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Texas A&M Transportation Institute

Guidelines for Utilization of Field Sands in Superpave Mixtures of Texas

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16. Abstract

Field sands have been used in hot mix asphalt (HMA) pavements to improve workability since they are readily available and less expensive than crushed materials. However, due to their potential adverse effects on performance, field sands are typically limited to 10% of the aggregates. A key issue is the presence of harmful clay particles that can significantly impact asphalt concrete (AC) performance. This study investigated the effects of clay minerals on AC performance, focusing on Superpave mixtures and evaluating their clay and sand effects. Clay properties were assessed using the methylene blue value (MBV) and sand properties using the sand equivalent (SE) test. The Hamburg wheel tracking test (HWTT) was used for evaluating rutting and stripping properties of the mixtures. Superpave gradation C, twenty-four field sand sources, two binder grades (PG 64-22 and PG 70-22), and hydrated lime were used for this study. The maximum and minimum values of the MBV for the field sands were 45.8 mg/g and 3.7 mg/g, respectively. For the aggregate blend, the maximum MBV was 10 mg/g, and the minimum MBV observed was 2.4 mg/g. The field sands had SE values in the range of 37 to 98 whilst the mixtures evaluated had an SE in the range of 50 to 91 when quantified on the aggregate blend. For PG 64-22, an MBV of less than 4 mg/g indicated excellent performance, while for PG 70-22, an MBV of less than 8 mg/g was optimal. These findings were consistent across field sand percentages of 5%, 10%, and 20% (by weight of the total aggregates) that were investigated. Results also showed that the use of a higher binder grade and hydrated lime increases the stripping resistance of the asphalt mixtures incorporating field sands. New guidelines are recommended for implementing a method that incorporates field sands into Superpave mixtures without compromising performance.

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Abstract

Field sands have been used in hot mix asphalt (HMA) pavements to improve workability since they are readily available and less expensive than crushed materials. However, due to their potential adverse effects on performance, field sands are typically limited to 10% of the aggregates. A key issue is the presence of harmful clay particles that can significantly impact asphalt concrete (AC) performance. This study investigated the effects of clay minerals on AC performance, focusing on Superpave mixtures and evaluating their clay and sand effects. Clay properties were assessed using the methylene blue value (MBV) and sand properties using the sand equivalent (SE) test. The Hamburg wheel tracking test (HWTT) was used for evaluating rutting and stripping properties of the mixtures. Superpave gradation C, twenty-four field sand sources, two binder grades (PG 64-22 and PG 70-22), and hydrated lime were used for this study. The maximum and minimum values of the MBV for the field sands were 45.8 mg/g and 3.7 mg/g, respectively. For the aggregate blend, the maximum MBV was 10 mg/g, and the minimum MBV observed was 2.4 mg/g. The field sands had SE values in the range of 37 to 98 whilst the mixtures evaluated had an SE in the range of 50 to 91 when quantified on the aggregate blend. For PG 64-22, an MBV of less than 4 mg/g indicated excellent performance, while for PG 70-22, an MBV of less than 8 mg/g was optimal. These findings were consistent across field sand percentages of 5%, 10%, and 20% (by weight of the total aggregates) that were investigated. Results also showed that the use of a higher binder grade and hydrated lime increases the stripping resistance of the asphalt mixtures incorporating field sands. New guidelines are recommended for implementing a method that incorporates field sands into Superpave mixtures without compromising performance.

Implementation Statement

This report provides guidelines for incorporating field sands in Superpave asphalt mixtures. The guidelines are based on the test results of over 20 field sand sources available in Texas.

At this time, the recommendations should be implemented on several new and ongoing projects to confirm their applicability and, if needed, refine the limits and/or criteria accordingly. As part of the implementation process, a guide should be developed to disseminate to the TxDOT staff and other relevant stakeholders.

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Chapter 1

Introduction

Problem Statement

Field sands have been used in hot mix asphalt (HMA) pavements to improve workability since they are readily available and are less expensive than crushed materials. Since field sands are more round compared to crushed aggregates, mixtures containing more field sands can be compacted to a given density at lower binder contents. However, considering their adverse effects on performance, field sands are limited to 10 to 15% of the total aggregates (by weight). The most common feature of field sand that can significantly affect asphalt concrete (AC) performance is the presence of harmful clay particles. Understanding the impact of these clay particles on AC performance was the subject of this research. The objectives of this project were to determine the upper limit of specific field sand in a mix given the amount of active clay present in it, define the process to determine the clay content, and measure how they affect the performance of the asphalt mixtures. To address these objectives, this study focused on developing and verifying the guidelines for incorporating field sands into Superpave mixtures. This includes the evaluation of different sand properties and their relations with possible performance issues. The findings from this research provided insight into the potential rutting and stripping failures of the mixtures and some measures to improve the resistance to these failures.

Objectives and Scope of Work

The outcome of this project is a guideline on the selection criteria and use of field sand in Superpave mixtures. This study focused on evaluating rutting and moisture damage with respect to field sand properties. The implementable products consist of a procedure to evaluate the amount of harmful clay and limiting values for clay properties. The standard guideline may encourage agencies to use the field sands in their mixtures informed by their effects on the performance of the paving product. The steps in developing the guideline can be explained in the following manner:

1. To establish a limiting clay threshold as a function of its activity, performance tests were carried out on Superpave mixtures prepared with different levels of chemical activity of the fines, or material passing the #200 sieve. The activity level was varied by using a combination of highly active clay (i.e., bentonite) and inactive (i.e., calcium carbonate) fines.
2. To establish limiting thresholds for field sand in a mix considering the activity of the fines. The Hamburg wheel tracking test (HWTT) was carried out on various mixtures with a wide range of combinations of field sands containing different fines with different activity levels.
3. To verify the proposed limiting threshold and guidelines, field sands were incorporated into a Superpave mixture to validate the allowable field sand percentage given the chemical properties of the aggregate blend fines.

Organization of the Report

To address the objectives, this report is divided into seven chapters including the introduction. The chapters are as follows:

Chapter 1. Introduction, establishes and outlines the problem statement, as well as the objectives and scope.

Chapter 2. Comprehensive Information Search investigates the effect of field sands on mix performance to focus the research efforts on promising approaches informed by previous studies.

Chapter 3, Developing Trends and Thresholds for Active Clay Content, evaluates the potentially detrimental effects of the clay minerals within the field sands on the performance of mixtures.

Chapter 4. Impact of Active Clay on the Hamburg Wheel Tracking Test examines the rutting and moisture susceptibility of Superpave mixtures with different clay activity levels.

Task 5. Development of Guidelines to Select the Percentage of Field Sand, uses different field sand sources to determine their impact on mix performance and improves the resistance of mixtures against rutting and stripping.

Task 6. Verification of the Proposed Guidelines validates the performance chart that aids to select the amount of field sand to use without hindering the mix's performance.

Chapter 7. Recommended Guidelines and Conclusions, recommends guidelines for selecting a percentage of field sand that can be incorporated into the mix without affecting the performance of Superpave mixtures.

This report summarizes the major research outputs of TxDOT Project# 0-7111. The information presented herein can be implemented to optimize the use of field sands. Nevertheless, other findings that contributed to the development of this product can be found in the Technical Memorandums delivered as part of this research project.

Chapter 2

Comprehensive Information Search

Introduction

Fine aggregates are a critical component in the production and performance of asphalt mixtures, since they are used to fill in the voids between the coarse particles, to increase the density of the asphalt mixtures, and to provide load transfer among the larger particles (Tayebali *et al.* 1998, Xiao and Amirkhanian 2015). The properties of fine materials used in asphalt mixtures also play an essential role in their overall strengths and workability (Stakston *et al.* 2002). The types of fine aggregate materials used in asphalt mixtures can be either field (or natural) or crushed (or manufactured) (Almadwi and Assaf 2021). Field sand is collected by dredging rivers or mined from deposits, such as deserts. On the other hand, crushed sand is produced by crushing quarried stone and sieving it to manufacture the desired characteristics. Although field sands are more cost-effective, crushed sands are commonly preferred for asphalt mixture production. Manufactured sands tend to be more angular than field sands, providing a better aggregate interlock. Consequently, crushed materials often produce asphalt mixtures with greater strength and rut resistance than those made with natural sand. The decision-making process to disregard field sand from an asphalt mixture design is not straightforward (NASEM 2011). Field sands can be favorable from economic, performance, and mixture workability perspectives (Breakah *et al.* 2011, Almadwi and Assaf 2019a).

Field sands are often used in asphalt materials including Superpave mixtures to alleviate the demand for crushed fine aggregates because they are less expensive, readily available, and blend easily with other materials (Almadwi and Assaf 2019a, 2021). Also, the optimum asphalt content typically decreases with an increment in field sand in the asphalt mixture design, as shown in Table 2-1. The reduction in asphalt content is an indication that the more field sand is added, the more round particles and the less compaction energy is required to compact the asphalt mixture to a prescribed air voids content (Ahmed and Mohiuddin 2016). However, the smooth texture and round shape of field sands reduce the interlocking between the aggregates in asphalt mixtures, making them more prone to rutting (Parker and Brown 1992).

Table 2-1. Typical relationship between the percentage of field sand in asphalt mixture and optimum asphalt content (Ahmed and Mohiuddin 2016).

Percentage of Field Sand by Total Fine Aggregate (%)	Optimum Asphalt Binder Content (%)
0	5.3
25	5.2
75	5.0
100	4.9

Texas has a variety of field sand sources, including rivers and deserts (Fulbright *et al.* 1990, Snedden and Nummendal 1991, Holliday 2001). To minimize the use of asphalt binder and crushed materials, the current TxDOT Item 344 specification allows no more than 10% of the total aggregate blend (by mass) as field sand or other uncrushed fine aggregates in Superpave mixtures.

Though such a percentage seems safe to use, some mixtures containing low field sand contents are more susceptible to rutting and moisture damage problems in the field. While other Superpave mixtures having relatively high field sand contents perform well over the design life of the asphalt pavement, delivering substantial cost savings (Albayati and Abdulsattar 2020). Some natural sands have performed as well as manufactured fine aggregates (Stuart and Mogawer 1994). The lack of a specification regulating the amount of field sand, including clay particles, in a Superpave mixture could lead to inappropriate usage of field sands or sudden pavement failure, such as early rutting and stripping issues.

Field Sand in Asphalt Mixtures

Description of field sand

Field sands, typically referred to in the literature as natural sands, are primarily natural uncrushed particles with a more rounded and smoother surface than crushed sand, are extracted from the riverbanks, riverbeds, or the desert (Figure 2-1). The quality of field sands depends on their origin and location (Stuart and Mogawer 1994). Aziz et al. (2018) studied the differences in the gradation of particles, moisture content, specific gravity, and workability between field and crushed sands. They showed that: (i) the grain-size distributions of the field and crushed sands were comparable; (ii) the moisture contents of crushed sands were comparatively less than those of the field sands; and (iii) crushed sands had higher specific gravity as compared to the field sands. Due to the higher specific gravity, a higher asphalt mixture theoretical maximum specific gravity is obtained with the crushed sands. But increments in the percentage of crushed stone sand in asphalt mixture decrease workability (Aziz *et al.* 2018).

(a) (b)

Figure 2-1. (a) River sands, and (b) Desert sands.

Acceptable limits of field sand

In 1988, the Federal Highway Administration's (FHWA's) Technical Advisory T5040.27 provided the following recommendations regarding field sands:

> "The quality of natural sand varies considerably from one location to another. Since most natural sands are rounded and often contain some undesirable materials, the amount of natural sand generally should be limited to 15 to 20% for high volume pavements and 20 to 25% for medium and low volume pavements. These percentages may increase or decrease depending on the quality of the natural sand and the types of traffic to which the pavement will be subjected (as cited in Stuart and Mogawer 1994)."

Over the years, due to the shortcomings of using high percentages of field sands in asphalt mixtures, agencies have determined various upper limits of natural sand content ranging from 10 to 30% (Ahlrich 1991). The Federal Aviation Administration limits the field sand to a maximum of 15%. Field sand percentage in heavy-duty pavement asphalt mixtures is limited to 15% by mass (weight) of total aggregate by the United States Army Corps of Engineers (Khosla *et al.* 2000). Currently, TxDOT allows up to 10% field sand in the Superpave asphalt mixtures.

Literature on the incorporation of field sand in asphalt mixtures

Much information about the incorporation and optimization of field sand in asphalt mixtures is available in the literature. Ahlrich (1991) studied the effects of two natural sands on the engineering properties of asphalt mixtures. Ahlrich (1991) prepared aggregate blends using crushed limestone with 0, 10, 20, and 30% mason sand or concrete sand by total aggregate mass. Based on the Marshall stability, indirect tensile (IDT) strength, resilient modulus, and unconfined creep-rebound tests, Ahlrich (1991) observed that using natural sands instead of crushed materials decreased the strength characteristics of the asphalt mixtures. The study concluded that the maximum limit for natural sand by total aggregate must be 15%, with the caveat that the mixtures placed under heavy traffic should not use natural sands. The occurrence of unstable asphalt pavements due to the incorporation of high field sand contents (Ahlrich and Anderton 1992) and observance that geographical areas with crushed stone and angular field sands were less susceptible to rutting (Parker and Brown 1992) lead to further investigations.

In a study focused on demonstrating how the Corps of Engineers gyratory testing machine (GTM) air roller testing procedure could be used to evaluate asphalt mixtures, Ruth *et al.* (1992) prepared asphalt mixtures with various amounts of field sands, between 10 and 20% of total aggregate. As shown in Figure 2-2, they successfully showed the effect of field sand content in reducing the shear resistance of asphalt mixtures, but no limiting threshold was established. Ruth *et al.* (1992) recommended using field sands exclusively to improve the workability of asphalt mixtures, where necessary. Stuart and Mogawer (1994) designed twelve aggregate blends by adjusting four field sands at three different levels in a total aggregate mass ratio of 10, 20, or 30%. In contrast to the study by Ruth *et al.* (1992), they determined that the percentage of field sand in the asphalt mixture and the quality of sands used were unrelated to the shear resistance and rutting performance. Therefore, Stuart and Mogawer (1994) could not develop an approach that estimated how much field sand can be incorporated into an asphalt mixture. Shoenberger (1996) documented the utilization of field sand in a stone matrix asphalt mixture at an airfield pavement, reporting a good quality mixture performance. The field sand was added to the asphalt mixture by 13% weight of the total aggregate.

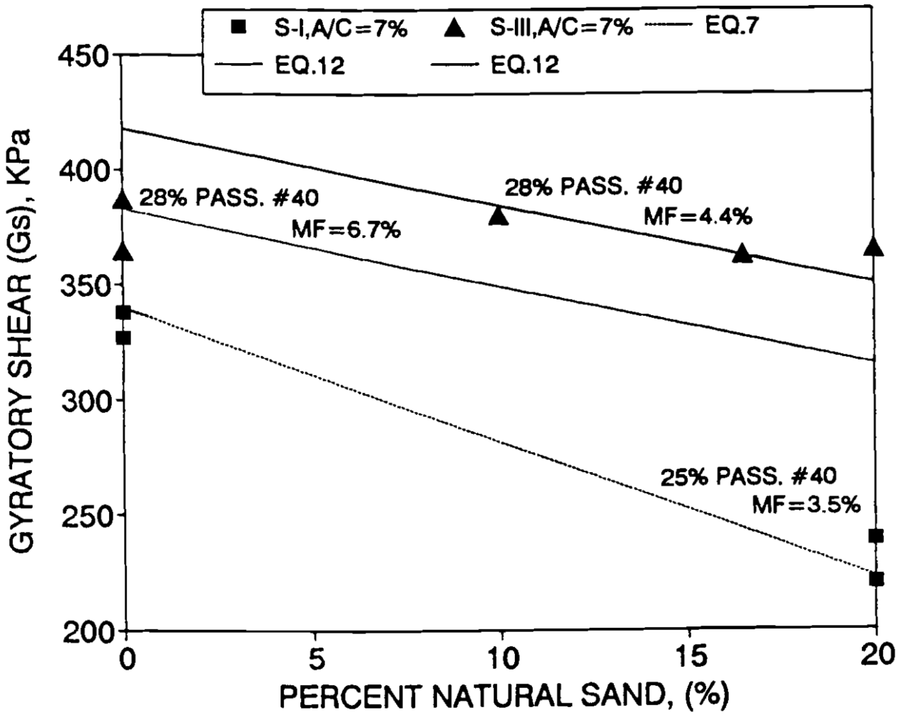


Figure 2-2. Effect of natural sand content on gyratory shear (Ruth *et al.* 1992).

Tayebali *et al.* (1998) studied the effects of mineral filler type and amount on the design and performance of asphalt mixtures. They compared the performance of a mineral filler composed of 20% field sand and 80% crushed granite sand to a mineral filler with 100% crushed granite. The mixtures containing 100% crushed granite mineral filler showed a lower accumulation of permanent strain than does having a 20/80 blend of field sand and crushed granite (Tayebali *et al.* 1998). Motivated by the necessity of controlling the amount of field sand in asphalt mixtures, Freeman and Kuo (1999) proposed using ASTM C1252, "*Standard Test Methods for Uncompacted Void Content of Fine Aggregate,*" as a quality control tool for field sand content in asphalt mixtures. They demonstrated that the funnel test effectively differentiated between aggregates blends that contained 0, 10, 15, 20, and 30% natural sand, as shown in Figure 2-3. Freeman and Kuo (1999) concluded that this test method could be employed during construction. However, they indicated that the method must be calibrated in advance with the materials to be used on a particular project.

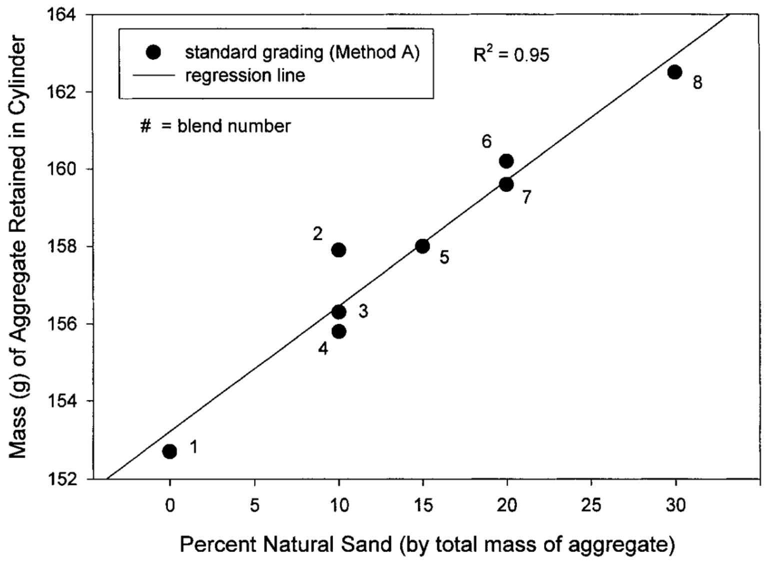


Figure 2-3. Estimation of field sand content using ASTM C 1252 in Freeman and Kuo (1999).

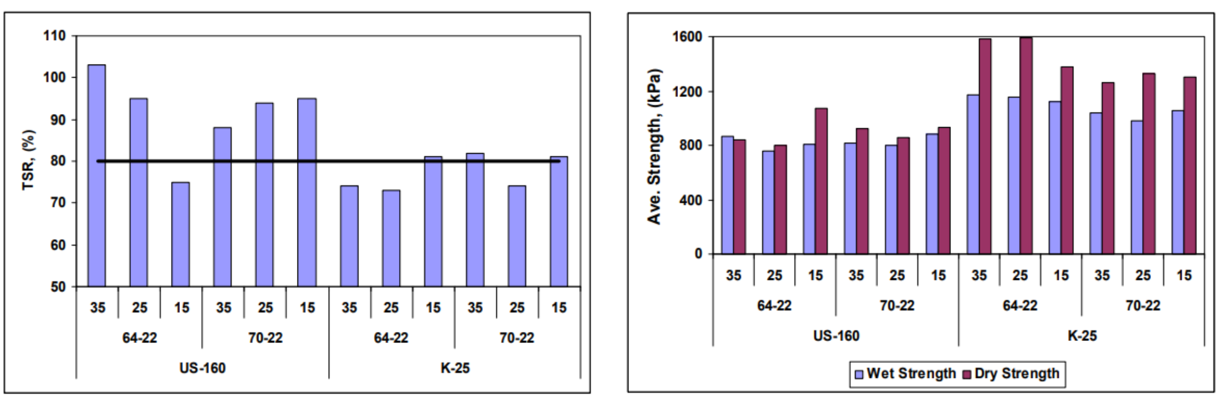
In the early 2000s, increased attention was placed on investigating the angularity properties of fine aggregate rather than the effect of field sand amount on asphalt mixture properties. Stakston *et al.* (2002) prepared coarse- and fine-graded 19- and 12.5-mm asphalt mixtures by combining rounded, field sand with angular, manufactured sand in different proportions of 100/0, 60/40, 40/60, and 0/100 blends of field sand and manufactured sand. The ratios were selected to cover the range of angularity commonly accepted in practice. Stakston *et al.* (2002) indicated that increasing the fine aggregate angularity (FAA, AASHTO T 304 or ASTM C1252) could require a higher compaction effort and that the effect of aggregate source could affect resistance to traffic loading.

Topal and Sengoz (2005) analyzed the FAA of four field sands and 26 crushed sands used for paving materials in Turkey. They revealed that some crushed fine aggregates were not angular, and some fine natural aggregates were subangular. Some of the field sands evaluated were more angular than some crushed sands in the study. Vitton *et al.* (2008) looked into FAA of field sands and crushed sands. The purpose of the study was to determine whether the uncompacted void content of fine aggregate, direct shear test, compacted aggregate resistance test, modified light clegg hammer, and an aggregate imaging system can help discriminate between different sources of materials and different gradations. The experimental results showed that all the test methods could distinguish field and crushed sands. But only the compacted aggregate test and aggregate imaging system could discriminate between different gradations (Vitton *et al*. 2008).

Through laboratory tests, Xie *et al.* (2008) assessed the content of field sand on air voids and the performance of asphalt mixtures. Test results showed that both air voids and high-temperature stability of asphalt mixtures decreased with an increase in the field sand content. Asphalt mixtures' dynamic stability was significantly reduced when the field sand content exceeded 20%. At a field sand content of 10%, asphalt mixtures' moisture stability reached a desirable resistance (Xie *et al.* 2008). In a study evaluating the influence of aggregate type and mixture proportions on the frictional characteristics of asphalt pavements, Kowalski *et al.* (2008) combined commonly used field sands from the north-central region of the United States with high friction aggregates, such as quartzite or steel slag. The percentages of field sand content included in the asphalt were between 8 and 40% of the total aggregate by mass. The study did not have conclusive results on the effect of field sand content on the polishing resistance of the asphalt mixtures.

Chen *et al.* (2010) compared the performance of field and manufactured sands. They showed that manufactured sand could improve the high-temperature properties of asphalt mixtures. Brown (2010) designed a 4.75-mm asphalt mixture to construct a high-performance thin overlay test section. The asphalt mixture contained 69.3% limestone dry screenings, 18.8% crushed gravel, and 10.9% field sand, along with 1% hydrated lime by total aggregate blend. Breakah *et al.* (2011) investigated the influence of fine aggregate characteristics on the mechanistic-empirical performance of asphalt pavements. Breakah *et al.* (2011) prepared 12.5-mm asphalt mixtures using five different fine aggregate sources and five different aggregate blend gradations. The five fine aggregate sources utilized were one natural and four manufactured sands from parent materials of dolomite, limestone, traprock, and glacial gravel. The five gradations considered in the study were very fine, fine, dense, coarse, and very coarse, which were obtained by adjusting the amount of fine aggregate material in the mixture. Overall, the crushed limestone fine aggregate showed the poorest pavement performance.

Rahman *et al.* (2011) optimized 4.75-mm asphalt mixtures for thin overlays. Twelve different 4.75-mm asphalt mixture designs were developed using two binder grades and three different percentages of field sand combined with crushed quarry materials. As shown in Figure 2-4, four trial aggregate blends were created for 15, 25, and 35% field sand that satisfied Kansas Department of Transportation's (KDOT's) gradation guidelines. KDOT's specification allows up to 35% field sand provided the FAA of the blend meets the required criteria (FAA $\geq$ 42). After conducting rutting and moisture damage testing, Rahman *et al.* (2011) suggested limiting the field sand content to 15 and 20% rather than 35%. Rushing *et al.* (2012) designed asphalt mixtures with field sand that could withstand high tire pressure aircraft. The asphalt mixtures evaluated included 0, 10, or 30% field sand by total aggregate mass. Aside from the mixtures containing 30% field sand, all the mixtures met all the Federal Aviation Administration rutting performance criteria (Rushing *et al.* 2012).



(a) (b)

Figure 2-4. Indirect tensile strength results obtained by Rahman *et al.* (2011) using different field sand percentages: (a) tensile strength ratios and (b) dry and wet strength comparison.

Ramli *et al.* (2013) compared the stability and rutting resistance of an asphalt mixture containing crushed granite sand with an FAA equal to 46% and another asphalt mixture including field sand with an FAA equal to 37%. The asphalt mixture with crushed granite sand was found to have better stability and rutting resistance than the asphalt mixture with field sand. No reference about the aggregate blend proportion was given by Ramli *et al.* (2013).

Walubita *et al.* (2013) examined the dense-graded mixtures (Type C and D) which are widely used in Texas. Among the tested mixtures, one Type C mixture with 15% field sand was modified by removing the field sand and adding 1% lime. The modified mixture design exhibited significant improvements in the Hamburg test, with the measured rut depth being 4.4 mm after 15,000 HWTT load passes. The mixture with 15% field sand had a rut depth of 11.1 mm. However, no meaningful improvement was observed in the overlay tester (OT) test. Both mixtures failed to pass OT specifications.

Xiao and Amirkhanian (2015) researched the moisture susceptibility and rutting resistance of asphalt mixtures containing about 25% of reclaimed asphalt pavement (RAP) and 20% of field sand. The mixtures included both hydrated lime and liquid antistripping additives. A total of 12 mixtures were investigated, and a total of 160 specimens were produced and tested in that study. Although 20% field sand was used, the tensile strength ratio (TSR) values of all the mixtures were greater than 80%, regardless of mixture surface type, aggregate source, and liquid antistripping additive type. The rut depths reported for all the mixtures satisfied the rutting performance criteria used by Xiao and Amirkhanian (2015).

Leung and Wong (2016) combined two types of fine aggregates at different mass percentages to form different natural sand to total fine aggregate ratios (N/FA) of 0, 10, 20, 30, 40, and 50%. The fine aggregate combinations were mixed with a crushed grit sand coarse aggregate and a limestone mineral filler for HMA mixture design and freeze and thaw split testing.. By reviewing the results of the split strength ratio of the asphalt mixtures, Leung and Wong (2016) determined that 30% natural sand in total fine aggregate (about 13% of the total aggregate by weight) provided an optimal value to improve workability, adjust the percent air voids content (Figure 2-5), and mitigate asphalt mixture moisture susceptibility. Ahmed and Mohiuddin (2016) studied the effect of field sand percentage on fatigue life of asphalt mixtures. Two types of fine aggregate were used, namely field sand and crushed sand. The crushed sand was replaced by field sand with different percentages (i.e., 0, 25, 75, and 100%) by the total mass of the fine aggregate material passing the No. 8 (2.36 mm) sieve and retained on the No. 200 (0.075 mm) sieve. The fatigue life of asphalt mixtures with and without field sand was determined by subjecting them to the repeated flexural bending testing according to AASHTO T 321. This study suggested that the most appropriate proportion of field sand added to an asphalt mixture ranges between 0 and 25% by total mass of fine aggregate passing the No. 8 sieve and retained on the No. 200 sieve.

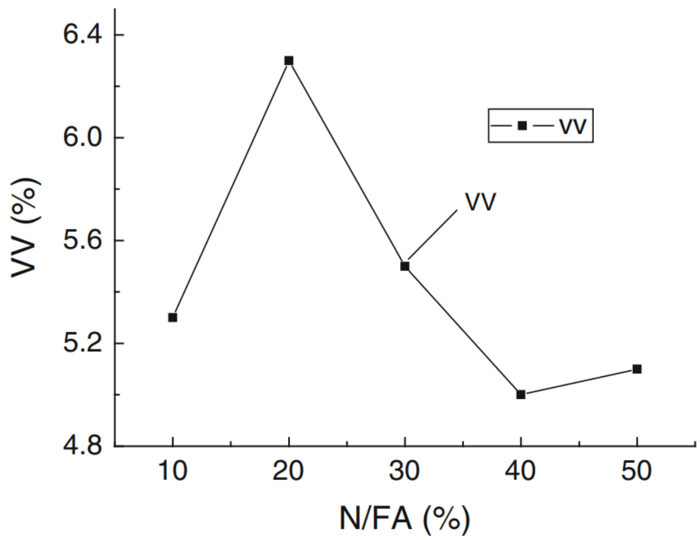


Figure 2-5. Natural sand to total fine aggregate ratio versus air void content (Leung and Wong 2016).

Huwae *et al.* (2017) attempted to establish a systematic design of asphalt mixtures containing field sands. With the main objective of using local materials to reduce the expenses needed for road construction, beach sand was used as field sand in the investigation. The Marshall mix design results obtained for this study suggested that the mixture prepared with field sand satisfied the requirements established by the local agency. However, the amount of field sand used by Huwae *et al.* (2017) by the total aggregate mass was not reported. Al-Jumaili and Shakoree (2018) examined the impacts of aggregate and filler type on cold asphalt and used field sand for the study.

The effect of field sands on the performance of asphalt mixtures has become a topic of interest in desert regions, such as Northern Africa and the Middle East (Almadwi and Assaf 2019a, 2019b, 2021). If asphalt mixtures with fields sands are not correctly designed, their incorporation into asphalt mixtures could lead to premature pavement failures even on low volume roads (Almadwi and Assaf 2019a, 2019b, 2021). Almadwi and Assaf (2019a) studied the rutting performance of an asphalt mixture having a 33% of field sand by total aggregate mass. The remaining portion of the asphalt mixture consisted of manufactured sands. Two different asphalt mixtures were investigated, namely a mixture prepared with a PG 70-10 and another mixture with a PG 58-10. Both mixtures exhibited a rut depth below 12 mm after 30,000 passes. Nevertheless, the mixtures exhibited rut depth versus wheel pass curves that demonstrated poor interlock between aggregates.

Albayati and Abdulsattar (2020) examined the performance of asphalt mixtures of desert and river sands, as shown in Figure 2-6. The field sand contents were 0, 25, 50, 75, and 100% of the fine aggregate passing #4 (4.75 mm) sieve. The study recommended a maximum limit of 25 and 50% of aggregates finer than 4.75 mm for river and desert sands to be used in the base course layers, respectively.

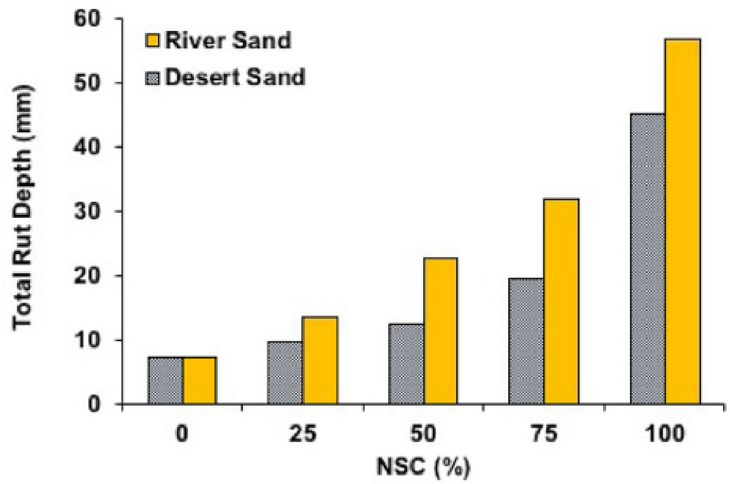


Figure 2-6. Predicted rut depth for different natural sand contents at the end of design life (Albayati and Abdulsattar 2020).

Using the IDT strength test, Tran and Takahashi (2020) evaluated the rutting resistance of wearing course asphalt mixtures with different fine aggregate sources, such as field sand and manufactured screening. The FAA value of the aggregate blend was found to affect the rutting resistance of the asphalt mixture when a portion of fine aggregates was replaced with different aggregate sources. However, when the aggregate gradation of the mixtures was changed, the FAA values did not correlate well with rutting resistance (Tran and Takahashi 2020). Neji *et al.* (2022) researched the reduction of asphalt content and production temperature of asphalt mixtures by incorporating RAP, dune sand, and hydrated lime. They showed that adding 10% dune sand reduced the asphalt content by 0.3%. Moreover, dune sand and hydrated lime could allow a 25°C reduction in the production temperature of the asphalt mixture (Neji *et al.* 2022).

Clay particles in asphalt mixtures

The most common feature of field sand that can significantly affect asphalt pavement performance is the presence of harmful clay particles (Nikolaides *et al.* 2007). Clay is defined in two ways: (i) clay is a size phrase that refers to fines less than 0.002 mm. DOTs typically classify anything that passes the No. 200 sieve as clay or fines (sometimes called micro-fines), but the mineralogy of the fraction passing the No. 200 sieve can differ considerably, or (ii) clay pertains to phyllosilicates, a group of chemically active minerals including chlorite, smectite, kaolinite, illite, palygorskite, talc, and other clay minerals that are finely grained (less than 0.002 mm). The structures of the common clay minerals are made up of combinations of two simple structural units, the silicon tetrahedron and the aluminum or magnesium octahedron (Nikolaides *et al.* 2007, Mukhopadhyay *et al.* 2013).

Fine particles can act as a surface coating on aggregates, which can be classified into three types, including (i) clay minerals such as chlorite and smectite, (ii) rock dust such as quartz and feldspar, and (iii) carbonate minerals (Gullerud and Cramer 2002). There are 137 aggregate sources on the Concrete Rated Source Quality Catalog, including igneous, metamorphic, and sedimentary rocks with different characteristics. This diversity will result in clay minerals with various compositions and engineering properties (Mukhopadhyay *et al.* 2013).

Expansive clay particles

Some clay minerals have the tendency to swell (expand) when exposed to water (Nikolaides *et al.* 2007, Mukhopadhyay *et al.* 2013). The expansive clays are composed of minor, negatively charged plates, and attract slightly polarized water molecules. Water absorption might result in a significant volume increase. Clay particles have multilayer structures. The main factors for clay swelling potential are the distance between layers and the presence of free cations in the interlayer region. When the distance between the layers is minimal, the bonding forces are strong enough to overcome water absorption, preventing swelling. On the other hand, when the distance between the layers is considerable, the attractive interlayer forces are weak. Water absorption in the interlayer happens in this situation and continues until the collapse of the bonds and swelling ensues. Smectites such as montmorillonite have swelling characteristics, and pyrophyllite, margarite, and illite are examples of non-swelling clays (Nikolaides *et al.* 2007, Mukhopadhyay *et al.* 2013).

Effects of clay particles and acceptable limits

Dust or clay particles can inhibit the asphalt binder from binding to aggregates adequately within the asphalt mixture. This phenomenon can result in water penetrating the asphalt binder film, causing the asphalt binder to be stripped from the aggregate. Moreover, clay particles in asphalt mixture can lead to permanent deformation, fatigue cracking, raveling, or moisture damage (Williams and Foreman 2006, Nikolaides *et al.* 2007, NASEM 2011, Mukhopadhyay *et al.* 2013, Bani Baker *et al.* 2018). Another disadvantage of clay contamination is clay balls. Clay ball, also called dust ball or dust cake, is a pavement surface defect. It's a clump of clay or soil that's been blended with an asphalt mixture. Smectite, mica, kaolinite, quartz, and calcite are the most common minerals in clay balls (Zhang *et al.* 2019). Some state agencies have limits like 1.5% by mass of fine materials passing No. 200 sieve in the coarse aggregate. The Florida DOT uses 2% by mass passing the No. 200 sieve as a limit for fine aggregate in asphalt mixture. The mineralogy of the fine materials is usually not considered by DOTs (Mukhopadhyay *et al.* 2013).

Effect of clay particles on asphalt mixture performance

Kandhal *et al.* (1998) characterized six different types of material passing the No. 200 sieve (or P200) implementing Rigden voids, particle size analysis, and methylene blue (MB) tests on the P200 materials including permanent deformation, fatigue cracking, and stripping evaluations on the asphalt mixtures with the P200 materials. Asphalt mixtures were prepared with two P200 to asphalt binder ratios (0.8 and 1.5) by mass. Methylene blue value (MBV) was correlated well with permanent deformation and stripping, but no correlation with fatigue cracking was observed (Kandhal *et al.* 1998).

Nikolaides *et al.* (2007) conducted sand equivalent (SE) and MB tests on limestone and non-limestone aggregates from various quarries in Greece. The percentage of the mineral filler content varied between 8.5 to 18.9%, for the limestone aggregates, and 4.5 to 12.5%, for the non-limestone aggregates. As shown in Figure 2-7, no correlation was observed between the two test results. The study recommended that both tests be carried out for non-limestone aggregates. For limestone aggregates that passed the SE test, the MB test was not recommended to be carried out. However, Nikolaides *et al.* (2007) concluded that the SE test is limited to determining the aggregates' suitability to be used in pavements.

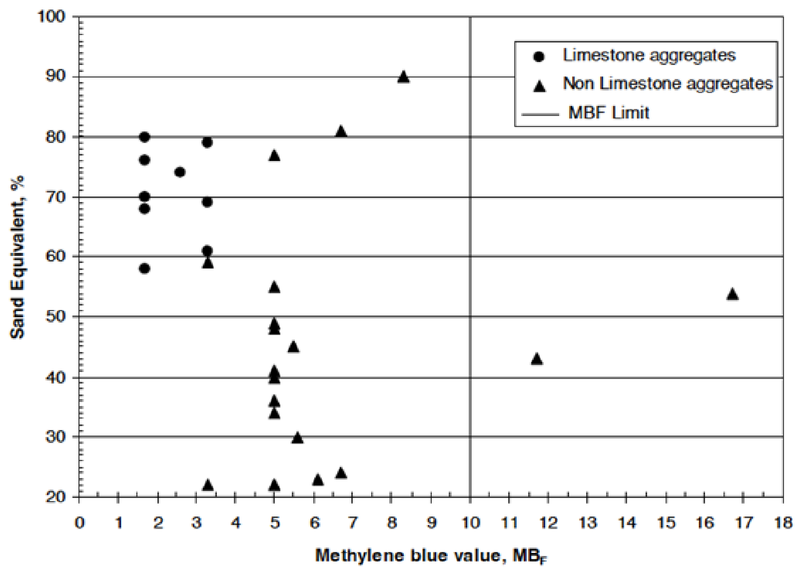
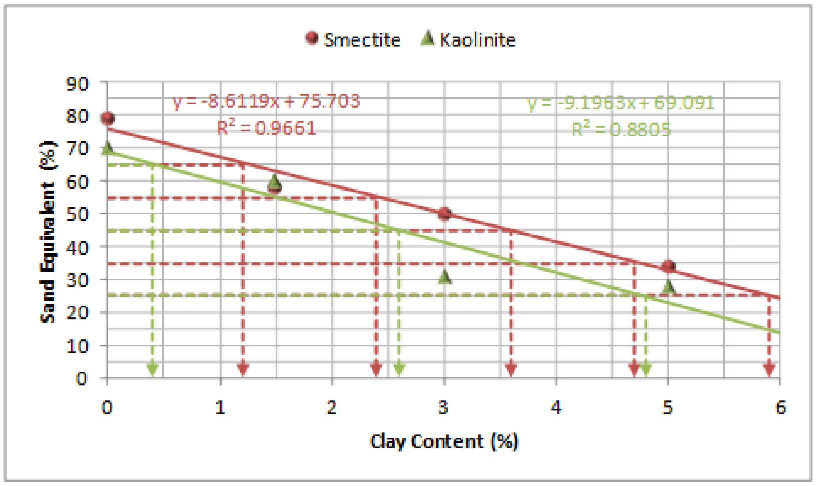


Figure 2-7. Sand equivalent and methylene blue analysis (Nikolaides *et al.* 2007).

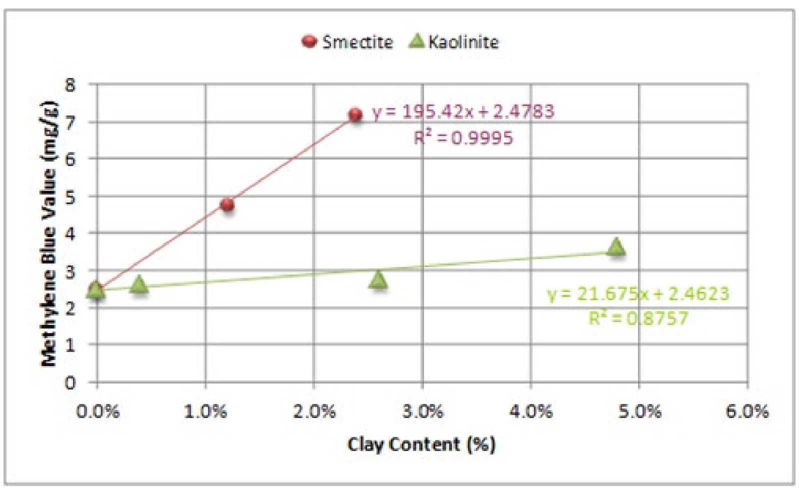
Mukhopadhyay et al. (2013) evaluated the effect of clay both in concrete materials and asphalt mixtures. The study reported that MB (Tex-252-F) and X-ray diffraction (XRD) are promising methods for identifying and quantifying clay minerals in fine aggregates. A modified methylene blue (MMB) test was proposed to eliminate the human guesswork in the test process. As shown in Figure 2-8a, the SE test (Tex-203-F) results obtained during the investigation could not differentiate between smectite (expansive clay) and non-expansive clay (kaolinite). According to the SE test results, kaolinite was more hazardous than smectite. However, theoretically speaking, smectite particles should be more harmful than kaolinite particles. As opposed to the SE test, the MB test could differentiate between expansive and non-expansive clays, as evident in Figure 2-8b. The required binder content for smectite clay increased as the clay contamination increased, but the design binder level for kaolinite clay was higher for the lowest quantity of clay and reduced as the clay content grew. With the addition of clay, the number of Superpave gyratory compactor (SGC) gyrations decreased. The lower compaction energy equates to increased workability.

Mukhopadhyay *et al.* (2013) also demonstrated that after 20,000 Hamburg wheel tracking test (Tex-242-F) load cycles, the mixtures with higher smectite clay amounts performed poorly, failing to meet the minimum rut depth requirement of less than 12.5 mm. They concluded that adding smectite clay to asphalt mixtures has a detrimental impact on rutting, moisture susceptibility, and cracking resistance. This outcome is unusual because it is commonly known that asphalt mixtures with strong rutting performance have low cracking resistance and vice versa. On the other hand, the kaolinite clay mixtures performed well, with minimal rutting and no signs of stripping.

However, the asphalt mixtures with kaolinite performed poorly in cracking resistance at higher clay levels. The HWTT results showed that satisfying the TxDOT minimum specified 45% for the SE test did not necessarily lead to an acceptable rutting performance. Based on the HWTT results, a preliminary threshold limit of MBV of 7.2 mg/g was recommended by Mukhopadhyay *et al.* (2013), with a corresponding SE threshold value of 55%.



(a)



(b)

Figure 2-8. Results for Jones Mill aggregate samples without clay and various amounts of smectite and kaolinite clay: (a) Sand equivalent and (b) methylene blue value (Mukhopadhyay *et al.* 2013).

Bani Baker *et al.* (2018) investigated the effect of using natural bentonite clay as a partial replacement of mineral filler in asphalt mixtures. Due to its chemical activity and absorption properties, bentonite clay has been typically applied as a sealant since it can swell and provide a self-sealing, low permeability barrier (Hassan *et al.* 2012, Dong *et al.* 2018). Different bentonite contents were used by Bani Baker *et al.* (2018) to replace the mineral filler with the total mass of its portion of total aggregates, namely 5, 10, 15, and 20%. Their results suggested that when natural bentonite clay concentration is less than 20% of the total filler, the Marshall stability and IDT strength values are greater than those in the control sample (0% bentonite). The hydraulic conductivity of modified asphalt mixtures, including natural bentonite clay, decreased (Bani Baker *et al.* 2018). Hassan *et al.* (2012) demonstrated that adding bentonite to asphalt binder leads to decreased penetration and ductility as well as increased softening point of the material. Dong *et al.* (2018) showed that bentonite clay particles could compromise the asphalt mixture cohesion due to their water absorption and swelling properties.

Summary of Literature Review

The following bullet-lists offer a summary of the literature review:

- Field sand is fine aggregate mined from deposits or dredged from rivers. Field sand is typically used due to its lower cost, availability, and ability to blend with other materials. However, excessive, or inappropriate use of field sand in asphalt mixtures can lead to premature pavement failures, such as rutting, shoving, and bleeding.
- The smooth texture and round shape of field sand, whilst improving the asphalt mixture's workability, tend to reduce the interlocking between the aggregates in the mixture, ultimately reducing strength properties. Occasionally, field sands exhibit sub-angular characteristics.
- Several transportation agencies, including TxDOT, limit the amount of field sand in the asphalt mixture to between 10 and 15% of the total aggregate mass. For research purposes, field sand percentages of the total aggregate above 30% have been investigated. Limits for the allowable amount of clay particles in field sands are not typically specified.
- Clay presence in field sand may significantly affect the asphalt mixture performance depending on the clay type and mineralogy. In addition, the literature suggests that expansive or active clays in asphalt mixtures can lead to stripping, permanent deformation, fatigue cracking, raveling, moisture damage, and clay balls.
- Although several correlations between field sand content and asphalt mixture performance have been reported, the interactions among different field sand properties (i.e., angularity, sand equivalent, and chemical activity of clay particles) and the performance of mixtures containing different levels of field sands are mostly still uncertain.

Overall, this literature review indicates that: (i) most studies are not widely comprehensive since they are based on few local field sand sources (i.e., most studies are localized), and (ii) they place little to no emphasis on evaluating the properties of field sands used, the properties of clay particles in field sands, and the combined effects of sand and clay particles in asphalt mixtures. Therefore, there is a need to evaluate the field sands available in Texas to get the maximum allowable percentage for the Superpave asphalt mixtures and develop some guidelines for mixture design.

Chapter 3

Developing Trends and Thresholds for Active Clay Content

Introduction

The acceptable amount of field sand in asphalt mixtures depend significantly on the chemical activity or swelling potential of the existing clay particles within the natural material. These clay particles can adversely affect the rutting performance and moisture susceptibility of the resultant asphalt mixtures. Therefore, understanding and mitigating these effects is crucial for optimizing the use of field sands in AC pavements. To address this challenge, an experimental plan was developed to systematically investigate the influence of clay particles and the combination of clay and sand on AC performance. This section focuses on evaluating the rutting resistance and moisture susceptibility of Superpave mixtures incorporating different active clay percentages in the asphalt mixtures. The plan included assessing the chemical activity of clay particles through MBV. Additionally, the experimental design employed the HWTT, Tensile Strength Ratio (TSR), and permeability tests to measure rutting performance and moisture sensitivity. By carefully analyzing these parameters, this part of the study aimed to establish limiting thresholds for the active clay content, ensuring both performance and durability.

Experimental Methods

Materials

The materials required to complete this section of the research study included silica sand, manufactured coarse and fine aggregates, asphalt binder, bentonite, and calcium carbonate. The properties of these materials are discussed below.

Aggregate Material and Asphalt Binder

A Superpave C (SP-C) mix manufactured by a local producer in El Paso, Texas, was selected as a control mixture throughout this research. That mix was re-designed to make several asphalt mixtures and alternatives required for this study. The gradation of the SP-C mixture is presented in Table 3-1, along with the gradation of the aggregates used in the design of this SP-C mixture. The raw aggregate materials, namely igneous 3/4", gravel 3/8", and gravel screenings, were incorporated into the mixtures as required. A PG 70-22 asphalt binder was used to produce the asphalt mixture specimens. The aggregates and asphalt binder were mixed with bentonite clay, calcium carbonate fines, and silica sand, respectively. Although various asphalt mixture modifications were evaluated, an effort was made to minimize the variations in the gradation of the aggregate blends. The gradations for the mixtures containing different levels of bentonite, and calcium carbonate followed as much as possible the gradation of the control mixture. The normalized rutting resistance index (NRRI), indirect tensile strength (IDT), and crack propagation rate (CPR) of the reference mixture were 3.3, 107 psi, and 0.32, respectively.

Table 3-1. Gradation of the Aggregate Materials and Control Mixture.*

Sieve Size	Percent Passing			
	SP-C Control Mixture	Igneous 3/4"	Gravel 3/8"	Gravel screenings
1"	100.0	100.0	100.0	100.0
3/4"	99.8	99.0	100.0	100.0
1/2"	92.4	67.5	100.0	100.0
3/8"	76.1	15.0	88.0	100.0
No. 4	54.4	1.0	28.0	100.0
No. 8	33.7	0.8	3.0	71.0
No. 16	20.2	0.7	2.5	38.0
No. 30	14.2	0.6	2.0	25.0
No. 50	10.2	0.5	1.8	17.0
No. 200	6.1	0.4	1.5	9.6

Note: *All aggregates and silica sand were washed to remove clay particles and other particles finer than the No. 200 sieve per AASHTO T 11, *Standard Method of Test for Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing*.

Bentonite

A commercially available finely-ground powder (passing the No. 200 sieve), premium-grade, high-yielding Wyoming sodium bentonite, better known as bentonite clay, was used for this study. Bentonite that belongs to the family of nano clays can absorb several times of its dry mass in water (Eisenhour and Brown 2009). This bentonite clay was chosen to evaluate the existence of chemically active particles in asphalt mixtures. It was incorporated into the asphalt mixtures as a mineral filler replacement at different content levels.

Calcium Carbonate

A fine calcium carbonate material from a manufacturer in Texas was utilized as the mineral filler for the asphalt mixture design. Calcium carbonate fines show little to no chemical activity and are regarded as a very stable material. In contrast to bentonite clay, calcium carbonate fines have demonstrated a great potential for increasing the rutting resistance and fatigue life of asphalt mixtures, as well as decreasing their moisture damage susceptibility (Moghadas Nejad *et al.* 2020). As a result, this mineral filler was selected to compare with the performance of chemically active and inactive particles (i.e., bentonite vs. calcium carbonate) in asphalt mixtures.

Silica Sand

Manufactured silica sand was used in this step of the research to make the mix only show the effect of active clay particles in asphalt mixtures. The silica sand and the fines were added to the asphalt mixtures at a similar percentage as the field sands, allowing a comparison of the results of mixtures with and without field sand particles. The silica sand possesses similar characteristics as the field sands. However, silica sands typically have fewer clay particles than field sands (Ramdani *et al.* 2019).

Test Methods

The mixture design evaluated included manufactured silica sand free from clay particles. It was deemed suitable to add silica sand by 5% of the total aggregate blend to the reference mixture. Table 3-2 lists the proportions of the aggregate materials for the original, reference, and asphalt mixtures used. The use of fractionated RAP has been excluded for this project due to its inherent variability. Consequently, the original mixture design was reformulated to omit the use of RAP. The mixture was used to evaluate different mineral filler combinations of calcium carbonate and bentonite clay. Figure 3-1 illustrates the aggregate blend gradations for the mixtures discussed above. The asphalt binder content used all mixtures was 4.7%.

Table 3-2. Aggregate blend proportions in percentages.

Design	Igneous 3/4"	Dolomite 3/8"	Dolomite Screenings	Fractionated RAP	Silica Sand	Mineral Filler
Original Mixture*	26	32	31	10	0	1[a]
Reference Mixture	25	25	45	0	0	5[b]
Clay Mixture	24	24	42	0	5	5[c]

* Aggregate material was not washed.

[a] Lime mineral filler.

[b] Calcium carbonate mineral filler.

[c] Calcium carbonate and bentonite clay mineral filler.

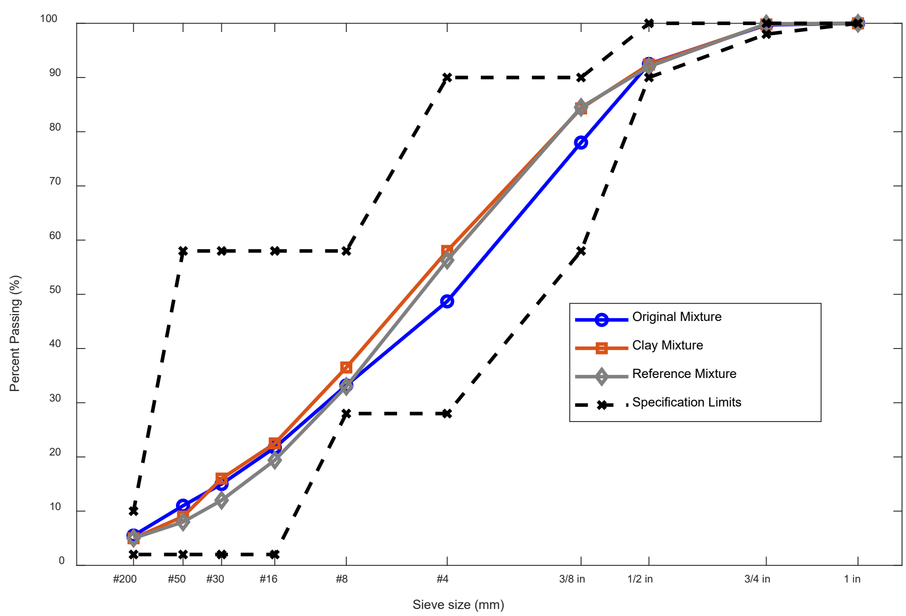


Figure 3-1. Gradation of original, reference, and bentonite asphalt mixtures.

Table 3-3 shows the test methods that were carried out for this study MB testing was conducted on various combinations of calcium carbonate and bentonite clay material passing the No. 200 sieve. The compacted asphalt mixture specimens containing the exact proportions of calcium carbonate and bentonite clay were prepared for HWTT, Indirect Tensile Strength (IDT), and permeability testing. The IDT test procedure was conducted using dry and moist-conditioned specimens. The wet specimens were conditioned following the moisture-induced stress testing (MIST) method.

Table 3-3. Test Methods.

No.	Test Method	Standard	Purpose
1	Methylene Blue (MB)	Tex-252-F	Quantify the chemical activity of fines (materials passing the No. 200 sieve)
2	Hamburg Wheel-Tracking Test (HWTT)	Tex-242-F	Evaluate the rutting susceptibility of compacted asphalt mixtures specimens
3	Indirect Tensile Strength Test (IDT)	Tex-226-F	Determine the tensile strength of compacted asphalt mixture specimens
4	Moisture Induced Stress Testing (MIST)	AASHTO TP 140	Exposure of compacted asphalt mixture specimens to moisture and hydrostatic pore pressure
5	Permeability	FM 5-565	Determine the rate at which water flows through clay induced compacted asphalt mixtures

Table 3-4 shows the experimental testing matrix. Six different experimental combinations were evaluated. Three experimental replicates were performed for each experimental procedure, except for HWTT, for which just one replicate was performed. No field sand materials were utilized for this portion of the study. All the material passing the No. 200 sieve in the mixture was composed of either calcium carbonate (CaCO3) or a combination of CaCO3 and Bentonite Clay (BC). The mineral filler material represented 5% of the total aggregate blend. The testing matrix was designed to explore the relationship between MBV and asphalt mixture performance testing at different BC levels (i.e., chemical activity). This experimental design was selected to determine an MB value threshold based on typical rutting and moisture susceptibility limits used in the design of Superpave mixtures. Therefore, the MB results of fine particles were correlated to the performance parameters of asphalt mixtures containing the same fine particle ratios (i.e., calcium carbonate/bentonite clay).

Methylene Blue Test

*Methylene Blue (MB) Test*s were carried out following Tex-252-F, where 10 g of dry fines for each clay combination were mixed with 30 ml of distilled water. The MB solution was poured into a beaker containing the clay at 0.5 ml increments. The prescribed MB solution (0.5 ml) was poured into the beaker using a burette, and the contents were mixed for 1 min. A drop of slurry was placed on filter paper. This process was repeated until a halo around the drop of the slurry appeared. After that, the mix was agitated for another 5 min, and the drop was again placed on the filter paper. If the halo was still observed, the test was stopped, and the MBV was estimated using Equation 3-1:

$$\text{MBV} = \frac{C \times V}{W} \tag{3-1}$$

where C = concentration of methylene blue in the solution (mg/mL), V = volume of methylene blue solution required for titration (mL), and W = weight of dry material (g). An MBV of 10 mg/g of the field sand is typically considered acceptable and is indicative of how expansive the clay is in the corresponding field

Table 3-4. Experimental Matrix.

Experimental Combination Name	Material Passing No. 200 Sieve		Experimental Procedure				
	Percent CaCO3 (%)	Percent BC (%)	Clay Properties	Asphalt Mixture			
			MB	HWTT	IDT		Permeability
					Dry	Moist	
100% CaCO3 + 0% BC	100	0	X	X	X	X	X
90% CaCO3 + 10% BC	90	10	X	X	X	X	X
80% CaCO3 + 20% BC	80	20	X	X	X	X	X
70% CaCO3 + 30% BC	70	30	X	X	X	X	X
60% CaCO3 + 40% BC	60	40	X	X	X	X	X
50% CaCO3 + 50% BC	50	50	X	X	X	X	X

Hamburg Wheel Tracking Test

The *Hamburg Wheel Tracking Test (HWTT)* was conducted as per Tex 242-F. A 705 ± 22 N (158 ± 5 lb.) load was applied through a steel wheel across the specimen at 52 passes/min. A water bath with a temperature of 50 ± 1°C (122 ± 2ºF) was used to condition the specimens and to evaluate the specimen for moisture susceptibility. The specimens were nominally 150 mm (6 in.) in diameter and 62 mm (2.5 in.) in height, compacted to 93% density. The main output parameters from the HWTT were the number of passes and rut depth associated with the number of passes. Wu *et. al. 2017.* recommended the rutting resistance index (RRI) for evaluating the HWTT results using Equation 3-2:

$$\mathrm{RRI} = \mathrm{N} \times (1 - \mathrm{RD}) \quad (3\text{-}2)$$

where N = the number of load cycles (passes) which is fixed as per the binder grade, and RD = the rut depth (in.) at N. The test is considered complete when 20,000 cycles finish, or a rut depth of 12.5 mm is obtained, whichever comes first. If the test reaches 12.5 mm rut depth, then N is the number of cycles completed to reach this rut depth. RRI is normalized with respect to the minimum RRI for comparing mixtures with different PG binders. Normalized RRI (NRRI) is calculated using Equation 3-3. NRRI of a unity or greater means an acceptable mixture in terms of rutting.

$$\mathrm{NRRI} = \frac{Actual\ RRI}{Minimum\ RRI\ for\ Specified\ PG} \quad (3\text{-}3)$$

Indirect Tensile Strength

The *Indirect Tensile Strength (IDT)* test was carried out as per Tex-226-F. Three specimens of each combination were prepared having dimensions of 150 mm diameter and 62 mm height. The density of the specimens was kept around 93% i.e., the specimens were prepared at 7% air voids. The specimens were monotonically loaded under the Material Testing System (MTS) at a rate of 2 in per minute. Displacement, time, and load were recorded and the highest average load of three specimens was considered as the Tensile Strength of that mix, with 85 ~ 200 psi as the acceptable range.

Tensile Strength Ratio

The *Tensile Strength Ratio (TSR)* was calculated from the dry IDT and moist IDT. Both were calculated as explained above but the moist IDT specimens were first conditioned in the MIST (Moisture Induced Stress Tester). The specimens were conditioned in the MIST for 3500 cycles at 60 °C and a pressure of 40 psi. Specimens after conditioning were kept at a room temperature of 25 °C for two hours. Then, IDT was carried out on them. The TSR was calculated as the ratio of moist IDT to dry IDT. This ratio shows how severe the mix is susceptible to moisture damage. For this project, a TSR value exceeding 80% (i.e., TSR > 80%) was used to indicate moisture tolerance, i.e., none moisture susceptible mixtures.

Permeability

Permeability was done according to FM 5-565. Three specimens of each mix were prepared at 93% density, and the average value was reported as the permeability of that mix. A calibrated cylinder of 31.75 mm inner diameter was filled with the specimen and a sealing tube which was used to confine the specimen laterally. A pressure of 0 to 103.42 kPa was applied to the sealing tube. Water was allowed to pass the specimen vertically through a graduated tube. The time taken by the water to pass through the specimen was recorded and Darcy's law was applied to calculate the permeability of the specimen, 100×10^{-5} cm/s is the limiting threshold for acceptability as per the Florida Department of Transportation (FDOT)

Results and Discussion

Methylene Blue

As shown in Table 3-5, the average MBV results obtained for all six combinations range between 1.6 and 102.7 mg/g. These results illustrate that inactive and active fines combinations, varying from 0 to 50% BC, were beyond the scope of this study. On infrequent occasions, a field sand source exceeds the MBV of 80.0 mg/g – so this project was confined to BC values less than or equal to 50%, i.e., BC ≤ 50%.

Figure 3-2 shows the correlation that exists between MBV and BC content with a correlation coefficient (R^2) of 97.83%. Higher amounts of BC yield higher MBV, meaning that more MB solution is needed to develop a light blue halo when testing. This relationship confirms that varying the BC content in asphalt mixtures can simulate the presence of chemically active and expansive clays. Accordingly, asphalt mixtures with higher BC contents should exhibit undesirable engineering properties, such as lower rutting resistance and higher moisture susceptibility.

Table 3-5. MBV Experimental Results.

Experimental Combination Name	Average MBV (mg/g)
100% CaCO3 + 0% BC	1.6
90% CaCO3 + 10% BC	15.0
80% CaCO3 + 20% BC	27.7
70% CaCO3 + 30% BC	53.3
60% CaCO3 + 40% BC	82.3
50% CaCO3 + 50% BC	102.7

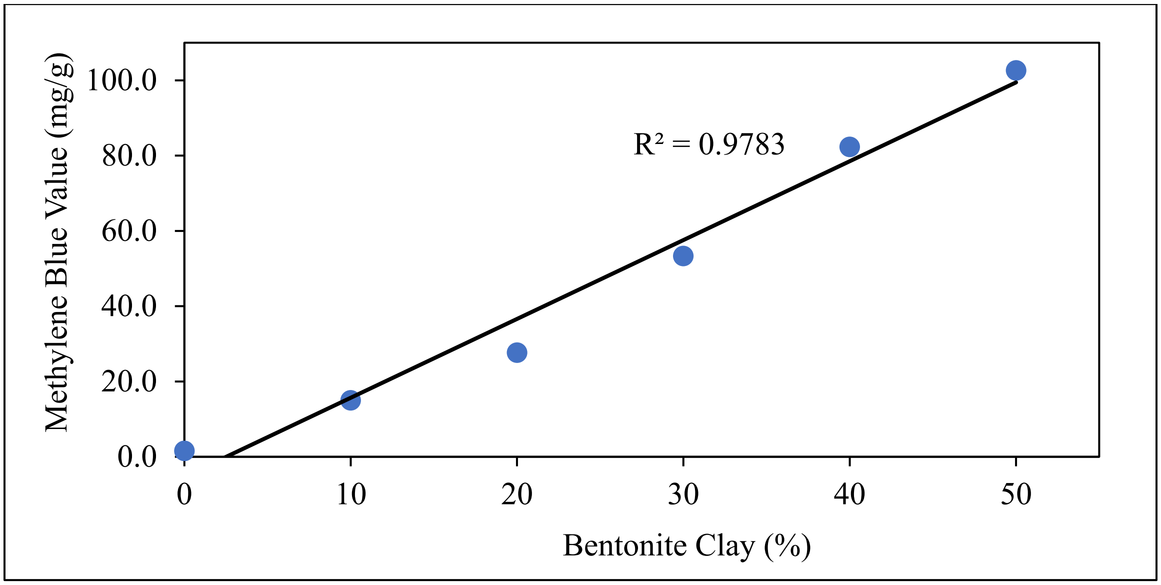


Figure 3-2. Relationship between bentonite clay content and methylene blue value.

Hamburg Wheel-Tracking Test

The HWTT results for the asphalt mixtures containing six different combinations of CaCO3 and BC are presented in Figure 3-3. The dotted line indicates the lower limit of NRRI. Of all six combinations, the first combination (i.e., 100% CaCO3 + 0% BC) is the only trial that yielded an acceptable NRRI. This combination did not include any harmful clay particles in the aggregate blend. The other five combinations have NRRI lower than the minimum recommended (i.e., 1.0). This outcome indicates the deteriorating effects of clay on rutting performance.

A more detailed analysis of the data reveals that a power function can explain the relationship between MBV and NRRI for this portion of the study. As shown in Figure 3-3, a significant drop is observed in the rutting performance when the BC content increases from 0 to 10%. Once the BC is included in the asphalt mixture as mineral filler, a random pattern is perceived in the rutting performance. However, as the MBV increases, the NRRI tends to decrease, indicating that the asphalt mixture is more prone to rutting failure at higher amounts of expansive clays. The main objective here is to determine a threshold for active clay content. Based on the HWWT results, it can preliminarily be suggested that this threshold is about 10 mg/g. This MBV is the intersecting point for the power function trend line and lower limit for NRRI.

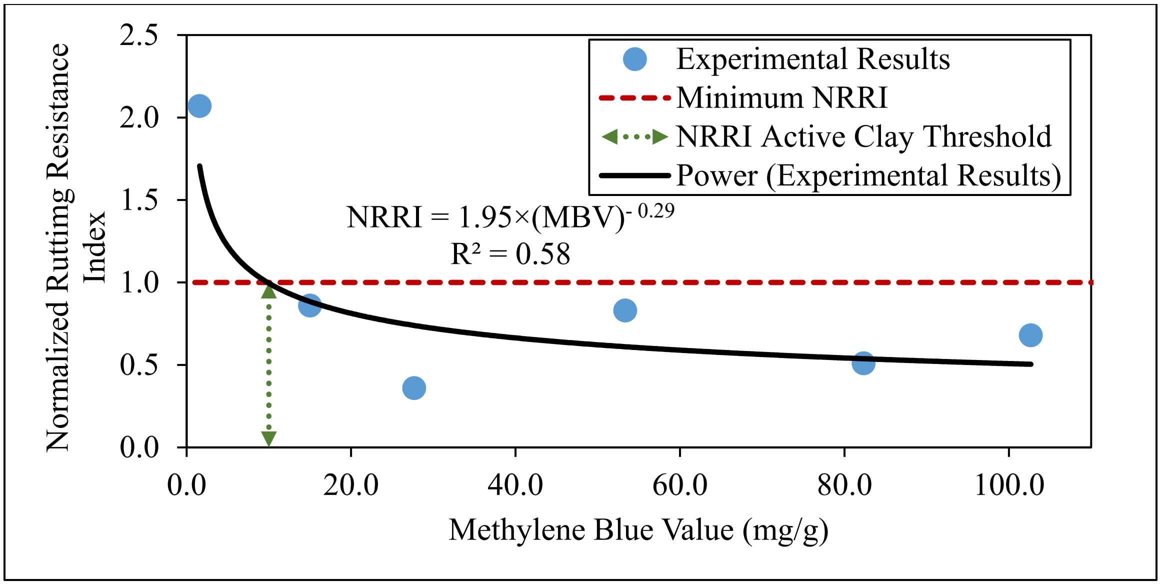


Figure 3-3. Relationship between methylene blue value and normalized rutting resistance index.

Tensile Strength Ratio

Indirect tensile tests were performed to determine the toughness properties of the asphalt mixtures containing active clay particles. Under dry conditions, the average IDT for all $CaCO_3$ and BC combinations ranges from 103 psi to 122 psi. The allowable lower and upper limits for IDT according to TxDOT Item 344 are 85 psi and 200 psi, respectively. All six combinations met the specification requirement, which means that all of them are within the acceptable range. This result suggests that the presence of expansive clay particles constrained to dry conditions does not deteriorate the specimens' IDT properties. The amount of clay had a significant effect on the toughness property. The IDT increased as $CaCO_3$ was replaced with BC in 10% increments.

Indirect tensile tests were also performed after moisture conditioning the specimens using the MIST equipment. This specimen conditioning method helps to determine the moisture susceptibility of the asphalt mixtures. The average IDT dropped after moist conditioning the specimens. The results for all the experimental combinations range between 62 psi and 87 psi. The mixture without expansive clay (i.e., 100% CaCO3 + 0% BC) and with 10% BC (i.e., 90% CaCO3 + 0% BC) satisfied the allowable lower limit of 85 psi by slight margins. The remaining asphalt mixtures under investigation showed lower strengths than the allowable limit. It is assumed that the amount of BC present in the mixture expands when in contact with water. This characteristic property of active clay weakens the toughness property of the asphalt mixture specimens.

Figure 3-4 illustrates the correlation between MBV and tensile strength ratio (TSR). TSR is the ratio of moist IDT to dry IDT. The typically acceptable lower limit for TSR to prevent moisture damage is 0.80 (Speight 2016). The TSR parameter is a good indicator of whether an asphalt mixture is moisture susceptible or not. The TSR data reveals that the internal asphalt binder-to-aggregate bond weakened as the amount of BC increased. A linear fit was determined to represent the relationship between MBV and TSR. However, no intersecting point was found between the 0.80 TSR limit and the linear fit of the data. As a result, a threshold for active clay content based on tensile strength data could not be established. This finding suggests that more data (i.e., more replicates or additional asphalt mixture designs) must be included in the analysis to determine a threshold of active clay content using IDT measurements. For example, theoretically speaking, the TSR for the asphalt mixture without BC or control mixture should have the highest TSR value. A higher TSR value for the control mixture could help establish a threshold of active clay content through cracking data.

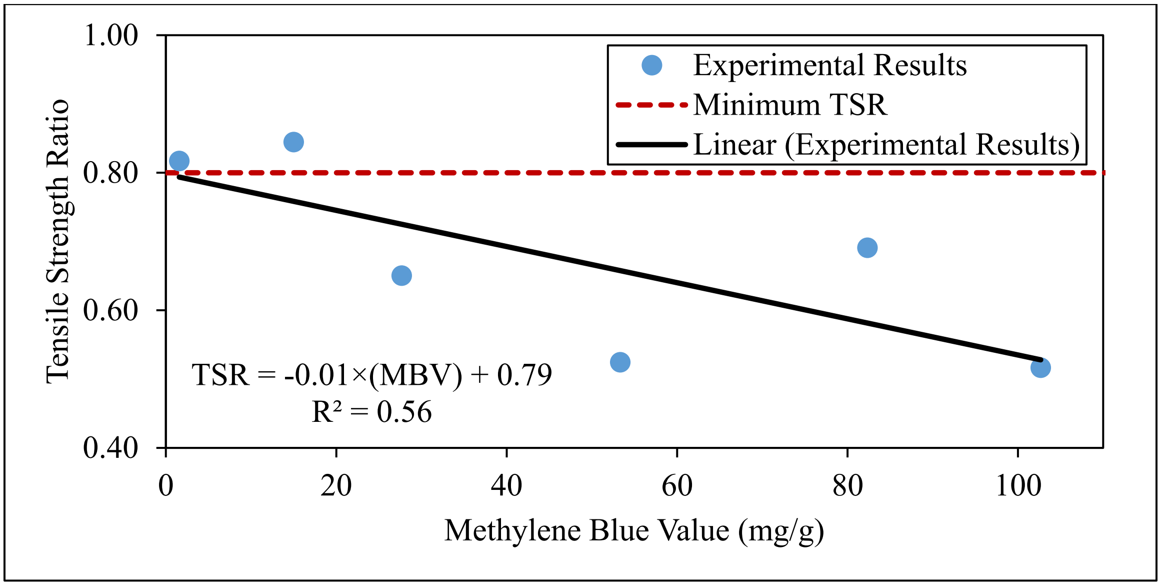


Figure 3-4. Relationship between methylene blue value and tensile strength ratio.

Permeability

The permeability (or hydraulic conductivity, *k*) values of the asphalt mixtures containing mineral filler variations were also evaluated. It was hypothesized that the permeability would decrease as the BC content increases. This effect will be due to the BC's expansive characteristics, which can absorb several times its dry mass when in contact with moisture, reducing the flow of water through the specimen. The permeability of BC-induced asphalt mixtures is shown in Figure 3-5. The asphalt mixture without clay exhibited the highest permeability. The presence of active clay for the other five mixtures generated a drop in permeability results, making them less permeable than the mixture without BC.

Like the rutting resistance results, a power function best represents the relationship between MBV and permeability. The FDOT typically recommends a permeability upper limit of 100×10^{-5} cm/s to prevent excessive water infiltration into the pavement structure (Choubane et al., 1998). However, the permeability coefficients for all the mixture combinations were below this suggested threshold. Additionally, the addition of BC reduces permeability. For this study, the permeability analysis was done to identify the presence of expansive clay and any shifting point in the hydraulic conductivity of the asphalt mixture. Thus, to suggest an active clay threshold based on hydraulic conductivity data, the derivative of the power function between MBV and permeability was calculated. The derivative analysis seems to indicate that the sensitivity to change of the power function permeability output with respect to a change in MBV is significant below 10 mg/g. However, once the MBV is above this inflection point, the rate of change of permeability as a function of MBV appears to be inconsequential.

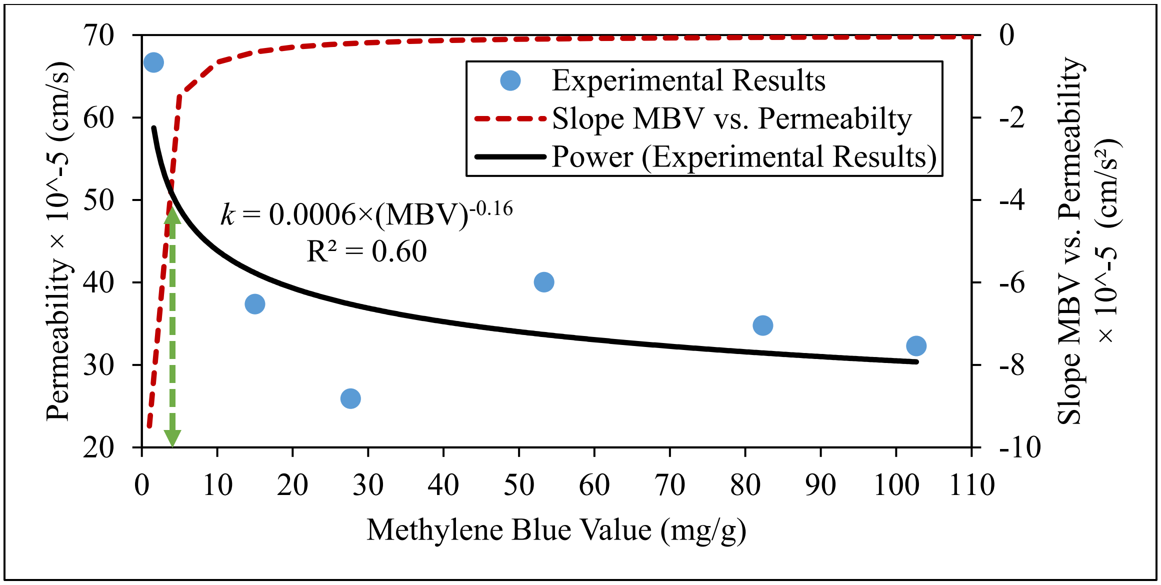


Figure 3-5. Relationship between methylene blue value and permeability.

Summary and Recommendations

This section was aimed to develop trends and thresholds for active clay content with the purpose of limiting their incorporation into asphalt mixtures to a certain allowable level, without impeding performance, durability, and longevity. The results obtained from the performance tests, namely rutting, tensile strength ratio, and permeability, suggest that a conservative threshold for active clay content in asphalt mixture is 10 mg/g MBV. This finding agrees with the limiting MBV criteria recommended in a past study (Nikolaides et al., 2007). Accordingly, the following recommendations were made as follows:

- The results of this chapter were regarded as preliminary. The proposed trends and thresholds for active clay content were based on limited data, and it was recommended that different asphalt mixture designs, materials, and proportions be used.
- Testing additional replicates to complement the performance evaluations reported herein and improve the confidence level of the results is strongly recommended. This is especially important for narrowing the research within the range of action of field sands in asphalt mixtures, typically below 20 mg/g.
- The findings of this chapter suggested a threshold for MBV significantly below MBVs observed in several field sand sources around Texas. However, the active clay components in field sands are typically combined with other mineral filler materials. Thus, the MBV threshold should not be taken nominally to determine the use of a field sand source. As a result, further research studies were designed to clarify such interactions among clay and sand as well as their effect on asphalt mixture performance.

Chapter 4

Impact of Active Clays on Hamburg Wheel Tracking Test

Introduction

AASHTO T330 indicates that asphalt mixtures should perform excellently if the MBV of the material smaller than 0.075 mm is below 6 mg/g. Marginally acceptable performance is expected when the MBV is between 7 and 12 mg/g, while values between 13 and 19 mg/g suggest potential problems or failures. An MBV above 20 mg/g indicates extreme moisture susceptibility. Asphalt mixture testing can also identify clay contamination. The Hamburg wheel tracking test (HWTT), as per AASHTO T324, is commonly used to evaluate the rutting potential and moisture susceptibility of asphalt mixtures. Bentonite is typically used in the concrete mix as a stabilizing agent because of its high plasticity and swelling index. Previous research has demonstrated the potential of bentonite as a replacement for mineral filler, but almost all past studies have minimized its expansive properties, which are difficult to achieve in practice or can be achieved but will require excessive use of resources and time. The main aim of using bentonite in this research was to utilize its swelling properties and replicate the effects of expansive clays in Superpave mixtures. Bentonite shows an expansive/swelling behavior when it encounters moisture. Additionally, to more accurately simulate clay contamination from field sands, this study included clay from three different field sand sources in a Superpave mix. The findings of this section of the project correlate MBV results well to HWTT results. Moreover, after evaluating different mixtures for permeability and TSR, it was found that none of the properties of field sand correlate well with performance in terms of TSR and permeability. Thus, the study focused on evaluating MBV and HWTT.

Experimental Methods

Materials

Table 4-1 shows how clay combinations were explored for this study. As signified by an “X”, inactive clays were combined with active clays to control and simulate different levels of clay contamination. Calcium carbonate ($CaCO_3$) and dolomite dust were used as inactive clays, and commercially available bentonite and natural clays obtained from natural sands were employed as active clays. $CaCO_3$ fines exhibit little to no chemical activity and are regarded as a very stable material. Compared to active clays, $CaCO_3$ fines have shown considerable potential for improving the rutting performance and fatigue life of asphalt mixtures and lowering their sensitivity to moisture damage (Nejad *et. al 2020)*. Even though it is proven that $CaCO_3$ has hardly any reactivity in a mixture, an alternative inactive filler was used to analyze the impact of clay with a different inert fine material. Dolomite clay was sourced from a dolomite fine screening material by washing out the minus 0.075 mm particles according to ASTM C117. The MBV was 1.6 mg/g for $CaCO_3$ and 1.9 mg/g for dolomite dust. These values indicate the resemblance of both minus 0.075 mm materials, which are expected to have similar outcomes when separately combined with bentonite clays.

Bentonite is a very active swelling clay with an MBV of 205.0 mg/g. Bentonite belongs to the nano clays family and can absorb several times its dry mass in water (Eisenhour *et. al 2009)*. A commercially sourced sodium bentonite was used for this study. The material was first dry sieved according to AASHTO T27 to separate fines passing the No. 200 (0.075 mm) sieve. Apart from bentonite, three natural clays were combined with $CaCO_3$. Three natural sand sources from different Texas locations and varying levels of clay contamination were selected, namely high active, active, and low active clays. After the natural sands were soaked in water for 24 hrs to loosen the clay from sand particles, the sands were washed using a mechanical agitator to separate material passing the #200 sieve, according to ASTM C117. The water and fines that passed the #200 sieve were captured and dried to get natural clay fines. The MBVs for high active clay, active clay, and low active clay were 37.8, 17.6, and 6.0 mg/g, respectively.

The inactive and active clay percentages were selected to test clay contamination exhibiting MBV between 1.6 to 20.0 mg/g. The percentages represent the ratios applied to manufacture the clay combinations. For example, to prepare 10 g of 98% $CaCO_3$: 2% Bentonite clay for MB testing, 9.8 g of $CaCO_3$ and 0.2 g of bentonite were mixed. Because of material availability, more permutations were evaluated for the $CaCO_3$: Bentonite clay combination. As previously mentioned, for dolomite and natural clays, dolomite fine screening and natural sands were processed to obtain minus 0.075 mm fines corresponding to these sources, limiting the available material.

Table 4-1. Clay Combinations Used to Test Active Clays.

Inactive Clay (%)	**Active Clay (%)**	**$CaCO_3$: Bentonite**	**Dolomite: Bentonite**	**$CaCO_3$: High Active Clay**	**$CaCO_3$: Active Clay**	**$CaCO_3$: Low Active Clay**
100%	0%	X	X	n/a	n/a	n/a
98%	2%	X	n/a	n/a	n/a	n/a
96%	4%	X	X	X	X	X
94%	6%	X	n/a	n/a	n/a	n/a
92%	8%	X	X	X	X	X
90%	10%	X	n/a	n/a	n/a	n/a
88%	12%	X	n/a	n/a	n/a	n/a
86%	14%	X	X	X	X	X

Note: X indicates that the combination was assessed; n/a: indicates the combination was not assessed.

Test Methods

Duplicate specimens were subjected to the MB test, followed by one set of HWTT for each clay combination. The testing protocol was designed to explore the correlation between MB and rutting performance in the presence of different clay levels (i.e., chemical activity). The MB test was done as explained in the previous section and following Tex-252-F. HWTT was done according to Tex-242-F with specimens compacted to 93% density. Two different parameters were calculated from the test i.e., NRRI and stripping inflection point (SIP). SIP was calculated based on the creep slope and stripping slope of the curve, which is generated when rut depth is plotted against the number of load passes, as shown in Figure 4-1 (Yin *et. al 2014)* . This number (SIP) was obtained directly from the HWTT software as a test output parameter and was also verified by manually inspecting the HWTT data.

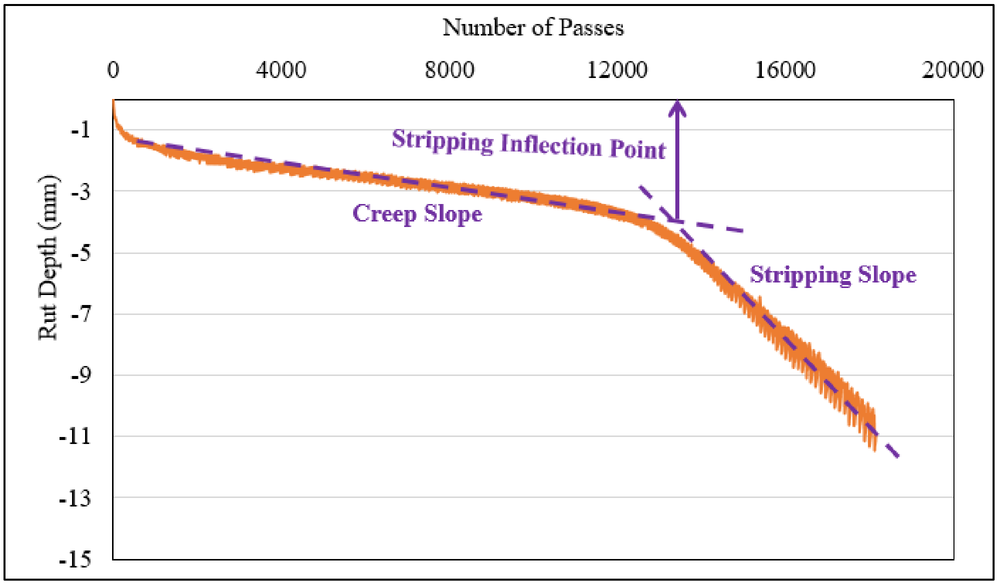


Figure 4-1. Determination of Stripping Inflection Point.

Mixture Design

Figure 4-2 shows the combined aggregate gradation for the ½ in. (12.5-mm) nominal maximum aggregate size Superpave mixtures used in this study. The figure also shows the lower and upper gradation limits set by TxDOT for such an SP-C mixture. As shown in Table 4-2, the aggregate blend consisted of igneous coarse aggregate with an average size of 3/8 in. (9.5 mm) to 3/4 in. (19.0 mm), dolomite intermediate aggregate with an average size of No. 4 (4.75 mm) to 3/8 in. (9.5 mm), dolomite fine screenings, silica sand, and clay combinations which represent the minus #200 (0.075 mm) material for all mixtures. To prepare the asphalt mixture specimens, the coarse, intermediate, and fine aggregate materials were washed following ASTM C117, which permitted the removal of all materials passing the #200 sieve. This process allowed for the inclusion of clay combinations at a specific percentage of 5% by total aggregate blend mass and neglected the presence of other minus 0.075 mm materials in the mixtures. As mentioned in the previous chapters, for consistency and in line with the traditional mix-design volumetrics for typical Texas type SP-C mixtures, all the mixtures evaluated in this section of the research were prepared using a PG 70-22 binder and a constant optimum binder content of 4.7%.

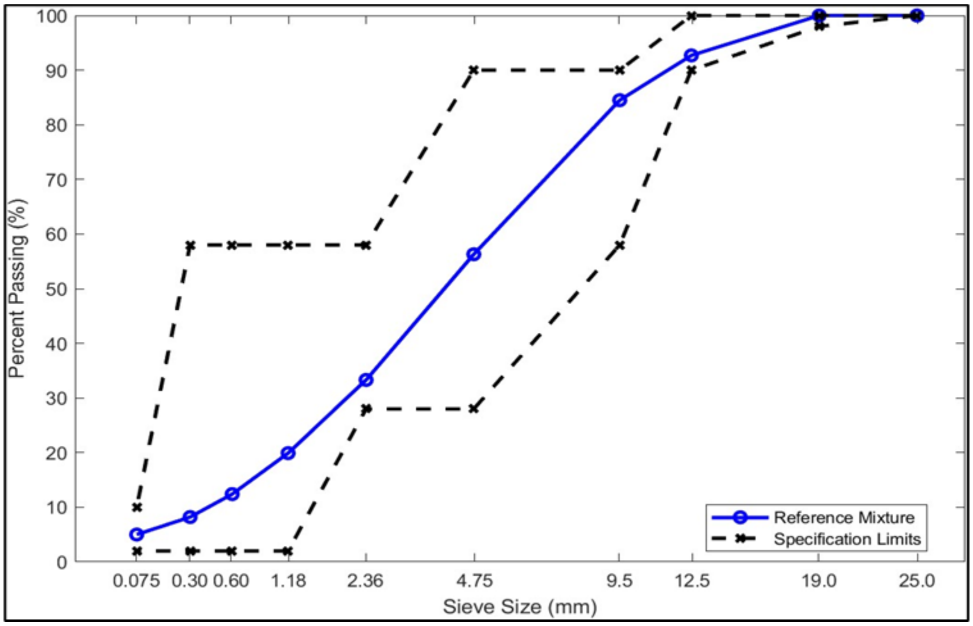


Figure 4-2. Aggregate Gradation Used to Test the Impact of Active Clays.

Table 4-2. Aggregate Mixture Design Proportions.

Aggregate Material	**Percentage (%)**
Igneous Coarse Aggregate	24.0[a]
Dolomite Intermediate Aggregate	24.0[a]
Dolomite Fine Screenings	42.0[a]
Silica Sand	5.0[a]
Clay Combination	5.0[b]

[a] Washed following ASTM C 117 (without minus 0.075 mm material).

[b] Minus 0.075 mm material in mixtures.

Results and Discussion

Table 4-3 shows the MBVs for the 21 different inactive and active clay combinations explored for this portion of the research project. The expected performance for each variation per AASHTO T330 is also reported. Combining inactive clays with active clays demonstrated a wide range of MBVs. Twelve combinations yielded MBVs of 6 mg/g or less, which means they are likely not to impact the performance of the asphalt mixture negatively. Three of twenty-one are marginally acceptable; four might have potential problems/possible failures, and two failed the AASHTO-recommended criterion. The 100% $CaCO_3$ and the 96% $CaCO_3$ with 4% low active clay combinations displayed the lowest MBV (i.e., 1.6 mg/g). In contrast, 86% dolomite with 14% bentonite had the highest value (i.e., 26.7 mg/g).

Table 4-3. Methylene Blue Test Results for Active/Inactive Clays.

Sample No.	Clay combination	Average methylene blue value (mg/g)	Expected performance (AASHTO T 330)
1	100% $CaCO_3$	1.6	Excellent
2	98% $CaCO_3$: 2% Bentonite	3.2	Excellent
3	96% $CaCO_3$: 4% Bentonite	5.8	Excellent
4	94% $CaCO_3$: 6% Bentonite	8.6	Marginally acceptable
5	92% $CaCO_3$: 8% Bentonite	11.4	Marginally acceptable
6	90% $CaCO_3$: 10% Bentonite	15.0	Problems / possible failures
7	88% $CaCO_3$: 12% Bentonite	17.7	Problems / possible failures
8	86% $CaCO_3$: 14% Bentonite	21.0	Failure
9	100% Dolomite	1.9	Excellent
10	96% Dolomite: 4% Bentonite	13.0	Problems / possible failures
11	92% Dolomite: 8% Bentonite	17.0	Problems / possible failures
12	86% Dolomite: 14% Bentonite	26.7	Failure
13	96% $CaCO_3$: 4% High Active Clay	3.0	Excellent
14	92% $CaCO_3$: 8% High Active Clay	4.3	Excellent
15	86% $CaCO_3$: 14% High Active Clay	7.0	Marginally acceptable
16	96% $CaCO_3$: 4% Active Clay	2.6	Excellent
17	92% $CaCO_3$: 8% Active Clay	3.9	Excellent
18	86% $CaCO_3$: 14% Active Clay	5.3	Excellent
19	96% $CaCO_3$: 4% Low Active Clay	1.6	Excellent
20	92% $CaCO_3$: 8% Low Active Clay	2.1	Excellent
21	86% $CaCO_3$: 14% Low Active Clay	2.4	Excellent

Figure 4-3 shows the variations in MBV with the percentage of different active clays. For each of the five combinations of inactive and active fines, MBV increases linearly with an increase in the active clay component. The MBVs of the combinations with bentonite are most sensitive to the active clay percentage, as evident from the slopes of the lines in Figure 4-3. Based on the AASHTO criterion (≤6.0 mg/g), the mixtures containing 4% or less bentonite should perform well. When the inactive clay component was changed from $CaCO_3$ to dolomite, the MBV became less sensitive to the percentage of bentonite. This outcome indicates that the combination type and the clay contamination proportion, in this case bentonite, control MBV. From Table 4-3, $CaCO_3$ with natural clay combinations did not have an extended range of MB values like bentonite clay. Bentonite has a larger surface area, negative charge, and ion exchange capacity than natural clays. That is why the absorption of chloride ions from the MB solution is much more intense when a higher percentage of clay is present, resulting in high MBV.

The $CaCO_3$ with natural clay combinations demonstrated MBVs between 1.6 and 7.0 mg/g. The natural clays were selected based on their MBVs. As previously mentioned, the MBVs for pure high active clay, active clay, and low active clay were 37.8, 17.6, and 6.0 mg/g, respectively. Based on past research (Aschenbrener T. 1992), these MBVs represent high, intermediate, and low clay activity for natural sand sources used for paving purposes. However, despite exhibiting different chemical activity levels, small variations in their MBVs were observed due to the low percentages of natural clay applied in the material combinations. Most natural clay combinations yielded MBVs of 6 mg/g or less except for 86% $CaCO_3$ with 14% high active clay.

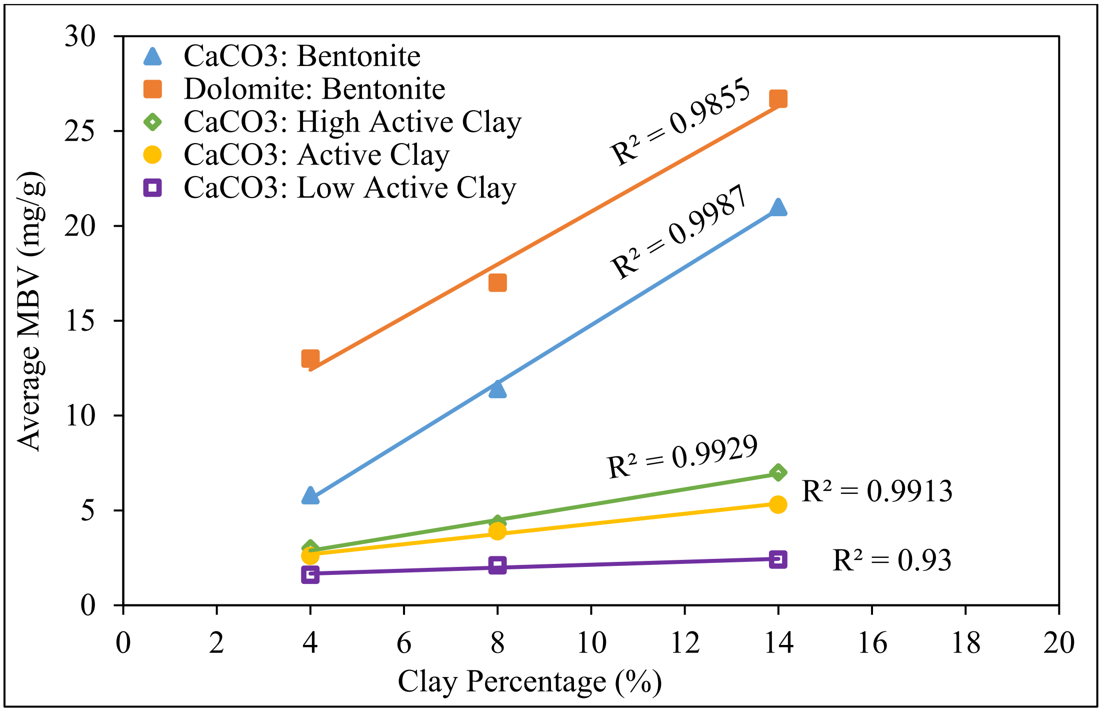


Figure 4-3. Relationship between Active Clay Percentage and Methylene Blue Value.

Hamburg Wheel Tracking Test Results

Table 4-4 contains the NRRI and SIP values for all combinations of the fines. The perceived performance of each mix based on their NRRI and SIP are also reported. An NRRI greater than 1.00 corresponds to a satisfactory mix in terms of rutting performance. The higher the SIP is, the higher the mix's resistance to moisture susceptibility will be. A SIP less than 9000 corresponds to a mix susceptible to moisture distress (Yin *et al. 2020*). The mix with 100% CaCO3 exhibits the highest NRRI (1.76) with no sign of stripping up to 20,000 cycles. This indicates that the presence of CaCO3 does not negatively impact the rutting performance of the mix. With highly active bentonite, resistance to rutting dropped from an NRRI of 1.75 to 0.68 for the mix with 86% CaCO3 and 14% bentonite combinations.

Table 4-4. Hamburg Wheel Tracking Test Results for Clay Combinations.

Sample No.	Clay combination	NRRI	SIP	Performance type
1	100% $CaCO_3$	1.76	> 20000	Satisfactory
2	98% $CaCO_3$: 2% Bentonite	1.75	> 20000	Satisfactory
3	96% $CaCO_3$: 4% Bentonite	1.66	> 20000	Satisfactory
4	94% $CaCO_3$: 6% Bentonite	0.83	6348	Not Satisfactory
5	92% $CaCO_3$: 8% Bentonite	1.23	9378	Satisfactory
6	90% $CaCO_3$: 10% Bentonite	0.93	7089	Not Satisfactory
7	88% $CaCO_3$: 12% Bentonite	0.92	6974	Not Satisfactory
8	86% $CaCO_3$: 14% Bentonite	0.68	5202	Not Satisfactory
9	100% Dolomite	1.66	16759	Satisfactory
10	96% Dolomite: 4% Bentonite	1.63	> 20000	Satisfactory
11	92% Dolomite: 8% Bentonite	1.31	10476	Satisfactory
12	86% Dolomite: 14% Bentonite	0.80	9944	Not Satisfactory
13	96% $CaCO_3$: 4% High Active Clay	1.59	> 20000	Satisfactory
14	92% $CaCO_3$: 8% High Active Clay	1.59	> 20000	Satisfactory
15	86% $CaCO_3$: 14% High Active Clay	1.53	> 20000	Satisfactory
16	96% $CaCO_3$: 4% Active Clay	1.42	> 20000	Satisfactory
17	92% $CaCO_3$: 8% Active Clay	1.62	> 20000	Satisfactory
18	86% $CaCO_3$: 14% Active Clay	1.75	> 20000	Satisfactory
19	96% $CaCO_3$: 4% Low Active Clay	1.52	16170	Satisfactory
20	92% $CaCO_3$: 8% Low Active Clay	1.51	16321	Satisfactory
21	86% $CaCO_3$: 14% Low Active Clay	1.48	16732	Satisfactory

As shown in Figure 4-4, a noticeable decrease in NRRI and SIP is observed as soon as the MBV exceeds 6.0 mg/g. These results corroborate a marginal performance region between 7 and 12 mg/g MBV based on the AASHTO T330 criteria. In terms of stripping, until 96% CaCO3: 4% bentonite, no stripping is noticed, but after that, the specimens show signs of stripping, meaning that the clay activity becomes a determinant factor on mixture performance.

The effect of expansive bentonite when the CaCO3 was replaced with dolomite dust is shown in Figure 4-5. The trends for these mixtures are like the trends observed for the CaCO3 combinations in Figure 4-4. As expected, the mix with 100% dolomite yielded the highest NRRI of 1.66. The NRRI fell below 1.00 when more than 8% bentonite was used. As judged by the reported SIPs, these mixtures do not show as drastic moisture susceptibility as the CaCO3 mixtures. The SIP value becomes borderline below 9000 when the bentonite percentage exceeds 8%.

Since the mixtures with $CaCO_3$ showed more sensitivity to rutting, the three natural clays with different levels of sensitivity were added to the mixture replacing bentonite and were not tested with dolomite dust. According to Table 4-4, the combinations of $CaCO_3$ combined with up to 14% of the three natural clays yielded MBVs of less than 6.0 mg/g except in one case (CaCO3 with 14% high active clay) where the MBV is close to 7.0 mg/g. As shown in Figure 4-6, all permutations of the mixtures performed satisfactorily indicating that the threshold of 6.0 mg/g is reasonable, if not conservative.

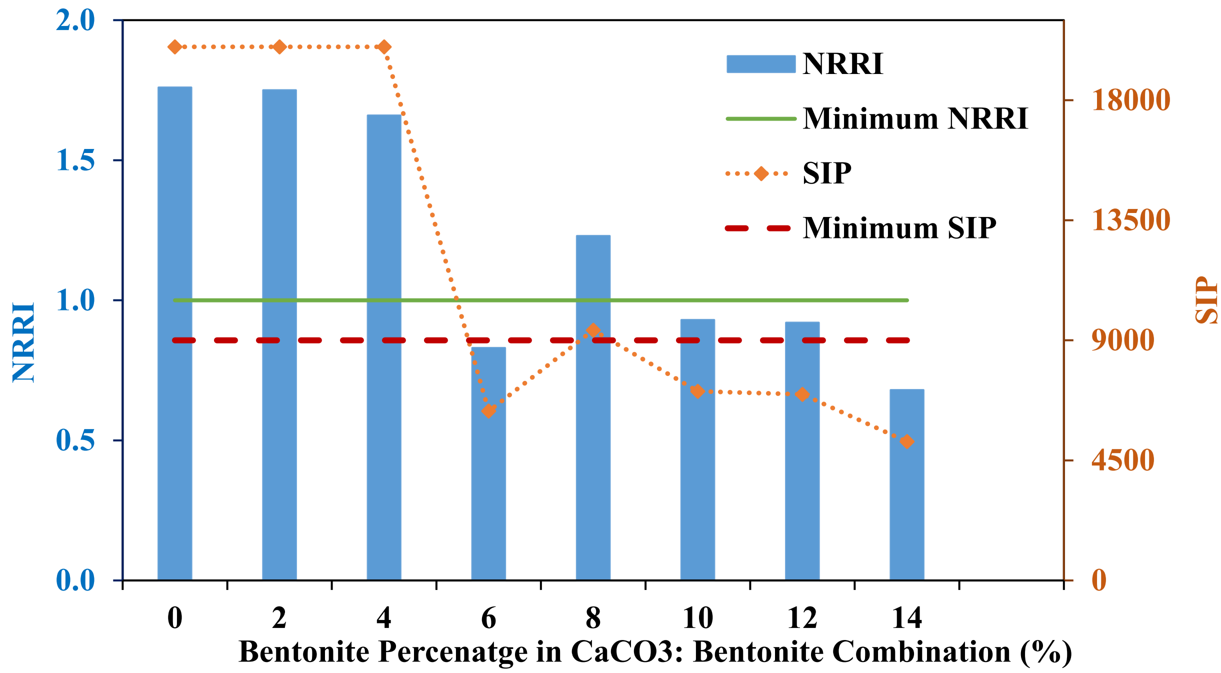


Figure 4-4. Mixture Performance for Calcium Carbonate: Bentonite Combinations.

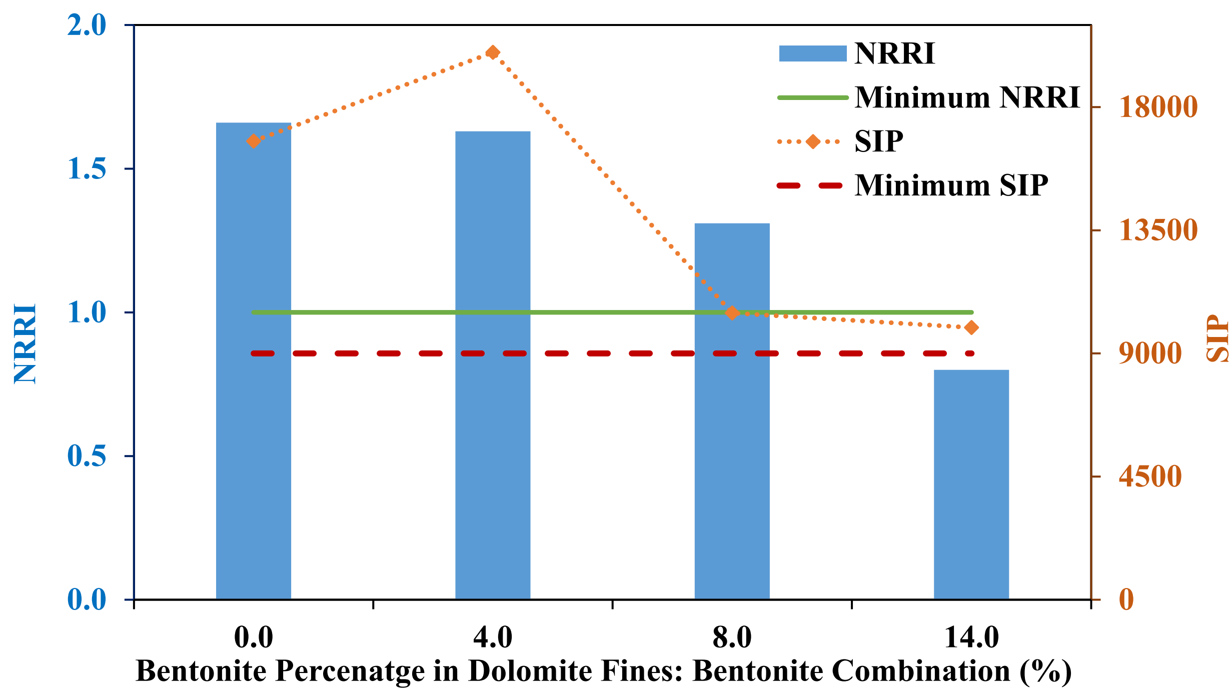


Figure 4-5. Mixture Performance for Dolomite Fines: Bentonite Combinations.

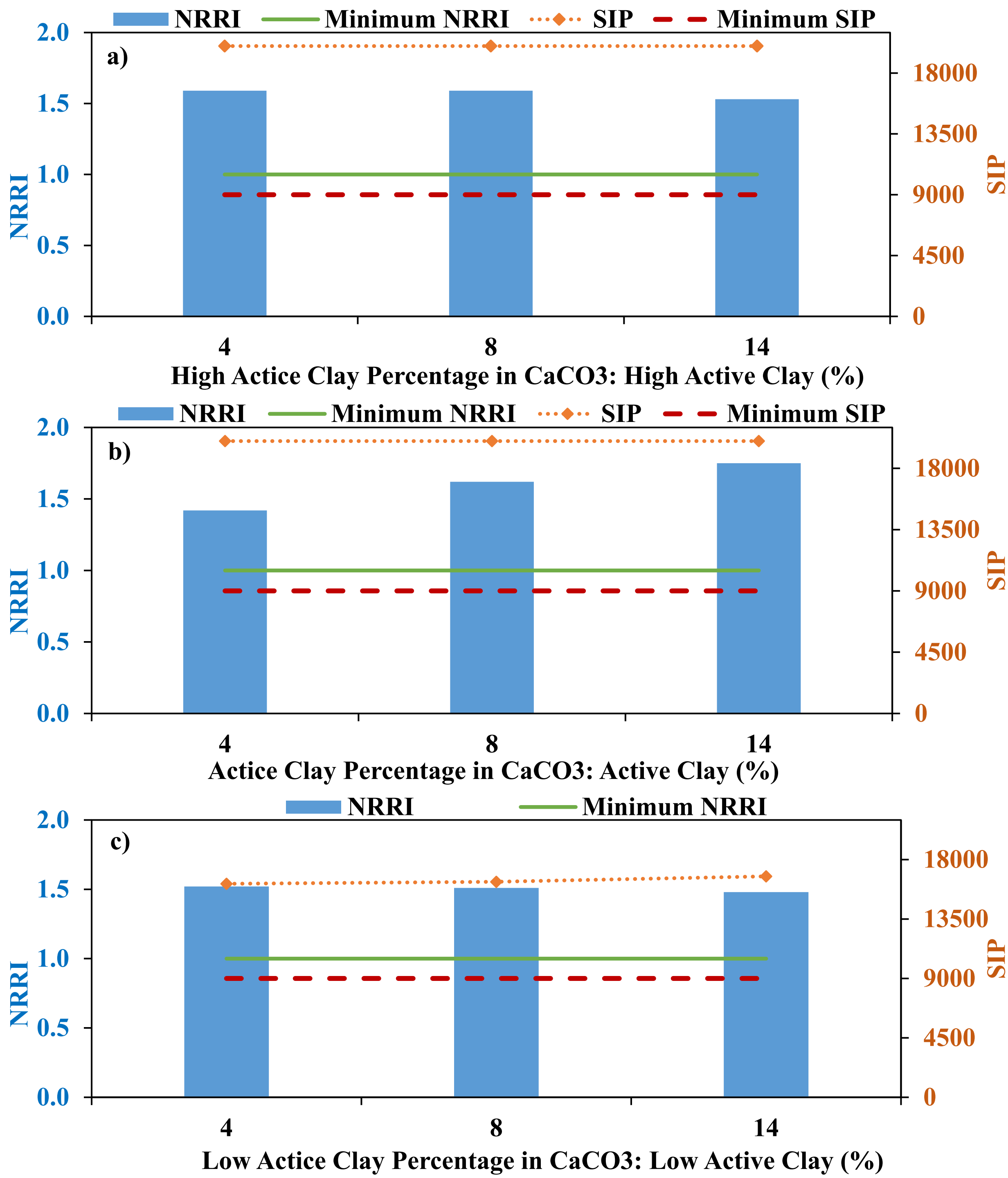
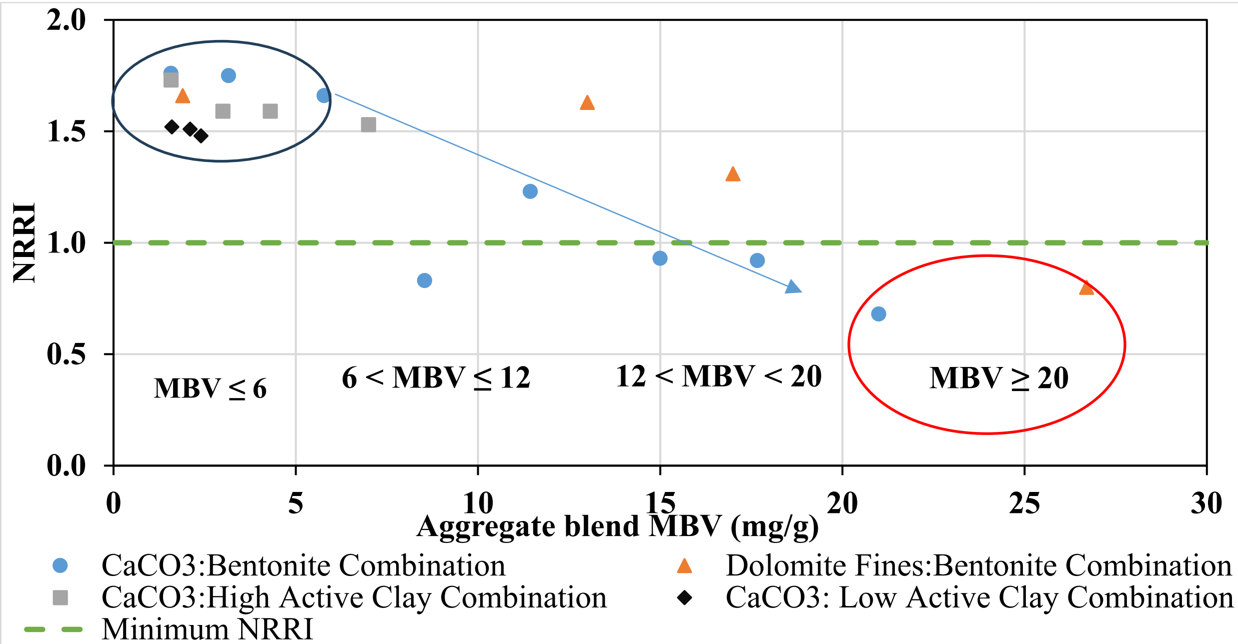


Figure 4-6. Percentage, NRRI, and SIP: (a) CaCO3: High Active Clay, (b) CaCO3: Active Clay, and (c) CaCO3: Low Active Clay.

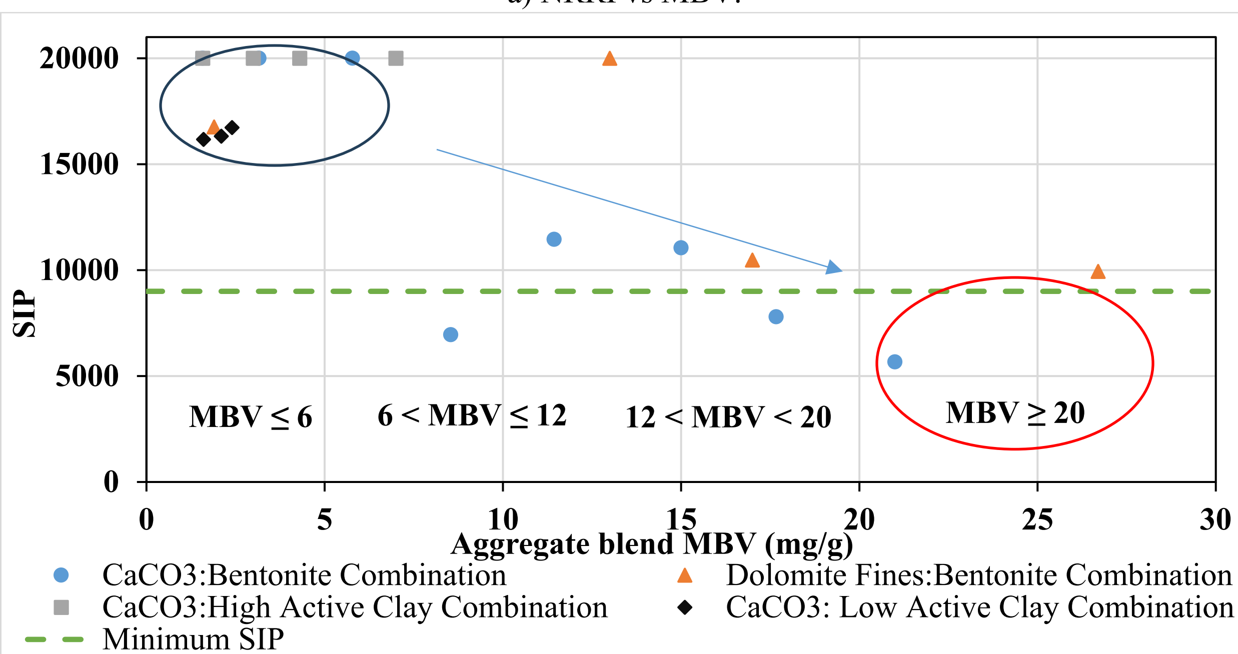
Performance of the Mixtures as the Function of MBV

Figure 4-7 demonstrates the variations in NRRI and SIP with respect to the MBV. Mixture combinations with MBV of 6.0 mg/g or less showed satisfactory performance regarding NRRI and

SIP. The mixtures with MBV values of between 6 and 20 mg/g show marginal performance with respect to NRRI and SIP when compared with the results from mixtures with MBV values of less than 6 mg/g**.** When the MBV value exceeds 20 mg/g, the mixtures exhibit poor performance in terms of rutting and stripping.



a) NRRI vs MBV.



b) SIP vs MBV.

Figure 4-7. Variations in Rutting Parameters with MBV: a) NRRI vs MBV, b) SIP vs MBV.

Figure 4-7 presents a comparative analysis of the MBV against the NRRI and SIP. The data points are delineated by two oval regions: a black circle that encompasses values indicative of excellent performance, and a red circle that highlights values associated with poor performance. A discernible downward trend (shown by the blue line) is observed in the plot, suggesting a correlation between increasing MBV and decreasing performance metrics (NRRI and SIP). This trend underscores the importance of optimizing MBV in asphalt mixtures to enhance overall durability and resistance to rutting and stripping.

Summary and Recommendations

This chapter presented an investigation of the effect of harmful clays of different activity levels on the rutting performance of asphalt mixtures. MB testing was used to determine clay contamination levels. HWTT was conducted to measure the rutting (NRRI) and moisture susceptibility (SIP) of the mixtures with different clay combinations, the following conclusions can be drawn from this chapter:

- MB test is a quick test to understand the expansive characteristics of clay. The MBV criteria, as established by AASHTO T330, can be implemented to mitigate the detrimental effect of harmful clay particles on the rutting performance of asphalt mixtures. If the MBV of minus #200 (0.075 mm) in the mixture is below 6.0 mg/g, the rutting and moisture susceptibility should be acceptable.
- A mix can show potential stripping even when showing good resistance to rutting or permanent deformation because of the chemistry between the clay minerals with the binder, especially when in contact with moisture.
- Above an MBV of 20.0 mg/g, the mixture performance is poor and a marginal region between 6.0 mg/g and 20.0 mg/g should be investigated to optimize the incorporation of field sands into asphalt mixtures.
- Recommendations for future follow-up studies should include using field sands as received, without washing, to evaluate their impact on mix performance. Also, studying and assessing the effects of clay activity using other binder grades such as PG 64-22 is recommended

Chapter 5

Development of Guidelines to Determine Field Sand Percentage Based on Methylene Blue Value

Introduction

This chapter aims to produce guidelines that designers can use to determine an optimal percentage of field sand in a particular Superpave mixture design. The amount of field sand on Superpave mixtures typically depends on the chemical activity or swelling of existing clay particles. This chapter discusses the effects of field sands, including the chemical activity of the clay, on the rutting performance and moisture susceptibility of Superpave mixtures. The main objective of this section is to develop guidelines for the use of field sand content based on typical asphalt mixture performance parameters. Fifteen field sands at 10% content by weight of the total aggregate were added to asphalt mixtures, and a volumetric design was conducted for each field sand source. An SP-C gradation was used and was kept almost similar for all the mixtures so that there was minimal effect of gradation on the performance of the corresponding asphalt mixtures. Two different binder grades were used, namely PG 64-22 and a PG 70-22, to quantify the effect of binder grade on the performance of the asphalt mixtures. The HWTT was used to comparatively evaluate the mixtures in terms of their rutting and moisture susceptibility.

Experimental Methods

Materials

Figure 5-1 shows the locations of the field sand sources. As shown in Table 5-1, the research team, with assistance from TxDOT, gathered field sands from twenty-four sources. The research team collected preliminary experimental data for the field sands, including MBV, sand equivalent (SE), and aggregate gradations. Based on the preliminary testing, the research team selected fifteen sources of field sands for the evaluation presented in this chapter.

Figure 5-2 shows that the SE results were graphically plotted against the MBV to better visualize the characteristics of the field sands. The maximum and minimum SE results obtained for all the field sands were 98 and 37, respectively. For the MBV analysis, the maximum and minimum values achieved were 45.8 mg/g and 3.7 mg/g, respectively. Thus, the range midpoints for the SE and MBV results are 68 and 24.8 mg/g, respectively. These midpoints were utilized to divide the field sand sources into four distinctive quadrants: (I) low SE and high MBV, (II) high SE and high MBV, (III) low SE and low MBV, and (IV) high SE and low MBV. Thereafter, the field sand sources were arbitrarily selected to guarantee that enough field sand sources were selected from each quadrant and to have a good representation of all field sands across Texas (i.e., to select at least one field sand source per district). As shown in Figure 5-2, the blue circles are the field sands used for the guideline development testing and the green triangles denote the field sands used for the subsequent validation. As listed in Table 5-1, field sands (FS) in the rest of this chapter are henceforth referred to by their numbers that is if the name is FS 1, it means that the sand is from Atlanta District and has an MBV of 28.5 mg/g and SE of 56.

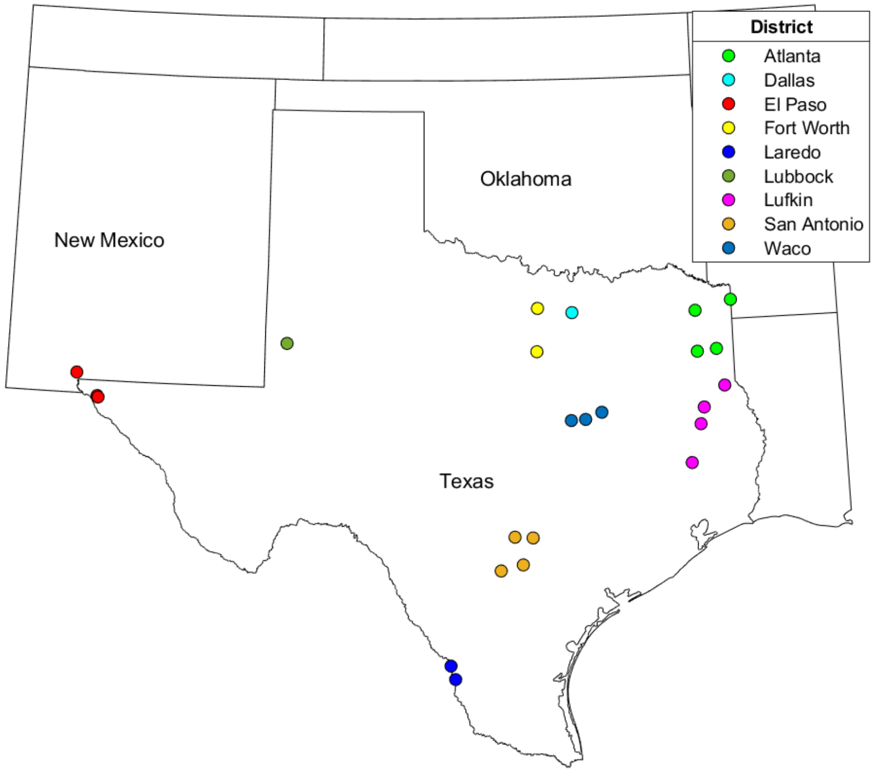


Figure 5-1. Location of Field Sand Sources Investigated.

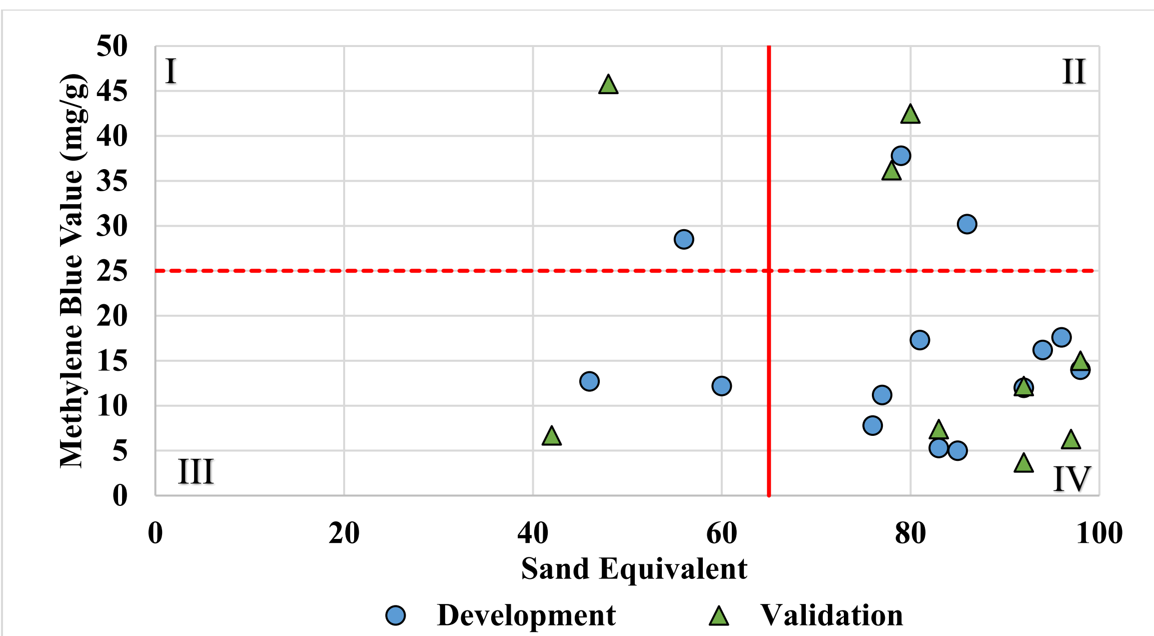


Figure 5-2. Field Sand Selection.

Table 5-1. Field Sand Sources.

No.	District Name	MBV (mg/g)	SE	Development	Validation
1	Atlanta	28.5	56	X	n/a
2	Atlanta	7.8	76	X	n/a
3	Atlanta	17.3	81	X	n/a
4	Atlanta	6.7	42	X	n/a
5	Fort Worth	11.2	77	X	n/a
6	El Paso	37.8	79	X	n/a
7	El Paso	16.2	94	X	n/a
8	El Paso	36.2	78	n/a	X
9	Dallas	6.3	97	n/a	X
10	Lufkin	12	92	X	n/a
11	Lufkin	7.4	83	n/a	X
12	Lufkin	12.7	46	X	n/a
13	Lufkin	14	98	X	n/a
14	Lufkin	14.2	38	X	n/a
15	Laredo	45.8	48	n/a	X
16	Laredo	42.5	80	n/a	X
17	Lubbock	30.2	86	X	n/a
18	Waco	17.6	96	n/a	X
19	Waco	12.2	60	X	n/a
20	Waco	15	98	n/a	X
21	San Antonio	5	85	X	n/a
22	San Antonio	5.3	83	X	n/a
23	San Antonio	3.7	92	n/a	X
24	San Antonio	12.2	92	n/a	X

Note: X indicates that the combination was assessed; n/a: indicates the combination was not assessed.

Table 5-2 contains the aggregate blend proportions for the mixture designs used in the study. The aggregate blends were composed of limestone dolomite 21.5 mm (#67), igneous 9.5 mm (3/8"), dolomite screenings, field sand, and RAP. Field sand content was fixed at 10% for this study. Although RAP was excluded in the previous chapter of this study, it has been reintroduced in this chapter to align with common practices in Texas. RAP is frequently used in mixture designs across the state due to its proven benefits in enhancing the sustainability and cost-effectiveness of pavement materials. By incorporating RAP in this chapter, the study aims to reflect more realistic paving conditions and provide insights that are directly applicable to current practices in Texas, ensuring the relevance and applicability of the findings to local industry standards. Figure 5-3 illustrates the typical aggregate blend gradation for the percentage of field sand in the mixture.

Table 5-2. Aggregate Blend Proportions.

Mixture Design	Percentage of Aggregate Material (%)				
	Dolomite 21.5 mm (#67)	Igneous 9.5 mm (3/8")	Dolomite Screenings	Field Sand	RAP
Mixtures with 10% field sand	10	53	17	10	10
Mixtures with 10% field sand + 1% Hydrated Lime*	10	53	16	10	10

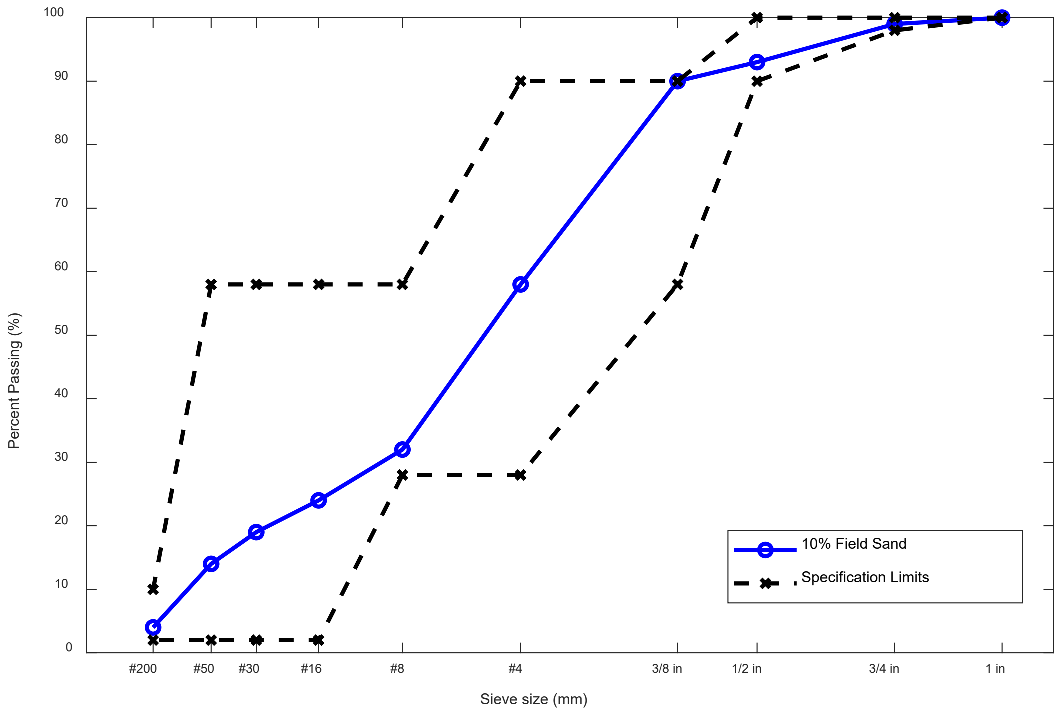


Figure 5-3. Typical aggregate gradations.

Table 5-3 shows a detailed list of the asphalt mixtures assessed. Lime was used as an additive to check for the improvement in performance of the asphalt mixtures. For this part of the study, all mixture variations were tested at their respective optimum binder contents (OBC).

Table 5-3. Asphalt Mixture Variations.

Field Sand	Methylene Blue Value (mg/g)	Optimum Binder Content (%)	10% Field Sand		
			PG 64-22	PG 64-22 + Lime	PG 70-22
1	28.5	5.5	X	X	X
2	7.8	5.4	X	X	X
3	17.3	5.0	X	X	X
4	6.7	5.2	X	X	X
5	11.2	5.6	X	X	X
6	37.8	5.3	X	X	X
7	16.2	5.2	X	X	X
8	36.2	n/a	n/a	n/a	n/a
9	6.3	n/a	n/a	n/a	n/a
10	12.0	6.0	X	X	X
11	7.4	n/a	n/a	n/a	n/a
12	12.7	5.6	X	X	X
13	14.0	5.1	X	X	X
14	14.2	5.2	X	X	X
15	45.8	n/a	n/a	n/a	n/a
16	42.5	n/a	n/a	n/a	n/a
17	30.2	5.6	X	X	X
18	17.6	n/a	n/a	n/a	n/a
19	12.2	5.2	X	X	X
20	15.0	n/a	n/a	n/a	n/a
21	5.0	5.4	X	X	X
22	5.3	5.0	X	X	X
23	3.7	n/a	n/a	n/a	n/a
24	12.2	n/a	n/a	n/a	n/a

Note: X indicates that the combination was assessed; n/a: indicates the combination was not assessed.

Test Methods

Table 5-4 lists the test methods that were conducted for this part of the study. The Sand Equivalent (SE) test was performed on the aggregate blend passing through the No. 4 sieve, whereas the MBV test was conducted on the material passing the No. 200 sieve of the aggregate blend.

Table 5-4. Test Methods.

No.	Test Method	Standard	Purpose
1	Sand Equivalent (SE)	Tex-203-F	Quantify the deleterious materials present in the aggregate blend
2	Methylene Blue Value (MBV)	Tex-252-F	Quantify the chemical activity of fines (materials passing the No. 200 sieve)
3	Hamburg Wheel-Tracking Test (HWTT)	Tex-242-F	Evaluate the rutting/stripping susceptibility of compacted asphalt mixture specimens

The SE test is a measure used to determine the relative proportions of fine dust or clay-like particles in soils or aggregates. The SE value is a ratio, expressed as a percentage, which compares the volume of sand to the volume of clay. This test was conducted as per Tex-203-F specification. In this test method, a calcium chloride solution is added to aggregates and the mixture is shaken for 45 seconds in a cylindrical tube. The mix is then allowed to settle for 10 minutes after which more solution is added to it. The sand reading and clay reading is taken after 20 minutes. SE value is calculated in percentage as the ratio of sand reading to the clay reading. This test was done on the aggregate blend.

Both the MB and HWTT tests were performed. A higher MBV corresponds to a greater expansiveness or reactivity of the clay. The MB tests were conducted on the material passing the 0.075 mm sieve of the aggregate blend gradation, including RAP. Correlating the MBV of field sand alone may lead to misleading conclusions since it does not account for the percentage of field sand in the mix. For that reason, the MB tests were performed on the fines of the aggregate blend, and not just on the fines of the field sands. As an illustrative example, Table 5-5 illustrates the gradations of four representative field sand sources. The material passing the No. 0.075 sieve varied from 3.3% to 13.1%. If 1 kg of each aggregate blend containing 10% of these sand sources is sampled, between 3 grams and 12 grams of field sand fines would be observed in the mix. The MBV of the field sand and the blend for each field sand are also shown in Table 5-5. The blend MBV is not only controlled by the MBV of the field sand but also by the percentage of fines in the field sand. The variation in the MBV of the blend with the MBV of the field sand for all field sands included in this study is presented in Figure 5-4. Acknowledging a few outliers, a reasonably strong correlation is observed between the two MBVs. However, the MBV of the blended aggregates (fines)is significantly less than the MBV of the field sand itself.

Table 5-5. Example Gradation and MBV of Field Sands.

Parameter	Sieve Size (mm)	FS 4	FS 6	FS 12	FS 13
Gradation	25.000	100.0	100.0	100.0	100.0
	19.000	99.2	100.0	100.0	99.2
	12.500	93.2	100.0	100.0	93.2
	9.500	90.0	99.8	99.4	90.0
	4.750	58.4	96.3	98.7	58.4
	2.360	32.1	92.0	98.2	32.2
	1.180	23.6	85.4	97.4	23.6
	0.600	19.0	69.4	94.3	19.0
	0.300	16.1	34.1	81.0	12.2
	0.075	4.4	3.3	13.1	4.2
MBV of Field Sand Fines, mg/g		6.5	37.5	12.7	14.0
MBV of Blend Fines, mg/g		4.4	7.5	4.8	4.1

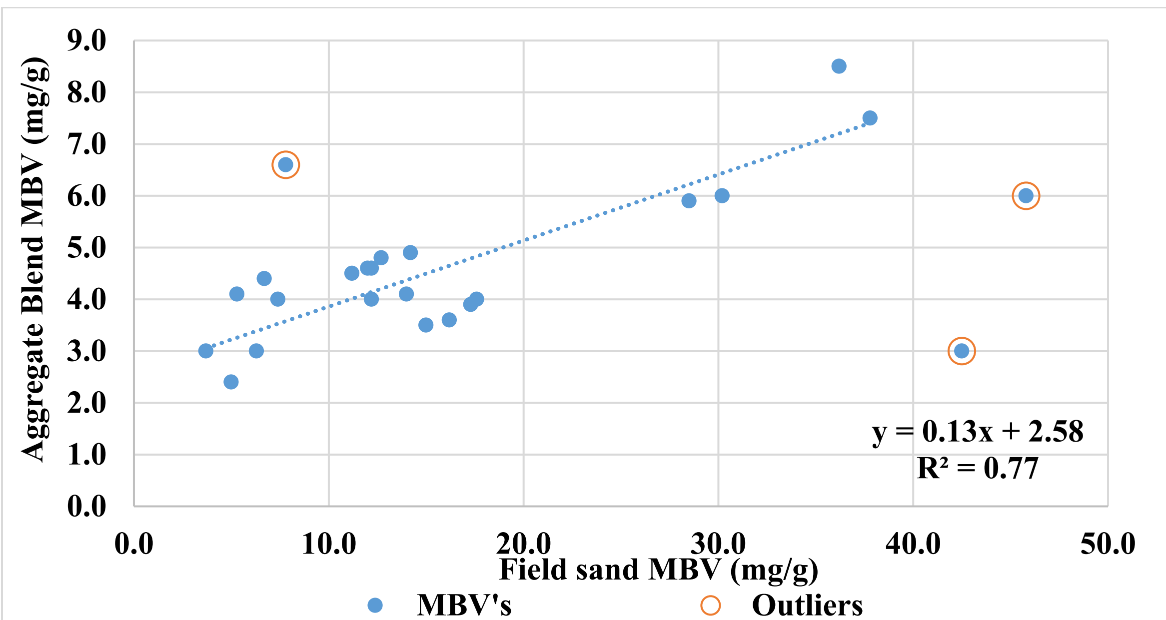


Figure 5-4. MBV of field sand versus the MBV of aggregate blend.

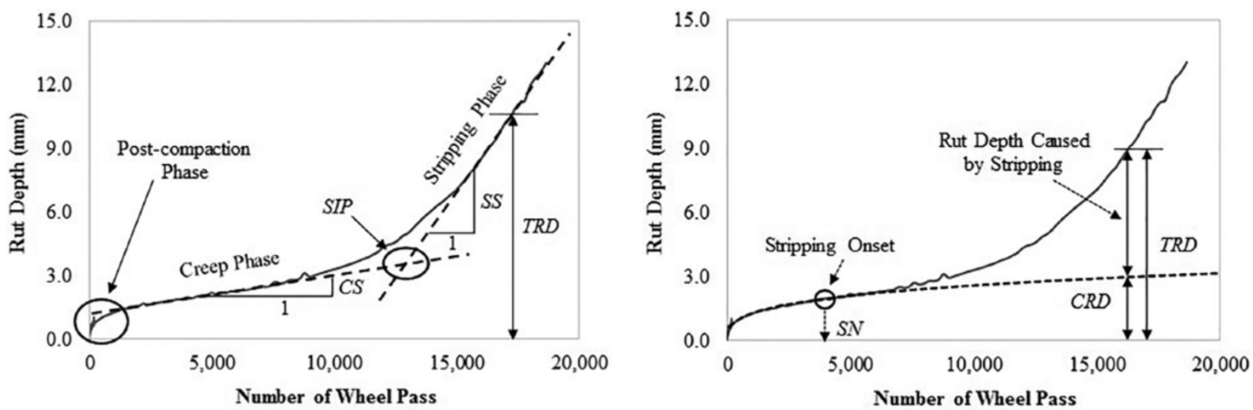
HWTT per Tex 242-F was employed to check the influence of field sands on the rutting and stripping performance of the asphalt mixtures. The main parameters obtained from this test were the normalized rutting resistance index (NRRI) and stripping inflection point (SIP). NRRI is based on the rut depth and the binder grade used in the mix. The rutting resistance index (RRI) proposed by Wu *et al. 2017* is calculated using Equation 5-1:

$$RRI = N \text{ x } (1 - RD) \quad (5\text{-}1)$$

where N = the number of load cycles (passes) as a function of the binder grade, and RD = the rut depth (in.) at N. RRI is normalized with respect to the minimum RRI for comparing mixtures with different PG binders. Normalized RRI (NRRI) is calculated using Equation 5-2 as follows:

$$\text{NRRI} = \frac{Actual\ RRI}{Minimum\ RRI\ for\ Specified\ PG} \qquad (5\text{-}2)$$

NRRI is based on the rut depth and the binder grade used in the mix. NRRI of a unity (i.e., 1.00) or greater means an acceptable mixture in terms of rutting resistance. SIP is the inflection point when the curve starts to strip. It was obtained by employing a method from Hasan *et. al. 2022,* and not directly from the HWTT software output to improve accuracy. The concept of SIP can be explained in Figure 5.5. As shown in the images, a typical rutting curve comprises of a creep phase and a stripping phase. If a tangent is drawn to these phases, the intersection will result in an inflection point known as SIP. The threshold for SIP in this study was set at 9000 load passes (i.e., SIP ≥ 9000) based on Fan Yin *et. al. 2020.*



- Source: Fan Yin *et. al.* (2020)

Figure 5-5. Schematic of the rutting response-curve and performance parameters.

Results and Discussion

MB tests were carried out for all the mix variations by weighing up 2500 g of the aggregate blend and then wash sieving the material to extract the materials passing the 0.075 mm sieve, as per AASHTO T330. Table 5-6 shows the MBVs obtained for all the mix variations. The maximum and minimum MBVs for the aggregate blends were 7.5 mg/g and 2.4 mg/g, respectively.

Table 5-6. Aggregate Blend MBV and SE.

Field Sand	Methylene Blue Value (mg/g)	10% Field Sand Methylene Blue Value (mg/g)	Sand Equivalent (SE)
1	28.5	5.9	81
2	7.8	6.6	78
3	17.3	3.9	85
4	6.7	4.4	66
5	11.2	4.5	61
6	37.8	7.5	73
7	16.2	3.6	91
10	12.0	4.6	89
12	12.7	4.8	84
13	14.0	4.1	87
14	14.2	4.9	81
17	30.2	6.0	77
19	12.2	4.6	76
21	5.0	2.4	87
22	5.3	4.1	87

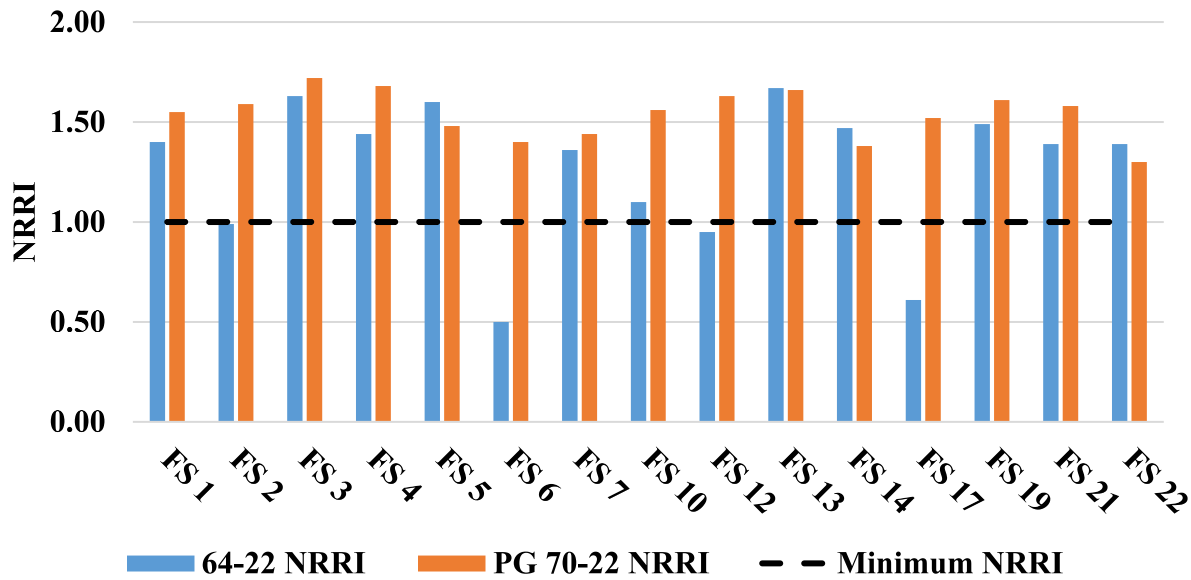
Table 5-6 also shows the SE results. As these tests were done on the aggregate blend, the SE values are higher, and MB values are lower than the field sand itself. It was observed that the aggregate blend SE values were greater than 60 and the MB values were less than 10 mg/g for all the field sands used for this part of the study.

Table 5-7 summarizes the rutting results obtained for the field sands used at 10% of the total weight of aggregates. One specimen was tested as is the HWTT has historically been proven to be a statistically reasonable repeatable test. The NRRI and SIP values for both, i.e., mixtures with PG 64-22 and PG 70-22, are shown, and the values of the performance parameters decreased as a lower binder grade was used in the mix. Since, it can be seen from the values that even if the NRRI of the mix passes the criteria of 1.00, it does not necessarily mean that the SIP value of the mix would be greater than 9000 load passes but conversely it can be seen that if the SIP value is greater than 9000, the mix passed the NRRI threshold.

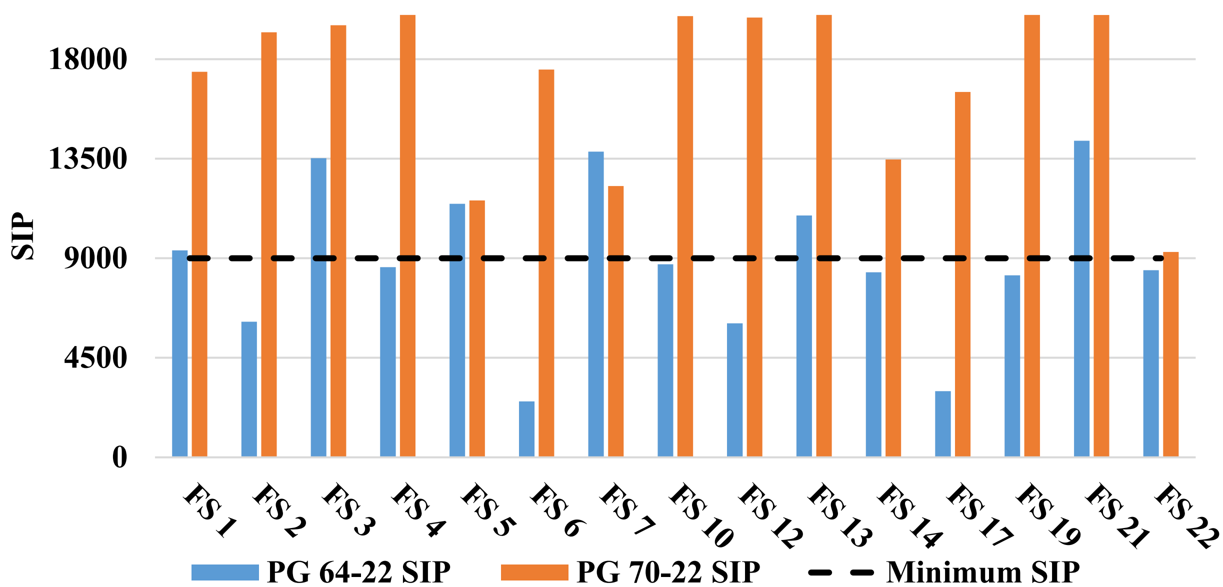
Table 5-7. HWTT results.

Field Sand Source	PG 70-22		PG 64-22	
	NRRI	SIP	NRRI	SIP
FS 1	1.55	17428	1.40	9360
FS 2	1.59	19216	0.99	6130
FS 3	1.72	19534	1.63	13520
FS 4	1.68	20000	1.44	8600
FS 5	1.48	11614	1.60	11460
FS 6	1.40	17530	0.50	2532
FS 7	1.44	12268	1.36	13820
FS 10	1.56	19950	1.10	8726
FS 12	1.63	19882	0.95	6058
FS 13	1.66	20000	1.67	10934
FS 14	1.38	13468	1.47	8366
FS 17	1.52	16520	0.61	2990
FS 19	1.61	20000	1.49	8230
FS 21	1.58	19998	1.39	14310
FS 22	1.30	9282	1.39	8460

Figure 5-6 shows the effect of binder grade on the NRRI and SIP parameters for the 15 mixtures investigated. When using a PG 70-22 binder grade, most mixtures showed higher NRRI and SIP values compared to using a PG 64-22 binder grade. It is important to note that some of the mixtures failed the NRRI and SIP threshold limits when using a relatively softer PG 64-22 binder, and the mixtures passed the threshold when the binder was substituted with PG 70-22. Hence, using a higher binder grade can enhance the quality of mixtures with field sand. This is particularly beneficial for paving projects in which producing or allocating crushed sands is challenging, and it may be more feasible to obtain a higher binder grade to address potential rutting or stripping problems.



a)



b)

Figure 5-6. Comparison between different binder grades: a) NRRI and b) SIP.

The effect of adding hydrated lime to the asphalt mixtures was evaluated using mixtures having 10% field sand. All the mixtures were first evaluated without an antistripping agent and using PG 64-22, thereafter hydrated lime was added at a rate of 1% of the total aggregate blend weight. Figure 5-7 illustrates how hydrated lime improves the rutting and stripping of FS 6 mix (namely FS 6 PG 64-22 WL). Without lime, the mix (FS 6 PG 64-22) shows a rut depth of 12.5 mm before 10,000 load passes (cycles), and with 1% lime, it (FS 6 PG 64-22 WL) takes 20,000 load passes (cycles) to reach the same rut depth.

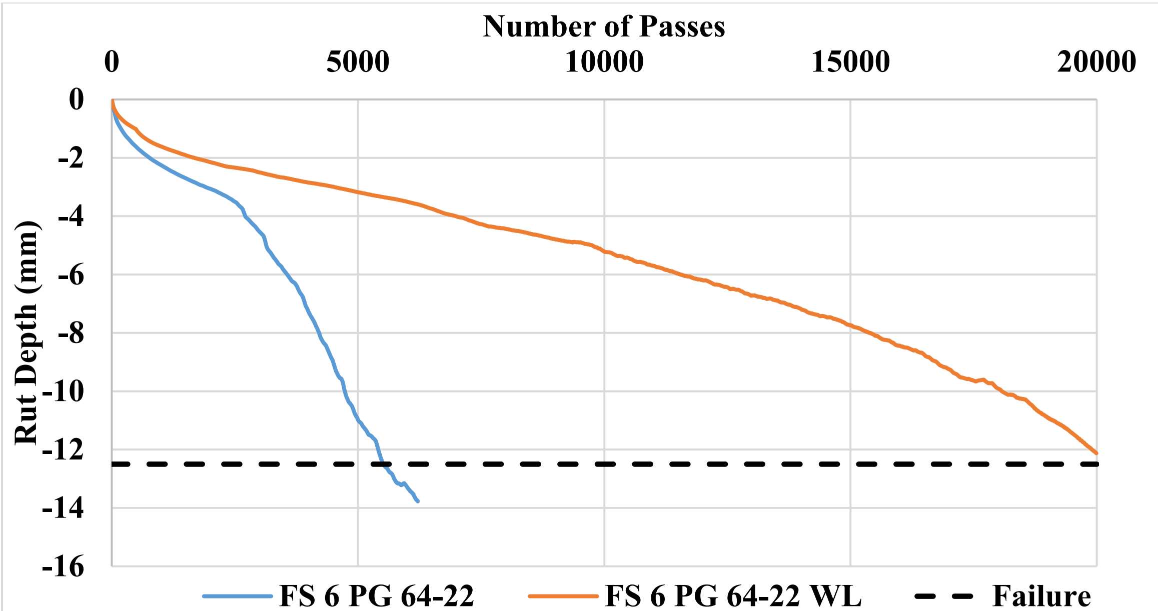
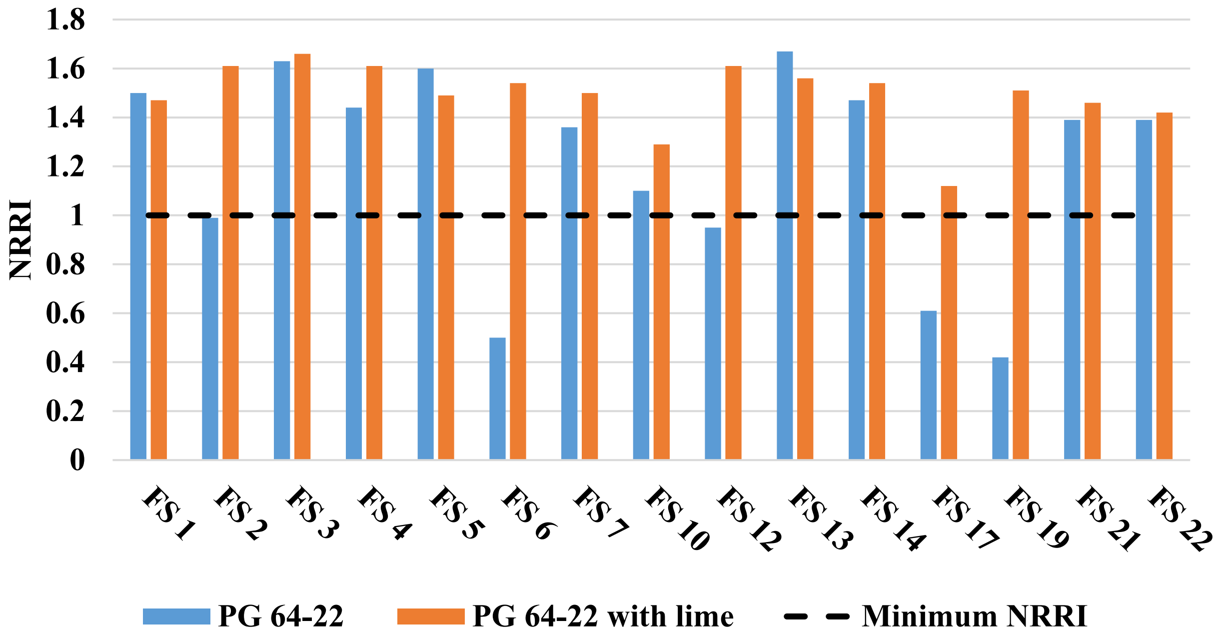


Figure 5-7. Example of improvement in the mix when lime was added (WL= With Lime).

As seen in Figure 5-8, the addition of lime increases the NRRI and SIP values. For some of the mixtures, it also helps to adjust the SIP value so that the mixture meets the 9,000 minimum threshold, such as FS 6 and FS 19. However, for FS 17 and FS 22, adding lime was insufficient to remediate the lack of stripping resistance in the mixtures. As previously mentioned, some mixture variations satisfy the NRRI criteria but do not meet the SIP minimum threshold. The analysis indicates that the SIP parameter is more rigorous and has the potential to better differentiate between well- and poor-performing mixtures containing field sands. It can help determine whether the addition of an antistripping agent merely masks the issues or actually enhances the performance.

The effects of binder grade and hydrated lime on NRRI and SIP were statistically checked with a t-test at 95% confidence level, as shown in Table 5-8. This statistical test gives the p-value, which can be used to determine if the difference between sample means is statistically significant. A p-value of less than 0.05 indicates that there is a significant difference between the two sets, and if the value is higher than 0.05, it signifies that there is not enough evidence to suggest a significant statistical difference exists between means. The p-values are less than 0.05 when comparing NRRI and SIP results. This indicates that PG 70-22 has a significant impact on the performance of the mixtures containing field sands and, indeed, improved the rutting and stripping performance. The addition of hydrated lime also had a statistically significant effect. With p-values of less than 0.05, the comparison of sample means suggests that adding lime has a positive impact on the stripping performance of the mixtures.



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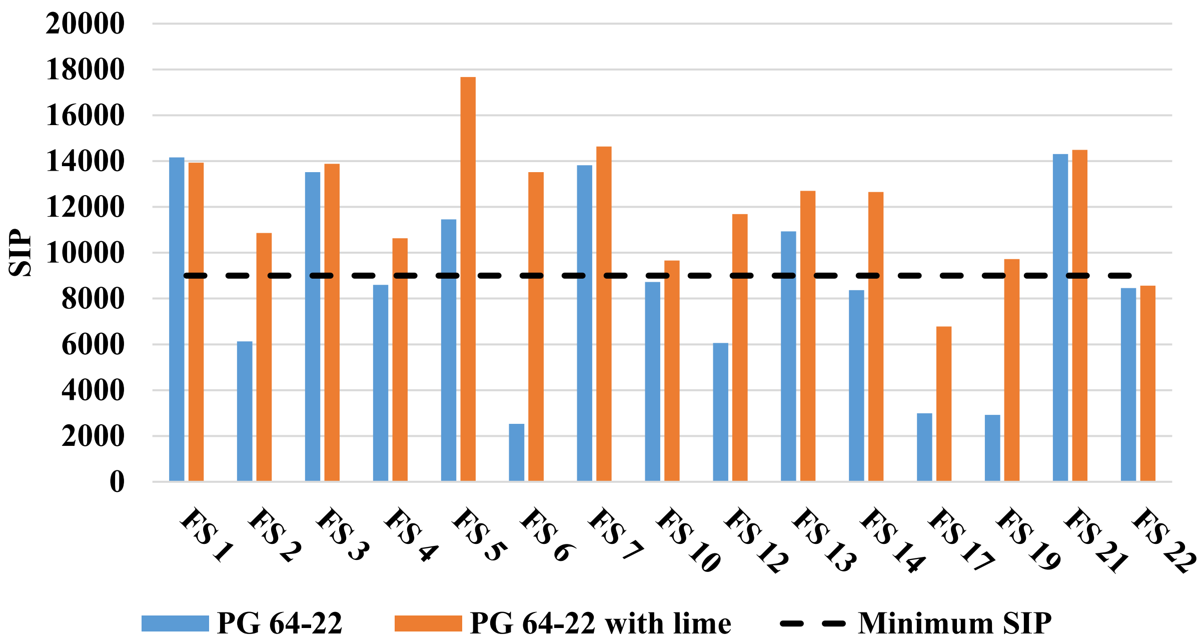


b)

Figure 5-8. Comparison of mixtures with and without hydrated lime: a) NRRI and b) SIP.

Table 5-8. Statistical Analysis at 95% Confidence Level.

Parameter	Mean Value		P(T<=t) one-tail
	PG 64-22	PG 70-22	
NRRI	1.26	1.54	0.004
SIP	8900	17113	< 0.001
Parameter	Mean Value		P(T<=t) one-tail
	Without Lime	With Lime	
NRRI	1.20	1.49	0.006
SIP	8866	12092	0.001

Figure 5-9 shows that when 10% of the field sand content and PG 70-22 were used, and the MBV was below 6.0 mg/g (i.e., MBV ≤ 6.0 mg/g), all the mixtures also passed the SIP threshold of 9,000 (i.e., SIP ≥ 9000). These results seem to obey the thresholds already developed in the previous chapters of this report. The results of the mixtures evaluated with PG 64-22 are shown in Figure 5-10 and suggest that more rigorous MBV criteria should be in place when using lower PG grades. As seen in the previous chapter, the results for PG 70-22 binder grade mixtures show that the performance in terms of SIP versus the MBV can be divided into regions, excellent, marginal, and failure.

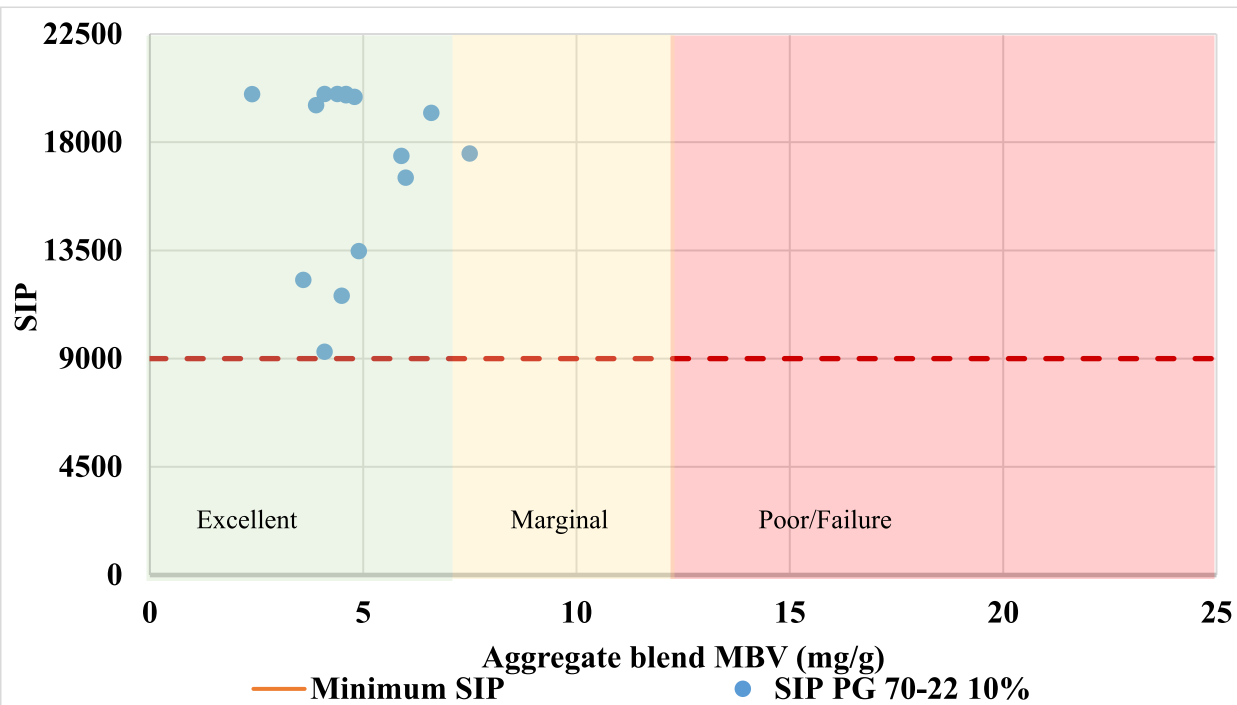


Figure 5-9. Effect of field sand percentage on SIP and MBV using PG 70-22 binder grade (Green = Excellent, Yellow = Marginal, Red = Poor/Failure).

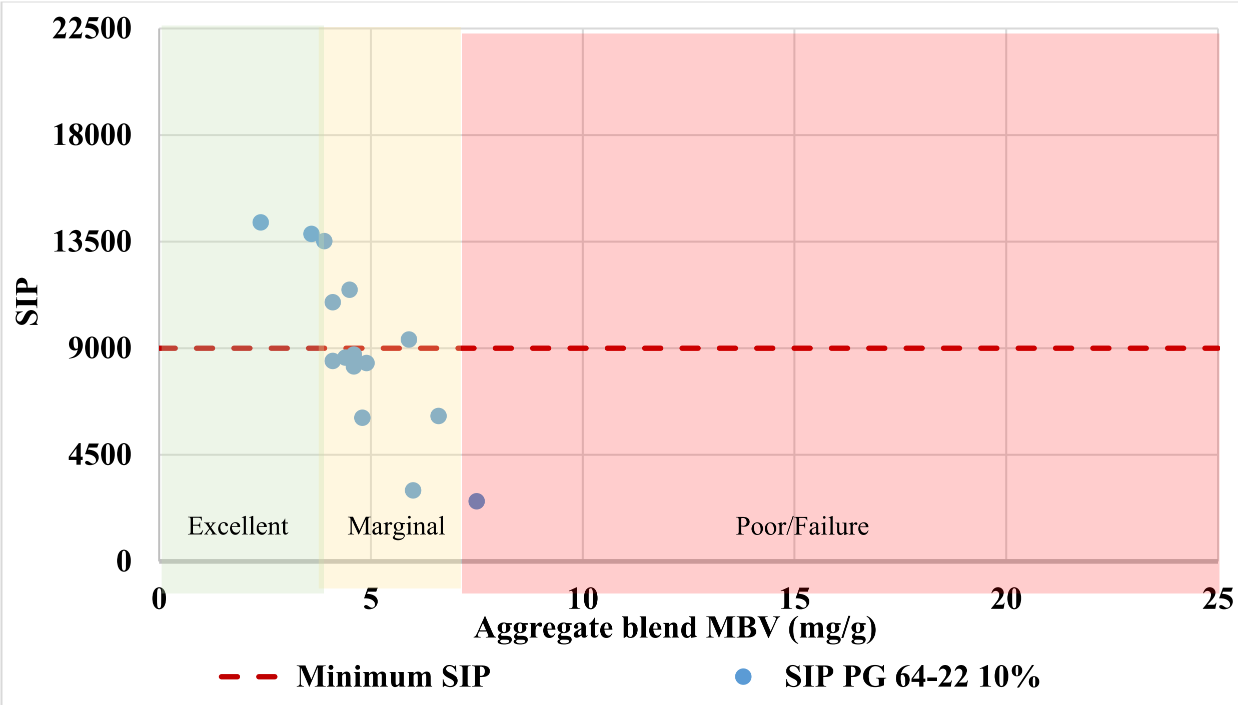


Figure 5-10. Effect of field sand percentage on SIP and MBV using PG 64-22 binder grade (Green = Excellent, Yellow = Marginal, Red = Poor/Failure).

Figures 5-9 and 5.10 depict the SIP results as a function of MBV for PG 70-22 and PG 64-22 respectively. The results in Figure 5-10 suggest that for PG 64-22, a conservative MBV threshold of 4.0 mg/g exists. A marginal region exists between MBVs of 4.0 and 6 .0mg/g. Above 6.0 mg/g, a decrease in performance is observed, with SIP levels being reached. The analysis for PG 70-22 is not as simple as for PG 64-22. Most PG 70-22 specimens tested passed NRRI (i.e., NRRI ≥ 1.00) and SIP criteria (i.e., SIP ≥ 9000). However, from the data, it can be inferred that if a PG 70-22 binder is used, an MBV of up to 8 mg/g can be allowed. The marginal region for PG 70-22 is most likely between 8 and 12 mg/g MBVs, and undesired critical rutting performance will occur after an MBV of 12 mg/g. These guidelines are summarized in Table 5.9. The relation of performance (SIP) with SE value was also evaluated and it was observed that SE did not correlate well with the performance of mixtures with field sands.

Table 5-9. Expected rutting performance based on MBV.

Methylene Blue Value (mg/g)* for PG 64-22	Methylene Blue Value (mg/g)* for PG 70-22	Expected Performance
≤ 4	≤ 8	Excellent
> 4 and ≤ 6	> 8 and ≤ 12	Marginal
> 6	> 12	Failure

* MBV of aggregate blend.

Summary and Recommendations

Based on the results reported in this chapter, the research team recommended developing guidelines based on the chemical activity of field sands. The findings of this chapter demonstrated that, indeed, MBV, PG binder type/grade, and lime affect the rutting performance of Superpave mixtures containing field sands. Guidelines for determining the allowable amount of field sand in the mixture were established based on the MBV criteria. However, the results must be further explored and validated in the next chapter. This approach will lead to more reliable ways of incorporating field sands in the mix-design. The following recommendation can also be drawn from this chapter:

- SIP can be a more robust parameter for predicting moisture susceptibility and behavior of asphalt mixtures containing field sand.
- The results suggest that binder grade significantly impacts the NRRI and SIP values, underscoring the importance of binder selection in influencing the performance of mixtures. Hence, the rutting performance of Superpave mixtures containing field sand can be safeguarded using PG 70-22. In addition to mitigating moisture damage (stripping), lime can also help to improve the rutting performance of asphalt mixtures with field sand, but this improvement should be verified with more studies.
- With the findings from this chapter, the subsequent Chapter 6 focused on validating the guidelines established herein, which are as follows: for PG 64-22 mixtures with field sands, a conservative MBV threshold of 4 mg/g exists. A marginal region exists between MBVs of 4 and 6 mg/g. Above 6 mg/g, a decrease in performance is observed, with SIP thresholds being reached. For PG 70-22 binder mixtures with field sands, an MBV of up to 8 mg/g can be allowed. The marginal region for PG 70-22 is most likely between 8 and 12 mg/g MBVs, and undesired rutting performance will occur above MBVs of 12 mg/g.

Chapter 6

Verification of Guidelines for the Use of Field Sands

Introduction

TxDOT Project 0-7111 aimed to produce and validate guidelines that designers can use to determine an optimal percentage of field sand in Superpave mixture designs. In this chapter, guidelines developed in the previous chapter, using 15 field sand sources at a 10% field sand content, were verified. Building upon the previous findings, this chapter evaluates the performance of asphalt mixtures using nine different field sand sources. Additionally, it also investigated the effects of varying the field sand content to 5% and 20% by weight of the total aggregates. This approach aims to broaden the spectrum of the MBV versus performance graph, providing a more comprehensive understanding of how different levels of field sand influence mixture performance. By testing a wider range of field sand percentages, the aim was to capture a broader set of data points that reflect actual field paving conditions more accurately, assessing the robustness and adaptability of the developed guidelines. The results from these experiments help to refine the relationship between MBV and performance, ensuring that the guidelines are effective across various scenarios and can be confidently applied to enhance the durability and quality of asphalt mixtures.

Experimental Methods

Materials

Similar aggregate materials to the previous chapter were used, including limestone dolomite #67, igneous 3/8", dolomite screenings, field sand, and RAP. Nine field sand sources were used for the verification of the proposed guidelines/performance plots. Among the nine new field sands, five were evaluated at 10% field sand content, two at 5%, and the other two at 20% field sand content in the mix. Also, among 15 field sand sources already evaluated at 10% field sand content 5 field sand sources were evaluated at 5% and 5 at 20 % field sand content to increase and widen the MBV spectrum. The different field sands and the percentages used in the mix are shown in Table 6-1. A volumetric mixture design was performed for each field sand source and percentage to determine the optimum binder content (OBC) for specimen fabrication.

Table 6-1. Field sand sources and percentage proportions.

Field Sand	Methylene Blue Value (mg/g)	5% Field Sand Methylene Blue Value (mg/g)	10% Field Sand Methylene Blue Value (mg/g)	20% Field Sand Methylene Blue Value (mg/g)
1	28.5	n/a	n/a	X
4	6.7	n/a	n/a	X
5	11.2	X	n/a	n/a
6	37.8	n/a	n/a	X
7	16.2	X	n/a	n/a
8	36.2	n/a	X	n/a
9	6.3	n/a	X	n/a
10	12.0	X	n/a	n/a
11	7.4	n/a	X	n/a
14	14.2	X	n/a	n/a
15	45.8	n/a	X	n/a
16	42.5	X	n/a	n/a
17	30.2	n/a	n/a	X
18	17.6	n/a	X	n/a
19	12.2	n/a	n/a	X
20	15.0	X	n/a	n/a
22	5.3	X	n/a	n/a
23	3.7	n/a	n/a	X
24	12.2	n/a	n/a	X

Note: X indicates that the mixture was assessed; n/a indicates that the mixture was not assessed in this chapter.

Test Methods

Table 6-2 shows the tests that were conducted, like those performed in the previous chapter. The SE test was done on the aggregate blend passing through the No. 4 sieve, whereas the MBV test was conducted on the material passing the No. 200 sieve of the aggregate blend. The SE and MBV for each aggregate blend used for the verification are summarized in Table 6-3. At a field sand content of 10%, the maximum and minimum MBVs for the aggregate blends were 8.5 mg/g and 3.0 mg/g, respectively. At 5% field sand content, the maximum and minimum values were 8.5 mg/g and 3.0 mg/g, respectively. Finally, for a 20% field sand content, the values ranged between 10.0 mg/g and 3.0 mg/g. These values illustrate the effects of field sand percentage on the MBV of the aggregate blend.

Table 6-2. Test Methods.

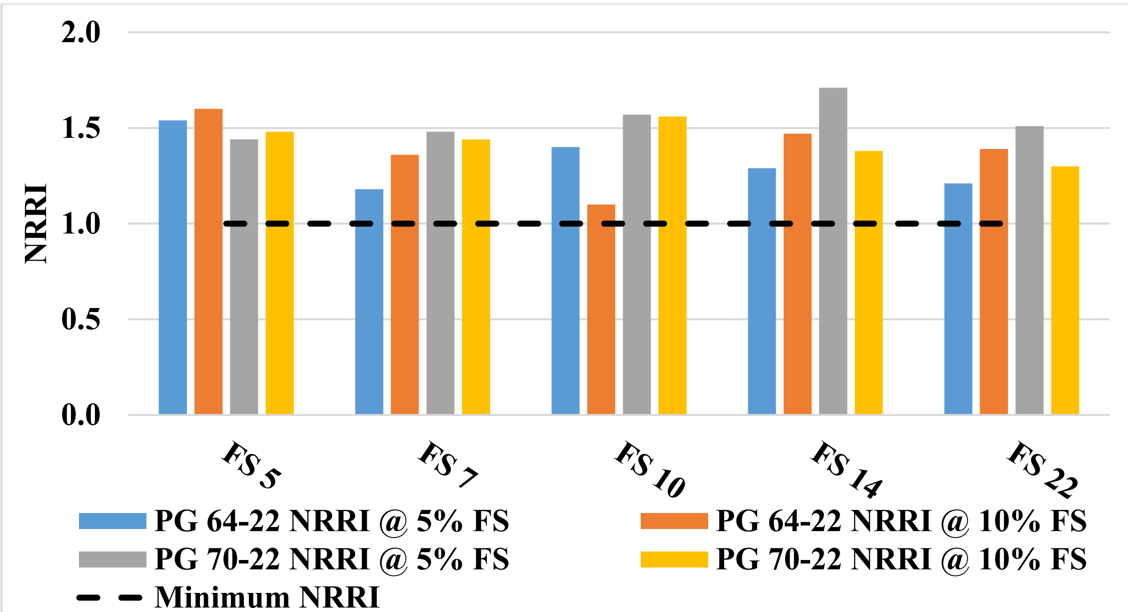
No.	Test Method	Standard	Purpose
1	Sand Equivalent (SE)	Tex-203-F	Quantify the deleterious materials present in the aggregate blend
2	Methylene Blue Value (MBV)	Tex-252-F	Quantify the chemical activity of fines (materials passing the No. 200 sieve)
3	Hamburg Wheel-Tracking Test (HWTT)	Tex-242-F	Evaluate the rutting/stripping susceptibility of compacted asphalt mixture specimens

Table 6-3. Aggregate Blend Properties.

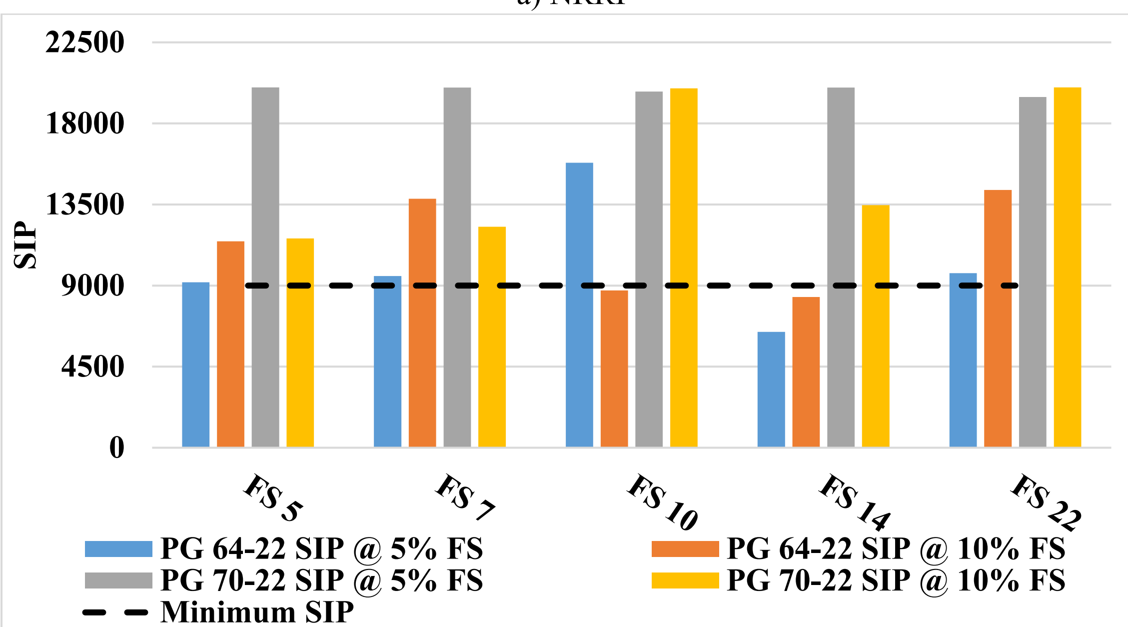
Field Sand Source	Field Sand Percentage (%)	Optimum Binder Content (%)	Sand Equivalent	MBV (mg/g)
FS 5	5	5.5	82	3.5
FS 7	5	5.4	80	3.8
FS 10	5	5.4	81	4.3
FS 14	5	5.3	79	5.5
FS 16	5	5.4	78	5.0
FS 20	5	5.3	81	3.5
FS 22	5	5.2	77	4.5
FS 8	10	5.7	66	8.5
FS 9	10	5.7	75	3.0
FS 11	10	5.5	79	4.0
FS 15	10	5.9	81	6.0
FS 18	10	5.2	89	4.0
FS 1	20	5.8	50	9
FS 4	20	5.2	60	5.5
FS 6	20	5.6	60	10
FS 17	20	5.3	69	9.5
FS 20	20	5.3	68	5.5
FS 23	20	4.8	77	3.0
FS 24	20	5.5	82	4.0

Results and Discussion

The NRRI and SIP comparisons for 5% and 10% field sand content are shown in Figure 6-1 for PG 64-22 and PG 70-22 mixtures. The 10% data has already been reported in the previous chapter and used here for comparison with 5% and 20% field sand contents. As can be observed in the figure, no meaningful variation was observed between mixtures containing 5% and 10% field sand contents. For various cases, asphalt mixtures containing 10% field sand performed the same or even better than mixtures having 5% field sand. In addition, it is worth noting that all the mixtures met the minimum NRRI criteria (NRRI≥1.00). However, it is important to highlight that several mixtures exhibited a SIP value below 9000. These findings indicate that whilst a 10% field sand content may be an appropriate upper limit when NRRI is the primary deciding criterion, it may not hold true when SIP is used as the basis for decision-making.



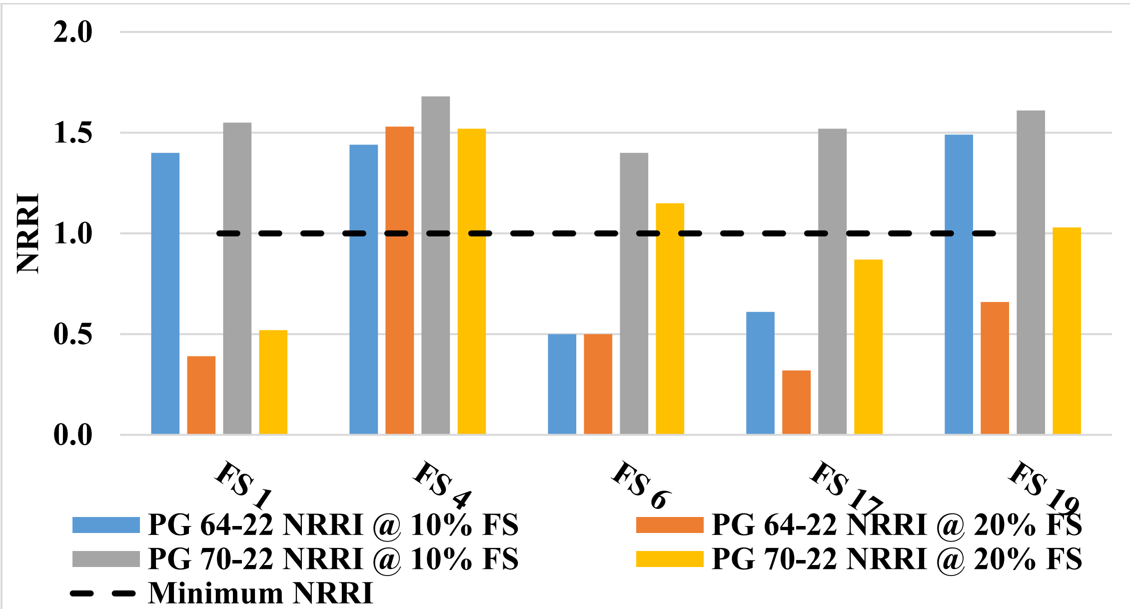
a) NRRI



b) SIP

Figure 6-1. Comparison of 5% and 10% field sand percentages: a) NRRI and b) SIP.

Figure 6-2 shows the NRRI and SIP values of 10% and 20% field sand content for PG 64-22 and PG 70-22 mixtures. The mixtures with a 20% field sand content performed worse than those with a 10% field sand content. This outcome confirms the detrimental impact of excessive field sand in asphalt mixtures on rutting and stripping performance. Moreover, although some mixtures containing 20% field sand satisfy the NRRI or SIP criteria, just one mixture met both the minimums and that was the mixture prepared with FS 4 using PG 70-22. The inference from these observations is that the use of >10% field sands in asphalt mixtures could lead to a reduced stripping resistance. Therefore, the utilization of field sand exceeding 10% should be restricted and subjected to thorough examination before approval.



a)

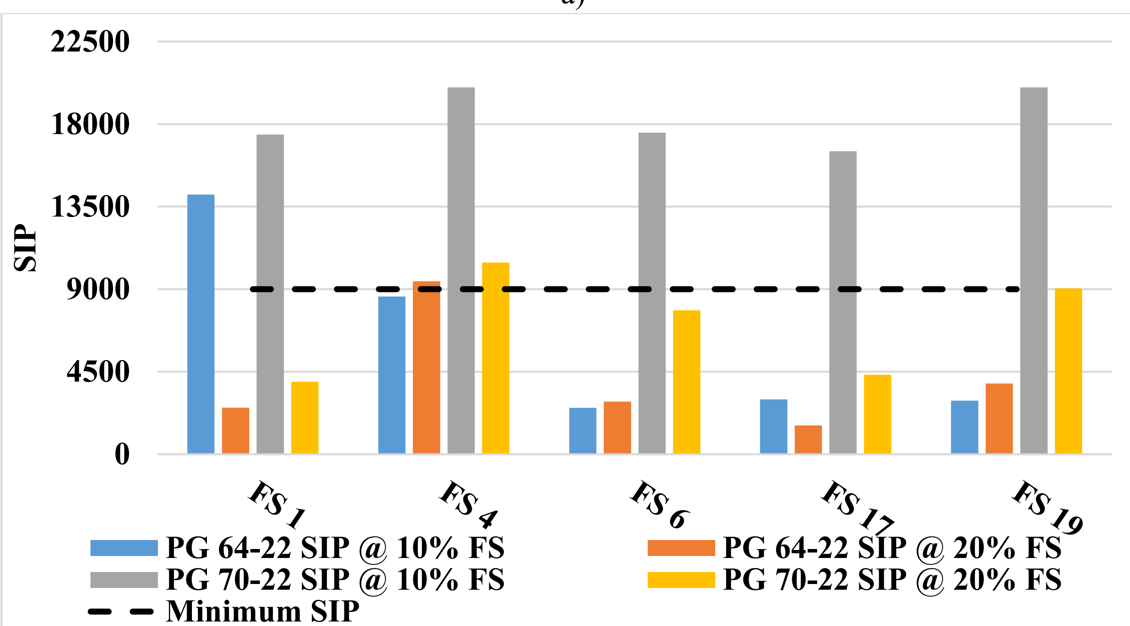


Figure 6-2. Comparison of 10% and 20% field sand percentages: a) NRRI and b) SIP.

The effect of field sand percentage was statistically checked with a t-test at 95% confidence level, as shown in Table 6-4. The t-tests revealed that the difference between 5% and 10% was not significant, but it was significant between 10% and 20% field sand contents as the p-values of PG 70-22 are less than 0.05.

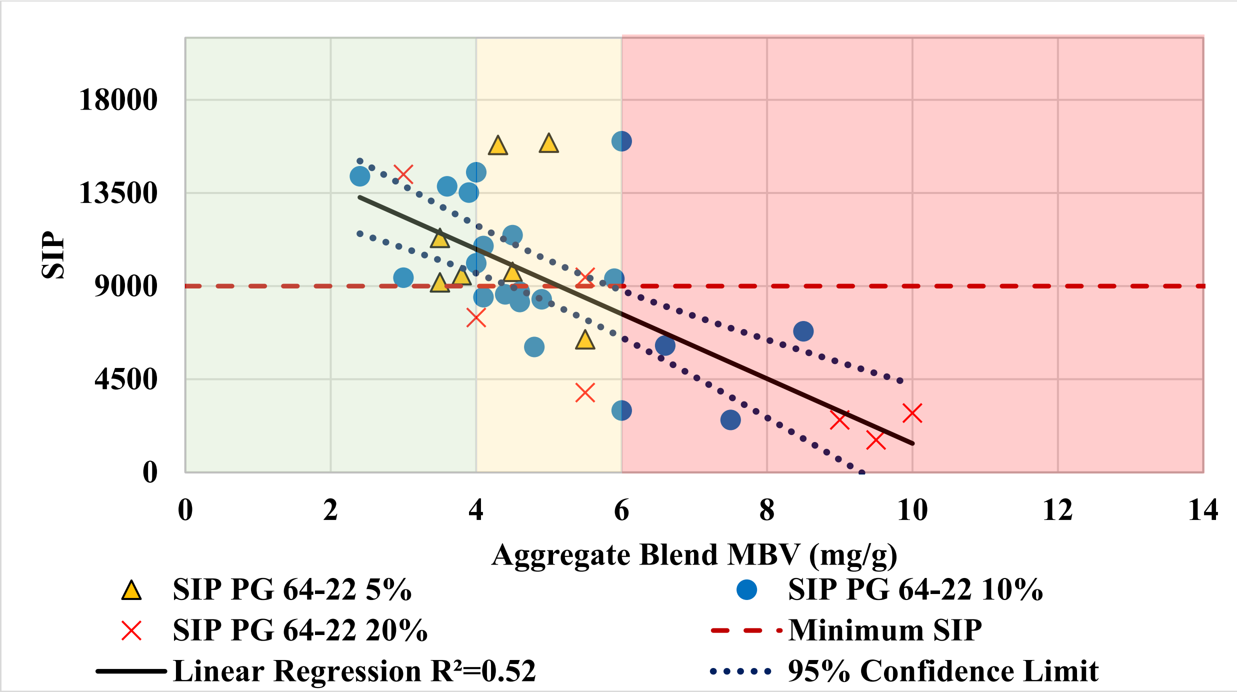
Table 6-4. Statistical Analysis at 95% Confidence Level.

Parameter	**Mean Value**		**P(T<=t) one-tail**
	5% Field Sand	**10% Field Sand**	
NRRI	1.54	1.43	0.090
SIP	10130	11336	0.300
Parameter	**Mean Value**		**P(T<=t) one-tail**
	10% Field Sand	**20% Field Sand**	
NRRI	1.55	1.02	0.010
SIP	18296	7126	<0.001

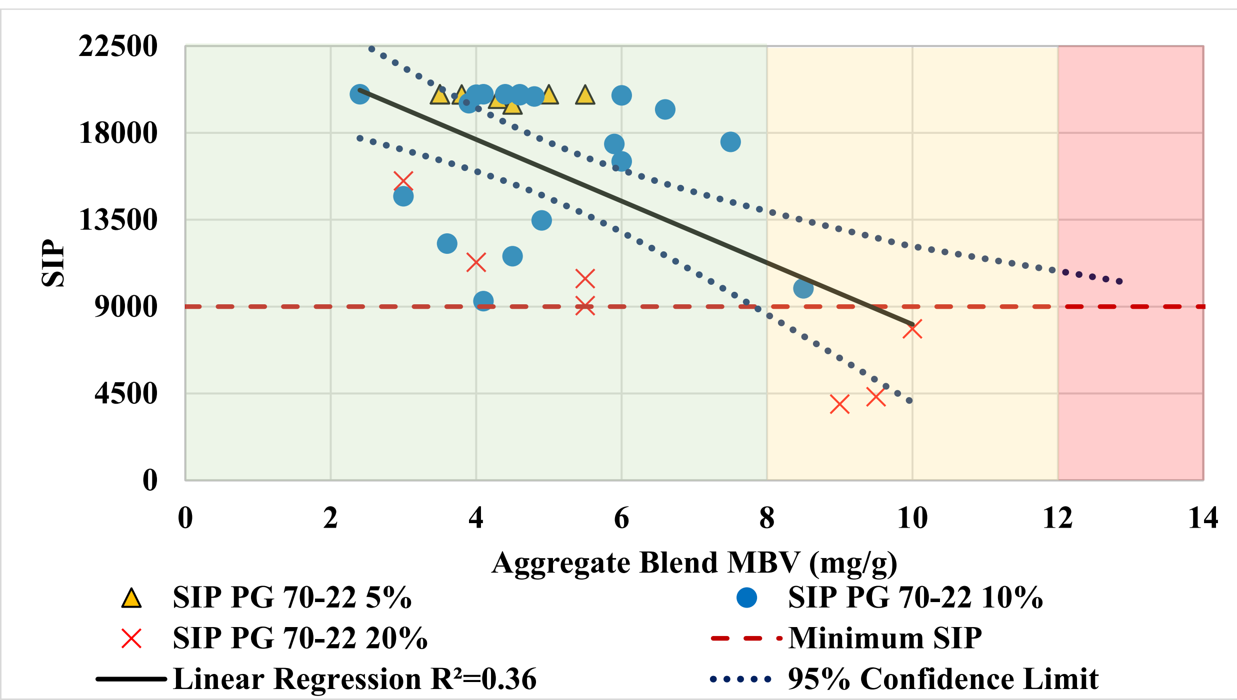
Figure 6-3 depicts the SIP results as a function of MBV for PG 64-22 and PG 70-22. The verification confirms that when the MBV is less than 8 mg/g, the mix performance is excellent. The findings suggest that for PG 64-22, a conservative MBV threshold of 4 mg/g exists for the aggregate blend. A marginal region exists between MBVs of 4 and 6 mg/g. Above 6.0 mg/g, a decrease in performance is observed, with failing SIP levels being reached. Most PG 70-22 specimens tested passed SIP criteria above 9,000. However, from the data, it can be inferred that if a PG 70-22 binder is used, an aggregate blend MBV of up to 8 mg/g can be allowed. The marginal region for PG 70-22 is between 8 and 12 mg/g MBVs, with critical rutting and stripping performance issues likely to occur above an MBV of 12 mg/g. It should be noted that not much of the data was gathered within the failure region (MBV >12) for PG 70-22 mixtures; the 12 mg/g MBV threshold is inferred from the linear regression analysis. These guidelines are summarized in Table 6-5 and should be further investigated to optimize the design of asphalt mixtures containing field sands**.**

Table 6-5. Expected Rutting Performance based on MBV of Aggregate Blend.

Methylene Blue Value of Aggregate Blend (mg/g) for PG 64-22	Methylene Blue Value of Aggregate Blend (mg/g) for PG 70-22	Expected Performance
≤ 4	≤ 8	Excellent
> 4 and ≤ 6	> 8 and ≤ 12	Marginal
> 6	> 12	Poor



a) PG 64-22



b) PG 70-22

Figure 6-3. Performance regions based on MBV: a) PG 64-22 and b) PG 70-22.

SUMMARY AND CONCLUSIONS

This chapter investigated the impact of different field sand 5% and 20% contents on the rutting and stripping resistance of asphalt mixtures. The study also confirmed the recommended criteria in terms of MBV for incorporating field sands in asphalt mixtures. Based on the results, the following recommendation were drawn:

- The field sand content has a significant effect on rutting and striping performance, especially at 20% by the total weight of the aggregate blend. Still, this should be further investigated as some mixtures can be used between 10% and 20% field sand content.
- It was statistically corroborated at 95% confidence level that for PG 64-22 mixtures with field sands, a conservative MBV threshold of 4 mg/g exists. A marginal region exists between MBVs of 4 and 6 mg/g. Above 6 mg/g, a decline in performance was observed, with the SIP lower limit threshold being reached. For PG 70-22 binder mixtures with field sands, an MBV of up to 8 mg/g can be allowed. The marginal region for PG 70-22 is most likely between 8 and 12 mg/g MBVs, and like PG 64-22, critical rutting performance issues will most likely occur above an MBV of 12 mg/g.

Chapter 7

Recommended Guidelines and Conclusions

Recommended Guidelines for The HMA Mixtures Consisting of Field Sands

Figure 7-1 illustrates the approach to determining the suitability of field sand in asphalt mixtures based on the current TxDOT specifications. Initially, 2500 grams of field sand are taken, and critical properties such as SE and MBV are determined. If the SE is greater than or equal to 45, the sand is deemed suitable for use, provided it meets other specifications outlined in Item 341, Section 2.1.3. The mix-design is then performed, followed by running the HWTT to assess rutting performance and moisture sensitivity. If the SE is less than 45 and the MBV is less than 10 mg/g, then the field sand may be used, provided the mixture performs well during HWTT testing. But, if the SE is less than 45 and the MBV is greater than 10 mg/g, the field sand is not used for the mixture design. A maximum of 10% field sand or any other uncrushed material can be used in any mixture design.

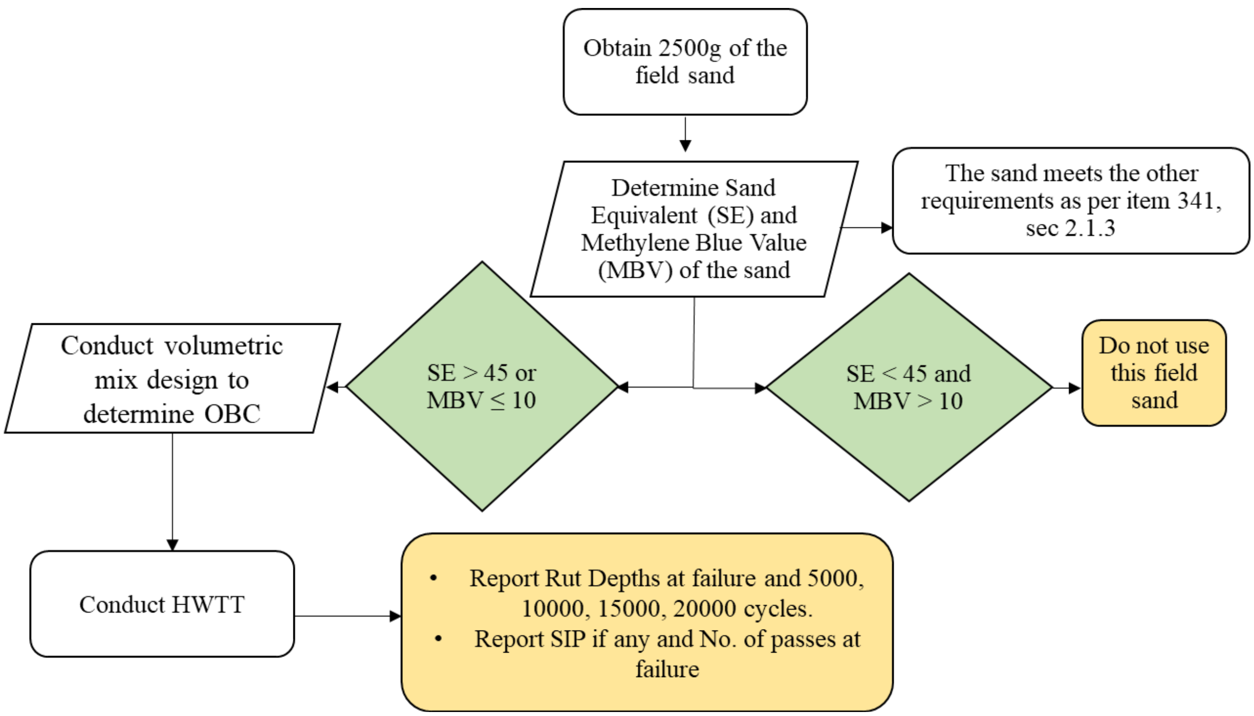


Figure 7-1. Summary of current TxDOT Guidelines.

By comparison, the proposed decision tree shown in Figure 7-2 introduces additional parameters. This includes selecting a suitable gradation with field sand, conducting the SE and MBV tests on the blended aggregate, and choosing an appropriate binder grade. Based on the test results, further actions are determined, such as reducing the field sand percentage or adjusting the binder grade. The HWTT is then used to obtain the SIP, which guides the final adjustments to the mix design. The proposed guidelines account for the binder grade, use of lime, and stripping potential.

Additionally, using the MBV criteria will allow designers to optimize the field sand content, allowing for the incorporation of field sands without compromising performance.

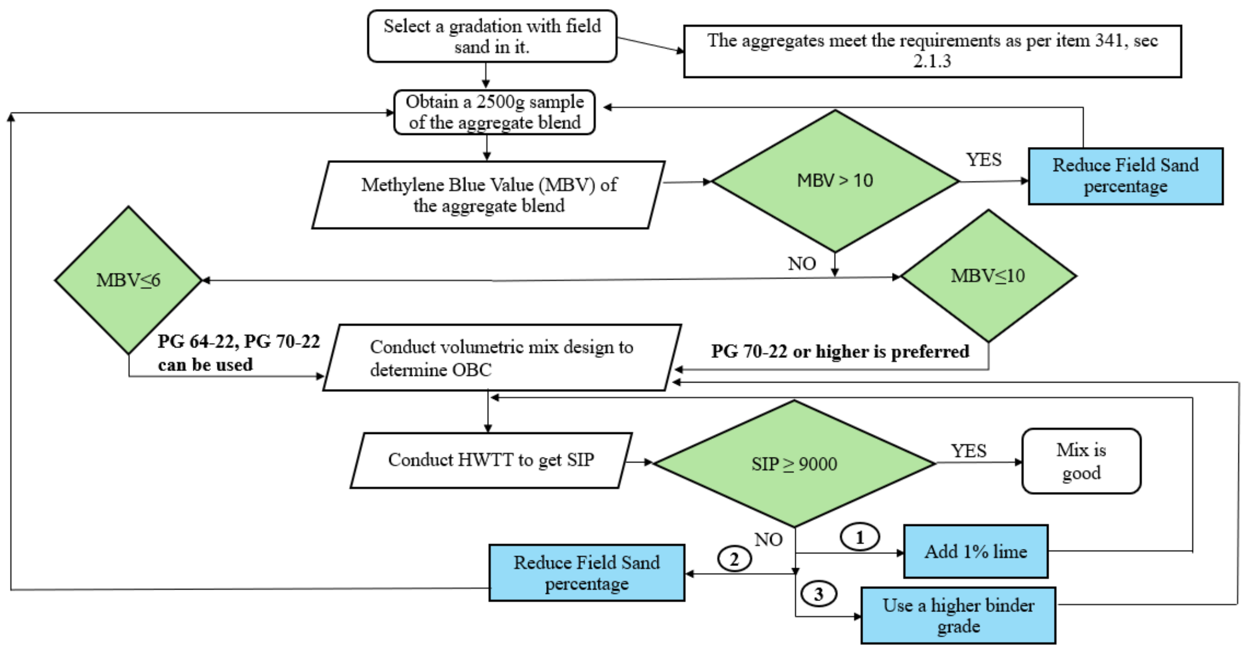


Figure 7-2. Proposed Guidelines.

Conclusions

The focus of this study was to develop guidelines for the use of field sands in the asphalt mixtures. Based on the extensive analysis conducted in this study, the following conclusions were drawn:

- MB test is a quick test to understand the expansive characteristics of clay.
- A mix can show potential stripping even when showing good resistance to rutting or permanent deformation because of the chemistry between clay minerals with the binder, especially when in contact with moisture.
- SIP can be a more robust parameter for predicting moisture susceptibility and behavior of asphalt mixtures containing field sand.
- The rutting performance of Superpave mixtures containing field sand can be safeguarded through using a higher PG binder grade, for instance, substituting a PG 64-22 with a PG 70-22. In addition to mitigating moisture damage (stripping), lime can also help to improve the rutting performance of asphalt mixtures with field sand, but this improvement is less effective and needs further verification.
- A conservative MBV threshold of 4 mg/g exists for PG 64-22 mixtures. A marginal region exists between MBVs of 4 and 6 mg/g. Above 6 mg/g, a decrease in performance is observed, with the SIP lower limit threshold being reached. For PG 70-22 binder mixtures with field sands, an MBV of up to 8 mg/g can be allowed. The marginal region for PG 70-

22 is most likely between 8 and 12 mg/g MBVs, with critical rutting performance will occur after an MBV of 12 mg/g.

- The field sand content has a significant effect on rutting and striping performance, especially at 20% by the total weight of the aggregate blend. Still, this should be further investigated as some field sands can be used at a dosage level between 10% and 20% of the aggregate blend.

Implementation Recommendations

Based on the findings and conclusions drawn from this study, the following recommendations are made for in-service field trials and practical implementation of the proposed guidelines:

- The proposed guidelines and criteria should be tried/implemented on actual mix-design and construction projects. Thereafter, field performance should be monitored for at least three years to validate, and if needed, refine the proposed limiting thresholds. This will also aid in furthering the workability assessment of the resultant asphalt mixtures.
- Intermittent laboratory testing of more diverse materials, sand sources, and mix-design volumetrics including cracking evaluation corresponding to new construction and/or rehab projects to further supplement, validate, and consolidate the proposed guidelines.
- Conduct parallel mix-designs, one based on the old spec (control) and one based on the proposed guidelines, - and thereafter, construct field test sections for comparative in-service performance monitoring.
- Conduct training workshops and webinars to present/disseminate the proposed guidelines to TxDOT technical personnel, engineers, and relevant stakeholders.

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Appendix A

Value of Research

Project Title

Guidelines for Utilization of Field Sands in Superpave Mixtures of Texas**.**

Project Statement

One of the main variables that influence the performance of asphalt pavements is rutting, which can lead, in several instances, to early pavement failure. There are many factors that can influence rutting such as aggregate property, binder content, climate, traffic, quality of construction, etc. Among the aggregate factors, field sands can impact rutting and stripping. A field sand having clay contamination or an MBV close to 80 mg/g can deteriorate immediately, as evidenced in a past paving project. During the construction of the asphalt road project, the authority noticed premature pavement distresses within the first few weeks. TxDOT personnel were noticing both rutting and stripping. It was an ongoing project at that time, so immediate steps to prevent further material failure were taken. After performing rutting tests in the laboratory for different pavement portions, few sections passed the test. From the testing it was noticed two main issues regarding the rutting failures: 1) the overall rut depth of the material, and 2) the mixtures stripping susceptibility. Due to the magnitude of these rutting failures, it immediately became a safety concern for the traveling public. After that, the authority investigated the cause behind this extreme failure. Through this process, it was suspected that unwashed gravel sand from a river source may be causing the stripping susceptibility of the mixture. To validate this, they performed a methylene blue test to understand the level of clay reactivity of the material. The tests confirmed that the material had an MBV of 80 mg/g. This high methylene blue indicates the presence of harmful clay in mix. The main goal of this study was to recommend guidelines that prevent the use of field sands containing harmful clays, and thereby ensure asphalt mixtures containing field sands are less susceptible to rutting and stripping and last longer. Table A.1 presents a summary of the functional areas and benefits from Project 0-7111.

Table A-1. Functional Areas for Project 0-7111

Benefit Area	Qualitative	Economic	Both	TxDOT	State	Both
Level of Knowledge	X			X		
Customer Satisfaction	X			X		
Environmental Sustainability	X			X		
Increased Service Life		X			X	
Reduced Construction, Operations, and Maintenance Cost		X			X	
Materials and Pavements		X			X	
Infrastructure Condition	X					

Qualitative Benefits

Level of Knowledge

This project conducted an extensive and comprehensive literature review including several national and international past studies. Chapter 2 provides a succinct summary of the effect of field sands on asphalt mixture and pavement performance, methods to characterize field sands, and recommendations for designing asphalt mixtures containing field sands. This synthesis can contribute to optimizing the incorporation of field sands into asphalt mixtures.

Customer Satisfaction and Infrastructure Condition

Sudden rutting or stripping failure due to the addition of field sands to asphalt mixtures can cause poor ride quality and, as a result, even damage to vehicles. The fine-tuning incorporation of field sands into paving materials can improve infrastructure conditions over time and help satisfy the demands of road customers or taxpayers.

Environmental Sustainability

The proper use of field sands can reduce the demand for scarce high-quality crushed fine aggregates (i.e., screenings). Using more field sands can provide a better allocation for manufactured aggregate products, leading to more sustainable and environmentally friendly production of asphalt mixtures.

Economic Benefits

Increased Service Life, Reduced Costs, and Materials and Pavements

This project started on September 1, 2021, and was completed on August 31, 2024, with a duration of 3 years. The total budgeted cost for this project was $500,002. For the purposes of this analysis and considering full implementation of the recommendations, the following were considered:

- A past forensic investigation provided insight into how the presence of clay can adversely impact asphalt mixture performance and lead to economic losses. The project outlined in the project statement section resulted in a financial loss of $30 million USD. This amount is a conservative estimate and is equivalent to approximately 15 days of production and construction.
- TxDOT places approximately 12 million metric tons of asphalt mix a year. At an approximate average cost of $90 per ton, this amounts to nearly $1,080 million USD per year in material cost.
- Several TxDOT districts used field sands for Superpave and dense graded mixture. The amount of field sand incorporated ranges between 5% to 10%.
- It is estimated that implementing the findings of this study can safeguard at least $15 million USD per year (about 1.5% of the budget used for asphalt mix), either in just one project or several projects across the state using field sand. Ultimately mitigating rutting and stripping of asphalt mixtures containing field sands over a 10-year period.

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

Project #	0-7111		
Project Name:	Determine Impact of Field Sands on Workability and Engineering Properties of Superpave Mixtures in Texas		
Agency:	UTEP/TTI	Project Budget	$ 500,002
Project Duration (Yrs)	3.0	Exp. Value (per Yr)	$ 15,000,000
Expected Value Duration (Yrs)	10	Discount Rate	0%
Economic Value			
Total Savings:	$ 134,499,998	Net Present Value (NPV):	$ 149,499,998
Payback Period (Yrs):	0.033333	Cost Benefit Ratio (CBR, $1 : $___):	$ 299

Figure A-1. Parameters Used for Economic Analysis for VoR

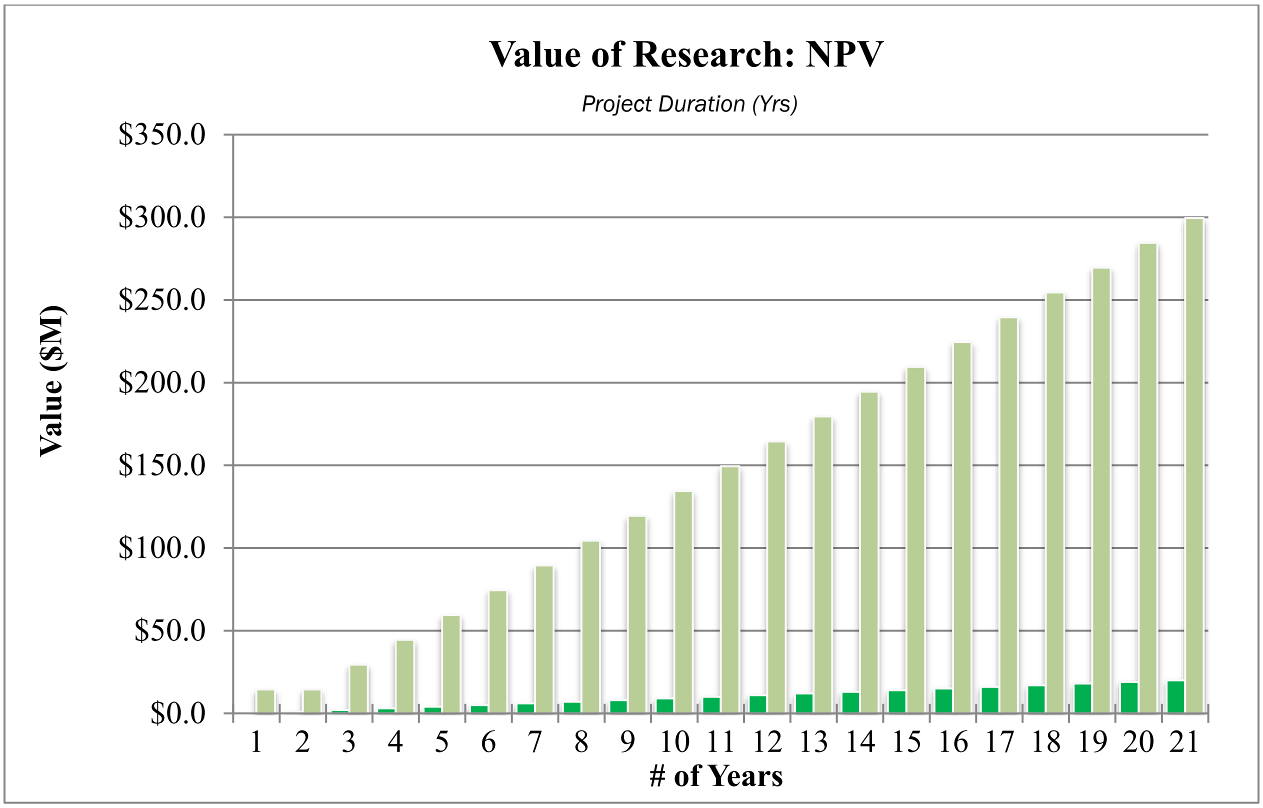

Figure A-2. Net Present Value Over a 20 Year Period