F, Part II	1.5
Micro-Deval abrasion, %	Tex-461-A	Note[2]
Los Angeles abrasion, %, Max	Tex-410-A	30
Magnesium sulfate soundness, 5 cycles, %, Max	Tex-411-A	20
Crushed face count,[3] %, Min	Tex-460-A, Part I	95
Flat and elongated particles @ 5:1, %, Max	Tex-280-F	10
Fine Aggregate		
Linear shrinkage, %, Max	Tex-107-E	3
Combined Aggregate[4]		
Sand equivalent, %, Min	Tex-203-F	45

1. Surface Aggregate Classification of "A" is required unless otherwise shown on the plans.
2. Used to estimate the magnesium sulfate soundness loss in accordance with Section 347.2.1.1.2., "Micro-Deval Abrasion."
3. Only applies to crushed gravel.
4. Aggregates, without mineral filler or additives, combined as used in the job-mix formula (JMF).

Table 2
Gradation Requirements for Fine Aggregate

Sieve Size	% Passing by Weight or Volume
3/8"	100
#8	70–100
#200	0–30

Table 3
Gradation Requirements for Mineral Filler

Sieve Size	% Passing by Weight or Volume
#8	100
#200	55–100

2.4. Asphalt Binder. Furnish the type and grade of binder specified on the plans that meets the requirements of Item 300, "Asphalts, Oils, and Emulsions."

2.4.1. Performance-Graded (PG) Binder. Provide an asphalt binder with a high-temperature grade of PG 70 or 76 and low-temperature grade as shown on the plans in accordance with Section 300.2.10., "Performance-Graded Binders," when PG binder is specified.

2.5. Tack Coat. Furnish polymer modified trackless tack coat or a PG binder with a minimum high-temperature grade of PG 64 for tack coat binder in accordance with Item 300, "Asphalts, Oils, and Emulsions." Specialized or preferred tack coat materials may be allowed or required when shown on the plans. Do not dilute emulsified asphalts at the terminal, in the field, or at any other location before use.

The Engineer will obtain at least two samples of the tack coat binder per project in accordance with Tex-500-C and test it to verify compliance with Item 300, "Asphalts, Oils, and Emulsions." The sample shall also perform Tex XXX-F (Tack Coat Shear Strength Measurement Test) to measure cohesive strength and tack coat shall exhibit a minimum of 15 psi strength as per the specified test.

2.6. **Additives.** Use the type and rate of additive specified when shown on the plans. Additives that facilitate mixing, compaction, or improve the quality of the mixture are allowed when approved. Provide the Engineer with documentation such as the bill of lading showing the quantity of additives used in the project unless otherwise directed.

2.6.1. **Fibers.** Provide cellulose or mineral fibers when PG binder is specified. Do not use fibers when A-R binder is specified. Submit written certification to the Engineer that the fibers proposed for use meet the requirements of DMS-9204, "Fiber Additives for Bituminous Mixtures." Fibers may be pre-blended into the binder at the asphalt supply terminal unless otherwise shown on the plans.

2.6.2. **Lime Mineral Filler.** Add lime as mineral filler at a rate of 1.0% by weight of the total dry aggregate in accordance with Item 301, "Asphalt Antistripping Agents," unless otherwise shown on the plans or waived by the Engineer based on Hamburg Wheel test results. Do not add lime directly into the mixing drum of any plant where lime is removed through the exhaust stream unless the plant has a baghouse or dust collection system that reintroduces the lime into the drum.

2.6.3. **Lime and Liquid Antistripping Agent.** When lime or a liquid antistripping agent is used, add in accordance with Item 301, "Asphalt Antistripping Agents." Do not add lime directly into the mixing drum of any plant where lime is removed through the exhaust stream unless the plant has a baghouse or dust collection system that reintroduces the lime into the drum. Lime added as mineral filler will count towards the total quantity of lime specified when the plans require lime to be added as an antistripping agent.

2.6.4. **Warm Mix Asphalt (WMA) Additives.** Department-approved WMA additives or processes may be used to facilitate mixing and compaction of HMA produced at target discharge temperatures above 275°F; however, such mixtures will not be defined as WMA.

2.7. **Recycled Materials.** Recycled materials are not allowed for use.

3. EQUIPMENT

Provide required or necessary equipment in accordance with Item 320, "Equipment for Asphalt Concrete Pavement."

4. CONSTRUCTION

Produce, haul, place, and compact the specified paving mixture. In addition to tests required by the specification, Contractors may perform other QC tests as deemed necessary. At any time during the project, the Engineer may perform production and placement tests as deemed necessary in accordance with Item 5, "Control of the Work." Schedule and participate in a mandatory pre-paving meeting with the Engineer on or before the first day of paving unless otherwise shown on the plans.

4.1. **Certification.** Personnel certified by the Department-approved hot-mix asphalt certification program must conduct all mixture designs, sampling, and testing in accordance with Table 6. Supply the Engineer with a list changes are made. Provide a mixture design developed and signed by a Level 2 certified specialist. Provide Level 1A certified specialists at the plant during production operations. Provide Level 1B certified specialists to conduct placement tests.

4.2. **Reporting and Responsibilities.** Use Department-provided Excel templates to record and calculate all test data, including mixture design, production and placement tests, control charts, and thermal profiles. Obtain the latest version of the Excel templates at http://www.txdot.gov/inside-txdot/forms-publications/consultants-contractors/forms/site-manager.html or from the Engineer. The Engineer and the Contractor will provide any available test results to the other party when requested. The Engineer and the Contractor will immediately report to the other party any test result that requires suspension of production or placement or that fails to meet the specification requirements. Record and submit all test results and pertinent information on Department-provided Excel templates to the Engineer electronically by means of a portable USB flash drive, compact disc, or via email.

Subsequent sublots placed after test results are available to the Contractor, which require suspension of operations, may be considered unauthorized work. Unauthorized work will be accepted or rejected at the discretion of the Engineer in accordance with Article 5.3., "Conformity with Plans, Specifications, and Special Provisions."

Use the procedures described in Tex-233-F, when directed, to plot the results of all production and placement testing. Update the control charts as soon as test results for each sublot become available. Make the control charts readily accessible at the field laboratory. The Engineer may suspend production for failure to update control charts.

4.3. **Quality Control Plan (QCP).** Develop and follow the QCP in detail. Obtain approval for changes to the QCP made during the project. The Engineer may suspend operations if the Contractor fails to comply with the QCP.

Submit a written QCP before the mandatory pre-paving meeting, when directed. Receive approval of the QCP before beginning production. Include the following items in the QCP:

4.3.1. **Project Personnel.** For project personnel, include:
- a list of individuals responsible for QC with authority to take corrective action;
- current contact information for each individual listed; and
- current copies of certification documents for individuals performing specified QC functions.

4.3.2. **Material Delivery and Storage.** For material delivery and storage, include:
- the sequence of material processing, delivery, and minimum quantities to assure continuous plant operations;
- aggregate stockpiling procedures to avoid contamination and segregation;
- frequency, type, and timing of aggregate stockpile testing to assure conformance of material requirements before mixture production; and
- procedure for monitoring the quality and variability of asphalt binder.

4.3.3. **Production.** For production, include:
- loader operation procedures to avoid contamination in cold bins;
- procedures for calibrating and controlling cold feeds;
- procedures to eliminate debris or oversized material;
- procedures for adding and verifying rates of each applicable mixture component (e.g., aggregate, asphalt binder, lime, liquid antistrip, WMA, fibers);
- procedures for reporting job control test results; and
- procedures to avoid segregation and drain-down in the silo.

4.3.4. **Loading and Transporting.** For loading and transporting, include:

- type and application method for release agents; and
- truck loading procedures to avoid segregation.

4.3.5. **Placement and Compaction.** For placement and compaction, include:

- proposed agenda for mandatory pre-paving meeting, including date and location;
- proposed paving plan (e.g., paving widths and joint offsets);
- type and application method for release agents in the paver and on rollers, shovels, lutes, and other utensils;
- procedures for the transfer of mixture into the paver while avoiding segregation and preventing material spillage;
- process to balance production, delivery, paving, and compaction to achieve continuous placement operations and good ride quality;
- paver operations (e.g., operation of wings, height of mixture in auger chamber) to avoid physical and thermal segregation and other surface irregularities; and
- procedures to construct quality longitudinal and transverse joints.

4.4. **Mixture Design.**

4.4.1. **Design Requirements.** Use the PFC design procedure given in Tex-204-F, Part V, unless otherwise shown on the plans. Design the mixture to meet the requirements listed in Tables 7 and 8. Use a Superpave Gyratory Compactor (SGC) at 50 gyrations as the design number of gyrations (Ndesign).

The Engineer will provide the mixture design when shown on the plan. The contractor may submit a new mixture design at any time during the project. The Engineer will verify and approve all mixture designs (JMF1) before the Contractor can begin production.

Provide the Engineer with a mixture design report using the Department-provided Excel template. Include the following items in the report:

- the combined aggregate gradation, source, specific gravity, and percent of each material used;
- asphalt binder content;
- the tack coat application rate;
- results of all applicable tests;
- the mixing and molding temperatures;
- the signature of the Level 2 person or persons that performed the design;
- the date the mixture design was performed; and
- a unique identification number for the mixture design.

4.4.2. **Job-Mix Formula Approval.** The job-mix formula (JMF) is the combined aggregate gradation, Ndesign level, and target asphalt percentage used to establish target values for hot-mix production. JMF1 is the original laboratory mixture design used to produce the trial batch. The Engineer and the Contractor will verify JMF1 based on plant-produced mixture from the trial batch unless otherwise approved. The Engineer may accept an existing mixture design previously used on a Department project and may waive the trial batch to verify JMF1. The Department may require the Contractor to reimburse the Department for verification tests if more than 2 trial batches per design are required.

4.4.2.1. **Contractor's Responsibilities.**

4.4.2.1.1. **Superpave Gyratory Compactor.** Furnish an SGC calibrated in accordance with Tex-241-F for molding production samples. Locate the SGC at the Engineer's field laboratory and make the SGC available to the Engineer for use in molding production samples.

4.4.2.1.2. **Gyratory Compactor Correlation Factors.** Use Tex-206-F, Part II, to perform a gyratory compactor correlation when the Engineer uses a different SGC. Apply the correlation factor to all subsequent production test results.

4.4.2.1.3. **Hamburg, Three Wheel Polisher and Overlay Testing.** Use an approved laboratory from the Department's MPL to perform the Hamburg Wheel test, and provide results with the mixture design, or provide 10,000 g of the laboratory mixture and request that the Department perform the Hamburg Wheel test.

Provide 25,000 g of the laboratory mixture and request that the Department perform the Overlay test.

Provide 40,000 g of the laboratory mixture and request that the Department perform the Three Wheel Polisher test.

The Engineer will be allowed 15 working days to provide the Contractor with Hamburg Wheel, Three Wheel Polisher, and Overlay test results on the laboratory mixture design.

4.4.2.1.4. **Submitting JMF1.** Furnish a mix design report (JMF1) including Hamburg, Three Wheel Polisher and Overlay results. Provide representative samples of all component materials and request approval to produce the trial batch.

4.4.2.1.5. **Supplying Aggregates.** Provide approximately 40 lb. of each aggregate stockpile unless otherwise directed.

4.4.2.1.6. **Supplying Asphalt.** Provide at least 1 gal. of the asphalt material and sufficient quantities of any additives proposed for use.

4.4.2.1.7. **Ignition Oven Correction Factors.** Determine the aggregate and asphalt correction factors from the ignition oven in accordance with Tex-236-F. Note that the asphalt content correction factor takes into account the percent fibers in the mixture so that the fibers are excluded from the binder content determination. Provide the Engineer with split samples of the mixtures before the trial batch production, including all additives (except water), and blank samples used to determine the correction factors for the ignition oven used for quality assurance testing during production. Correction factors established from a previously approved mixture design may be used for the current mixture design if the mixture design and ignition oven are the same as previously used unless otherwise directed.

4.4.2.1.8. **Boil Test.** Perform the test and retain the tested sample from Tex-530-C until completion of the project or as directed. Use this sample for comparison purposes during production. The Engineer may waive the requirement for the boil test. Add lime or liquid antistripping agent as directed if signs of stripping exist.

4.4.2.1.9. **Trial Batch Production.** Provide a plant-produced trial batch upon receiving conditional approval of JMF1 and authorization to produce a trial batch, including the WMA additive, if applicable, for verification testing of JMF1 and development of JMF2. Produce a trial batch mixture that meets the requirements in Table 5 and Table 9. The Engineer may accept test results from recent production of the same mixture instead of a new trial batch.

4.4.2.1.10. **Trial Batch Production Equipment.** Use only equipment and materials proposed for use on the project to produce the trial batch. Provide documentation to verify the calibration or accuracy of the asphalt mass flow meter to measure the binder content. Verify that asphalt mass flow meter meets the requirements of 0.4 % accuracy, when required, in accordance with Item 520, "Weighing and Measuring Equipment." The Engineer may require that the accuracy of the mass flow meter be verified based on quantities used.

4.4.2.1.11. **Trial Batch Quantity.** Produce enough quantity of the trial batch to ensure that the mixture meets the specification requirements.

4.4.2.1.12. **Number of Trial Batches.** Produce trial batches as necessary to obtain a mixture that meets the specification requirements.

4.4.2.1.13. **Trial Batch Sampling.** Obtain a representative sample of the trial batch and split it into 3 equal portions in accordance with Tex-222-F. Label these portions as "Contractor," "Engineer," and "Referee." Deliver samples to the appropriate laboratory as directed.

4.4.2.1.14. **Trial Batch Testing.** Test the trial batch to ensure the mixture produced using the proposed JMF1 meets the mixture requirements in Table 8. Provide the Engineer with a copy of the trial batch test results.

4.4.2.1.15. **Development of JMF2.** Evaluate the trial batch test results, determine the target mixture proportions, and submit as JMF2 after the Engineer grants full approval of JMF1 based on results from the trial batch. Verify that JMF2 meets the mixture requirements in Table 8.

4.4.2.1.16. **Mixture Production.** After receiving approval for JMF2, use JMF2 to produce Lot 1.

4.4.2.1.17. **Development of JMF3.** Evaluate the test results from Lot 1, determine the optimum mixture proportions, and submit as JMF3 for use in Lot 2.

4.4.2.1.18. **JMF Adjustments.** If JMF adjustments are necessary to achieve the specified requirements, make the adjustments before beginning a new lot. The adjusted JMF must:

- be provided to the Engineer in writing before the start of a new lot;
- be numbered in sequence to the previous JMF;
- meet the mixture requirements in Table 8;
- meet the master gradation and binder content limits shown in Table 7; and
- be within the operational tolerances of JMF2 listed in Table 9.

4.4.2.1.19 **Requesting Referee Testing.** Use referee testing, if needed, in accordance with Section 348.4.9.1., "Referee Testing," to resolve testing differences with the Engineer.

4.4.2.2. **Engineer's Responsibilities.**

4.4.2.2.1. **Superpave Gyratory Compactor.** The Engineer will use a Department SGC calibrated in accordance with Tex-241-F to mold samples for laboratory mixture design verification. For molding trial batch and production specimens, the Engineer will use the Contractor-provided SGC at the field laboratory or provide and use a Department SGC at an alternate location. The Engineer will make the Contractor-provided SGC in the Department field laboratory available to the Contractor for molding verification samples.

4.4.2.2.2. **Hamburg Wheel, Three Wheel Polisher, and Overlay Testing.** At the Contractor's request, the Department will perform the Hamburg Wheel test on the laboratory mixture in accordance with Tex-242-F to verify compliance with the Hamburg Wheel test requirement in Table 8. The Department will perform the Overlay test in accordance with Tex-248-F to verify compliance with the Overlay test requirements in Table 8. The Department will perform the Three Wheel Polisher test in accordance with Tex-XXXX to verify compliance with the Three Wheel Polisher test requirements in Table 8. The Engineer will be allowed 15 working days to provide the Contractor with Hamburg Wheel, Three Wheel Polisher and Overlay test results on the laboratory mixture design.

4.4.2.2.3. **Conditional Approval of JMF1 and Authorizing Trial Batch.** The Engineer will review the Contractor's mix design report and verify specification conformance of the mixture and component materials. The Engineer will grant conditional approval of JMF1 within 2 working days of receiving the complete mixture design report (JMF1) and all required materials.

The Engineer will determine the Micro-Deval abrasion loss in accordance with Section 348.2.1.1.2., "Micro-Deval Abrasion," unless waived. If the Engineer's test results are pending after 2 working days, conditional approval of JMF1 will still be granted within 2 working days of receiving JMF1. When the Engineer's test results become available, they will be used for specification compliance.

Produce a trial batch after the Engineer grants conditional approval of JMF1.

4.4.2.2.4. **Ignition Oven Correction Factors.** The Engineer will use the split samples provided by the Contractor to determine the aggregate and asphalt correction factors for the ignition oven used for quality assurance testing during production in accordance with Tex-236-F. The Engineer will verify that the asphalt content correction factor takes into account the percent fibers in the mixture so that the fibers are excluded from the binder content determination.

4.4.2.2.5. **Testing the Trial Batch.** The Engineer will sample and test the trial batch within 1 full working day to ensure that the mixture meets the requirements in Table 8.

The Engineer will have the option to perform the following tests on the trial batch:

- Tex-235-F, to verify that drain-down meets the requirements shown in Table 8;
- Tex-530-C, to retain and use for comparison purposes during production; and
- Tex-245-F, to verify the Cantabro loss meets the requirement shown in Table 8.

4.4.2.2.6. **Full Approval of JMF1.** The Engineer will grant full approval of JMF1 and authorize the Contractor to proceed with developing JMF2 if the Engineer's results for the trial batch meet the requirements in Table 9.

The Engineer will notify the Contractor that an additional trial batch is required if the trial batch does not meet these requirements.

4.4.2.2.7. **Approval of JMF2.** The Engineer will approve JMF2 within one working day if the mixture meets the requirements in Table 5 as well as the master grading limits and binder content shown in Tables 7 and 8.

4.4.2.2.8. **Approval of Lot 1 Production.** The Engineer will authorize the Contractor to proceed with Lot 1 production (using JMF2).

4.4.2.2.9. **Approval of JMF3 and Subsequent JMF Changes.** JMF3 and subsequent JMF changes are approved if they meet the mixture requirements shown in Table 8, the master grading and binder content limits shown in Table 7, and are within the operational tolerances of JMF2 shown in Table 9.

4.4.2.2.10. **Binder Content Adjustments.** For JMF2 and above, the Engineer may require the Contractor to adjust the target binder content by no more than 0.3% from the current JMF.

4.5. **Production Operations.** Perform a new trial batch when the plant or plant location is changed. Perform QC at the frequency and within the tolerances listed in Table 9. Take corrective action and receive approval to proceed after any production suspension for noncompliance to the specification.

At any time during production, the Engineer may require the Contractor to verify the following based on quantities used:

- lime content (within ±0.1% of JMF), when PG binder is specified; and
- fiber content (within ±0.03% of JMF), when PG binder is specified.

The Engineer may allow alternate methods for determining the asphalt content and aggregate gradation if the aggregate mineralogy is such that Tex-236-F does not yield reliable results. The Engineer will require the Contractor to provide evidence that results from Tex-236-F are not reliable before permitting an alternate method unless otherwise allowed. Use the applicable test procedure as directed if an alternate test method is allowed.

4.5.1. **Storage and Heating of Materials.** Do not heat the asphalt binder above the temperatures specified in Item 300, "Asphalts, Oils, and Emulsions," or outside the manufacturer's recommended values. Provide the Engineer with daily records of asphalt binder and hot-mix asphalt discharge temperatures (in legible and discernible increments) in accordance with Item 320, "Equipment for Asphalt Concrete Pavement," unless otherwise directed. Do not store mixture for a period long enough to affect the quality of the mixture, nor in any case longer than 12 hr. unless otherwise approved.

4.5.2. **Mixing and Discharge of Materials**. Notify the Engineer of the target discharge temperature and produce the mixture within 25°F of the target. Monitor the temperature of the material in the truck before shipping to ensure that it does not exceed 350°F and is not lower than 215°F. The Department will not pay for or allow placement of any mixture produced above 350°F.

Control the mixing time and temperature so that substantially all moisture is removed from the mixture before discharging from the plant. Determine the moisture content, if requested, by oven-drying in accordance with Tex-212-F, Part II, and verify that the mixture contains no more than 0.2% of moisture by weight. Obtain the sample immediately after discharging the mixture into the truck, and perform the test promptly.

4.6. **Hauling Operations**. Clean all truck beds before use to ensure that mixture is not contaminated. Use a release agent shown on the Department's MPL to coat the inside bed of the truck when necessary.

Use equipment for hauling as defined in Section 348.4.7.3.2., "Hauling Equipment." Use other hauling equipment only when allowed.

4.7. **Placement Operations**. Collect haul tickets from each load of mixture delivered to the project and provide the Department's copy to the Engineer approximately every hour, or as directed. Use a hand-held thermal camera or infrared thermometer, when a thermal imaging system is not used, to measure and record the internal temperature of the mixture as discharged from the truck or Material Transfer Device (MTD) before or as the mix enters the paver and an approximate station number or GPS coordinates on each ticket. Calculate the daily yield and cumulative yield for the specified lift and provide to the Engineer at the end of paving operations for each day unless otherwise directed. The Engineer may suspend production if the Contractor fails to produce and provide haul tickets and yield calculations by the end of paving operations for each day.

Prepare the surface by removing raised pavement markers and objectionable material such as moisture, dirt, sand, leaves, and other loose impediments from the surface before placing mixture. Remove vegetation from pavement edges. Place the mixture to meet the typical section requirements and produce a smooth, finished surface with a uniform appearance and texture. Offset longitudinal joints of successive courses of hot-mix by at least 6 in. Place mixture so that longitudinal joints on the surface course coincide with lane lines, or as directed. Ensure that all finished surfaces will drain properly.

If micro-milling of pavement surface is required, the micro-milling specifications included in Item-XXX shall be followed.

4.7.1. **Weather Conditions**.

4.7.1.1. **When Using a Thermal Imaging System**. The Contractor may pave any time the roadway is dry and the roadway surface temperature is at least 60°F; however, the Engineer may restrict the Contractor from paving if the ambient temperature is likely to drop below 32°F within 12 hr. of paving. Provide output data from the thermal imaging system to demonstrate to the Engineer that no recurring severe thermal segregation exists in accordance with Section 348.4.7.3.1.2., "Thermal Imaging System."

4.7.1.2. **When Not Using a Thermal Imaging System**. Place mixture when the roadway surface temperature is at or above 70°F unless otherwise approved or as shown on the plans. Measure the roadway surface temperature with a hand-held thermal camera or infrared thermometer. The Engineer may allow mixture placement to begin before the roadway surface reaches the required temperature if conditions are such that the roadway surface will reach the required temperature within 2 hr. of beginning placement operations. Place mixtures only when weather conditions and moisture conditions of the roadway surface are suitable as determined by the Engineer. The Engineer may restrict the Contractor from paving if the ambient temperature is likely to drop below 32°F within 12 hr. of paving.

4.7.2. **Application of Tack Coat**. Clean the surface before placing the tack coat. The Engineer will set the rate between 0.04 and 0.10 gal. of residual asphalt per square yard of surface area. Apply a uniform tack coat at the specified rate unless otherwise directed. Apply a uniform tack coat to all contact surfaces of curbs, structures, and all joints. Allow adequate time for emulsion to break completely before placing any material. Prevent splattering of tack coat when placed adjacent to curb, gutter, and structures. Roll the tack coat with a pneumatic-tire roller to remove streaks and other irregular patterns when directed. The Engineer may suspend paving operations until there is adequate coverage.

4.7.3. Lay-Down Operations.

4.7.3.1. Thermal Profile. Use a hand-held thermal camera or a thermal imaging system to obtain a continuous thermal profile in accordance with Tex-244-F. Thermal profiles are not applicable in areas described in Section 348.4.9.5., "Miscellaneous Areas."

4.7.3.1.1. Thermal Segregation.

4.7.3.1.1.1. Moderate. Any areas that have a temperature differential greater than 25°F, but not exceeding 50°F, are deemed as having moderate thermal segregation.

4.7.3.1.1.2. Severe. Any areas that have a temperature differential greater than 50°F are deemed as having severe thermal segregation.

4.7.3.1.2. Thermal Imaging System. Review the output results when a thermal imaging system is used, and provide the automated report described in Tex-244-F to the Engineer daily unless otherwise directed. Modify the paving process as necessary to eliminate any recurring (moderate or severe) thermal segregation identified by the thermal imaging system. The Engineer may suspend paving operations if the Contractor cannot successfully modify the paving process to eliminate recurring severe thermal segregation. Provide the Engineer with electronic copies of all daily data files that can be used with the thermal imaging system software to generate temperature profile plots upon completion of the project or as requested by the Engineer.

4.7.3.1.3. Thermal Camera. Take immediate corrective action to eliminate recurring moderate thermal segregation when a hand-held thermal camera is used. Provide the Engineer with the thermal profile of every sublot within one working day of the completion of each lot. Report the results of each thermal profile in accordance with Section 348.4.2., "Reporting and Responsibilities." The Engineer will use a hand-held thermal camera to obtain a thermal profile at least once per project. Suspend operations and take immediate corrective action to eliminate severe thermal segregation unless otherwise directed. Resume operations when the Engineer determines that subsequent production will meet the requirements of this Section.

4.7.3.2. Hauling Equipment. Use live bottom or end dump trucks to haul and transfer mixture; however, with exception of paving miscellaneous areas, end dump trucks are only allowed when used in conjunction with an MTD with remixing capability or when a thermal imaging system is used unless otherwise allowed.

4.7.3.3. Screed Heaters. Turn off screed heaters to prevent overheating of the mat if the paver stops for more than 5 min. The Engineer may evaluate the suspect area in accordance with Section 348.4.9.6., "Recovered Asphalt Dynamic Shear Rheometer (DSR)," if the screed heater remains on for more than 5 min. while the paver is stopped.

4.8. Compaction. Roll the freshly placed mixture with a steel-wheeled roller without excessive breakage of the aggregate to provide a smooth surface and uniform texture. Do not use pneumatic-tire rollers. Use the control strip method given in Tex-207-F, Part IV, to establish the rolling pattern. Thoroughly moisten the roller drums with a soap and water solution to prevent adhesion. Use only water or an approved release agent on rollers, tamps, and other compaction equipment unless otherwise directed.

Use tamps to thoroughly compact the edges of the pavement along curbs, headers, and similar structures and in locations that will not allow thorough compaction with rollers. The Engineer may require rolling with a trench roller on widened areas, in trenches, and in other limited areas.

Use Tex-246-F to measure water flow to verify the mixture is adequately compacted. Measure the water flow once per sublot at locations directed by the Engineer. Take additional water flow measurements when the temperature of the mixture before compaction is below 275°F;

Allow the compacted pavement to cool to 160°F or lower before opening to traffic unless otherwise directed. Sprinkle the finished mat with water or limewater, when directed, to expedite opening the roadway to traffic.

4.9. **Acceptance Plan**. Sample and test the hot-mix on a lot and sublot basis. A production lot consists of 4 equal sublots. Lot 1 will be 2,000 tons. The Engineer will select subsequent lot sizes based on the anticipated daily production. The lot size will be between 2,000 and 4,000 tons. The Engineer may change the lot size before the Contractor begins any lot.

4.9.1. **Referee Testing**. The Construction Division is the referee laboratory. The Contractor may request referee testing if the differences between Contractor and Engineer test results exceed the operational tolerances shown in Table 9 and the differences cannot be resolved. The Contractor may also request referee testing if the Engineer's test results require suspension of production and the Contractor's test results are within specification limits. Make the request within 5 working days after receiving test results and cores from the Engineer. Referee tests will be performed only on the sublot in question and only for the particular tests in question. Allow 10 working days from the time the referee laboratory receives the samples for test results to be reported. The Department may require the Contractor to reimburse the Department for referee tests if more than 3 referee tests per project are required and the Engineer's test results are closer to the referee test results than the Contractor's test results.

4.9.2. **Asphalt Binder Sampling**. Obtain a 1-qt. sample of the asphalt binder for each lot of mixture produced. Obtain the sample at approximately the same time the mixture random sample is obtained. Sample from a port located immediately upstream from the mixing drum or pug mill in accordance with Tex-500-C. Label the can with the corresponding lot and sublot numbers and deliver the sample to the Engineer. The Engineer may also obtain independent samples. If obtaining an independent asphalt binder sample, the Engineer will split a sample of the asphalt binder with the Contractor. The Engineer will test at least one asphalt binder sample per project to verify compliance with Item 300, "Asphalts, Oils, and Emulsions."

4.9.3. **Tack Coat**. Obtain a 1-qt. sample of the tack coat material for each sublot.

4.9.4. **Operational Tolerances**. Control the production process within the operational tolerances listed in Table 9. Suspend production and placement operations when production or placement test results exceed the tolerances listed in Table 9 unless otherwise allowed. The Engineer will allow suspended production to resume when test results or other information indicates the next mixture produced will be within the operational tolerances.

4.9.5. **Miscellaneous Areas**. Miscellaneous areas include areas that typically involve significant handwork or discontinuous paving operations such as driveways, mailbox turnouts, crossovers, gores, spot level-up areas, and other similar areas. The specified layer thickness is based on the rate of 90 lb./sq. yd. for each inch of pavement unless another rate is shown on the plans. Miscellaneous areas are not subject to thermal profiles testing.

4.9.6. **Recovered Asphalt Dynamic Shear Rheometer (DSR)**. The Engineer may take production samples or cores from suspect areas of the project to determine recovered asphalt properties. Asphalt binders with an aging ratio greater than 3.5 do not meet the requirements for recovered asphalt properties and may be deemed defective when tested and evaluated by the Construction Division. The aging ratio is the DSR value of the extracted binder divided by the DSR value of the original unaged binder. Obtain DSR values in accordance with AASHTO T 315 at the specified high temperature performance grade of the asphalt. The Engineer may require removal and replacement of the defective material at the Contractor's expense. The asphalt binder will be recovered for testing from production samples or cores in accordance with Tex-211-F.

4.9.7. **Irregularities.** Identify and correct irregularities including segregation, rutting, raveling, flushing, fat spots, mat slippage, irregular color, irregular texture, roller marks, tears, gouges, streaks, uncoated aggregate particles, or broken aggregate particles. The Engineer may also identify irregularities, and in such cases, the Engineer will promptly notify the Contractor. If the Engineer determines that the irregularity will adversely affect pavement performance, the Engineer may require the Contractor to remove and replace (at the Contractor's expense) areas of the pavement that contain irregularities and areas where the mixture does not bond to the existing pavement. If irregularities are detected, the Engineer may require the Contractor to immediately suspend operations or may allow the Contractor to continue operations for no more than one day while the Contractor is taking appropriate corrective action.

4.9.8. **Ride Quality.** Measure ride quality in accordance with Item 585, "Ride Quality for Pavement Surfaces," unless otherwise shown on the plans.

5. MEASUREMENT

Ultra Thin Overlay Mixes will be measured by the ton of composite mixture. The composite mixture is defined as the asphalt, aggregate, and additives. The weights of asphalt and aggregate will be calculated based on the measured weight of TOM and the target percentage of asphalt and aggregate. Measure the weight on scales in accordance with Item 520, "Weighing and Measuring Equipment."

5.1. **Asphalt.** The asphalt weight in tons will be determined from the total weight of mixture. Measured asphalt percentage will be obtained using Tex-236-F or asphalt flow meter readings, as determined by the Engineer. Provide the Engineer with a daily summary of the asphalt mass flow meter readings when used for measuring asphalt percentage unless otherwise directed.

5.1.1. **Target Percentage.** The JMF target asphalt percentage will be used to calculate the weight of asphalt binder unless the measured asphalt binder percentage is more than 0.3 percentage points below the JMF target asphalt percentage or less than the minimum percentage specified in Table 6. Volumetric meter readings will be adjusted to 140°F and converted to weight.

5.1.2. **Measured Percentage.** The average measured asphalt percentage from each sublot will be used for payment for that lot's production when the measured percentage for any sublot is more than 0.3 percentage points below the JMF target asphalt percentage or less than the minimum percentage specified in Table 6.

5.2. **Aggregate.** The aggregate weight in tons will be determined from the total weight of Ultra Thin Overlay Mix less the weight of the asphalt.

6. PAYMENT

The work performed and materials furnished in accordance with this Item and measured as provided under Section 347.5., "Measurement," will be paid for at the unit bid price for "Ultra Thin Overlay Mix (Asphalt)" of the binder specified and for "Ultra Thin Overlay Mix (Aggregate)" of the grade and SAC specified. These prices are full compensation for surface preparation, materials including tack coat, placement, equipment, labor, tools, and incidentals.

Trial batches will not be paid for unless they are included in pavement work approved by the Department.

Pay adjustment for ride quality will be determined in accordance with Item 585, "Ride Quality for Pavement Surfaces."

Notes for Tables (adopted from Item 348):

Tables 1-3- Remain the same
Table 4- removed
Table 5- removed (RAP/RAS not allowed)
Table 6- Add Three Wheel Polisher Test required by both contractor and engineer
Table 7- Replace with Table Below

Sieve Size	Sieve	UTM B	UTM F	UTM H
[mm]	[#]	Percent Passing	Percent Passing	Percent Passing
12.5	1/2 in	100	100	100
9.5	3/8 in	95-100	95-100	100
4.75	#4	26-60	40-60	35-55
2.36	#8	20-28	17-27	19-30
1.18	#16	13-21	5-27	14-25
0.6	#30	12-18	5-27	14-25
0.3	#50	12-15	5-27	7-14
0.075	#200	8-10	5-9	1-4

Table 8- Add TWPD, minimum DFT value 0.4 after 100,000 cycles, maximum 4 mm rutting, and no visible raveling/bleeding

Table 9- as is in Item 348

Table 10- remove (no thickness spec necessary)