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Develop a Balanced Asphalt Mixture Design Procedure

Final Report

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14. Abstract

Balanced Mix Design (BMD) is a performance-based approach that supplements the traditional Superpave volumetric mix design process with laboratory performance testing to achieve an appropriate balance between rutting resistance and cracking resistance. This study was conducted to develop a practical BMD framework and preliminary performance criteria for asphalt mixtures used by the New Mexico Department of Transportation (NMDOT). A comprehensive review of BMD implementation practices adopted by state Departments of Transportation (DOTs) was performed to identify commonly used performance tests and benchmark threshold values. Based on this review, a performance-modified volumetric design procedure was developed for New Mexico. Rutting and cracking performance were evaluated using the Hamburg Wheel Tracking Test (HWTT), Illinois Flexibility Index Test (I-FIT), IDEAL Rutting Test (IDEAL-RT), and IDEAL Cracking Test (IDEAL-CT). Three performance-index-based methods were proposed to determine the balanced asphalt content (AC%): (1) the HWTT–I-FIT relative performance index, (2) the IDEAL-RT–IDEAL-CT relative performance index, and (3) a combined performance index integrating all four tests. A total of nineteen asphalt mixtures representative of New Mexico materials and production practices were evaluated, including eleven laboratory-compacted short-term aged (LCSTA) mixtures and eight field-produced reheated (FMRH) mixtures. Based on the selected rutting and cracking criteria, each mixture was classified as balanced or unbalanced, and the resulting dataset was used to establish preliminary New Mexico-specific performance thresholds for BMD implementation. The recommended performance criteria include a minimum of 10,000, 15,000, and 20,000 Hamburg Wheel Tracking Test passes to reach 6 mm rut depth for mixtures containing PG 64, PG 70, and PG 76 binders, respectively; a minimum Flexibility Index (FI) of 8 (preferred ≥ 10); a minimum CT_{Index} of 75 (preferred ≥ 100); and a minimum RT_{Index} of 80 (preferred ≥ 100). The proposed BMD framework and associated performance criteria provide a practical basis for implementing Balanced Mix Design for NMDOT.

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PREFACE

This report presents the development of a Balanced Mix Design (BMD) framework for New Mexico. It summarizes the results of a comprehensive laboratory study conducted to evaluate the rutting and cracking performance of asphalt mixtures representing a range of binder grades, aggregate sources, and reclaimed asphalt pavement (RAP) contents commonly used in the state.
Based on the experimental results, preliminary rutting and cracking performance thresholds are proposed to support implementation of BMD by the New Mexico Department of Transportation (NMDOT).

NOTICE

DISCLAIMER

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CHAPTER 1
INTRODUCTION

1.1 RESEARCH NEED

The New Mexico Department of Transportation (NMDOT) currently employs the Superpave volumetric mix design procedure for the design of asphalt mixtures used in highway construction. Although the Superpave system has been effective in controlling key volumetric properties, including air voids (Va), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA), these parameters do not directly evaluate mixture performance with respect to the two primary pavement distresses: rutting and cracking. Consequently, asphalt mixtures that satisfy Superpave volumetric requirements may still exhibit inadequate field performance.

While the Superpave methodology has generally provided satisfactory resistance to rutting, many mixtures designed using this approach have demonstrated insufficient resistance to cracking. This limitation is also important in New Mexico, where cracking-related distresses, including longitudinal cracking, thermal cracking, and reflective cracking, are among the most common forms of pavement deterioration. The issue is further exacerbated when reclaimed asphalt pavement (RAP) is incorporated into the mixture Because volumetric parameters do not directly quantify the relationship between rutting resistance and cracking resistance, mixtures meeting Superpave requirements may still exhibit unbalanced performance.

Balanced Mix Design (BMD) has emerged as a performance-based approach that supplements traditional volumetric design with laboratory performance testing to achieve an appropriate balance between rutting and cracking resistance. Development of a BMD procedure requires two principal components: (1) a practical mix design framework that accounts for regional traffic and environmental conditions, and (2) performance criteria for rutting and cracking against which locally produced asphalt mixtures can be evaluated.

A previous NMDOT research project, *Development of a Balanced Asphalt Mixture Design Procedure for New Mexico* (Project No. NM18MSC-02), identified three alternative approaches for implementing BMD. However, that study was limited to a single aggregate source and a small number of trial mixtures, which precluded the development of robust volumetric guidelines and performance thresholds representative of materials used throughout the state. To address this limitation, the present study was undertaken to develop a Balanced Mix Design framework for New Mexico using a broader set of laboratory-designed and plant-produced asphalt mixtures representing a range of aggregate sources, binder grades, and RAP contents commonly used by NMDOT. Laboratory performance testing was conducted to directly evaluate rutting and cracking resistance, and the resulting data were used to establish preliminary performance thresholds for statewide implementation. The proposed framework is intended to support NMDOT in adopting Balanced Mix Design for routine asphalt mixture design and quality assurance practice.

1.2 OBJECTIVES

The primary objective of this study was to develop a Balanced Mix Design (BMD) framework for the New Mexico Department of Transportation (NMDOT). To support this objective, a comprehensive performance database was developed using laboratory-designed and plant-produced asphalt mixtures representing a range of aggregate sources, binder grades, reclaimed asphalt pavement (RAP) contents, and traffic levels commonly used throughout New Mexico.

The objectives of this study were to:

- Develop a practical BMD procedure for determining balanced asphalt binder content using a performance-modified volumetric design approach.
- Develop a representative database of asphalt mixture volumetric and performance properties covering the range of materials and design conditions used in New Mexico.
- Evaluate the rutting and cracking performance of these mixtures using selected laboratory performance tests and establish preliminary performance thresholds for New Mexico.
- Provide recommendations for implementation of Balanced Mix Design in NMDOT's routine asphalt mixture design and quality assurance practices.

1.3 REPORT ORGANIZATIONS

This report is organized into six sections. They can be summarized below:

Section 1: Introduction - This section outlines the background, research necessity, objectives, and the overall structure of the report.

Section 2: Review of Current Practices - This section provides a summary of the evolution of asphalt mix design, the concept of Balanced Mix Design (BMD), performance tests, and the current practices employed by various state departments of transportation.

Section 3: Development of Balanced Mix Design Procedure - This section details the materials, mix designs, experimental program, and methodology utilized to establish the BMD for the New Mexico Department of Transportation (NMDOT).

Section 4: Determination of Performance-Based Design - This section presents the properties and the rutting and cracking performance of the evaluated mixtures in New Mexico.

Section 5: Development of New Mexico Performance Thresholds - This section describes the formulation of preliminary rutting and cracking criteria and the recommended framework for implementation.

Section 6: Conclusions and Recommendations - This section summarizes the principal findings and offers recommendations for implementation.

Appendices - This section includes supporting data and detailed test results.

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CHAPTER 2
REVIEW OF CURRENT PRACTICES

2.1 EVOLUTION OF ASPHALT MIX DESIGN PRACTICES

Asphalt mix design practices have evolved considerably over time in response to changes in traffic loading, materials, construction methods, and performance expectations. The primary objective of mix design has always been to produce an asphalt mixture that can be manufactured, placed, and compacted effectively while providing durable service under environmental and traffic demands. Over time, the industry has moved from largely empirical design methods to more refined volumetric and performance-based approaches. This evolution reflects the need for mixtures that not only meet laboratory criteria but also perform reliably in the field over the full pavement life cycle (1,2).

2.1.1 Early Empirical Mix Design Methods

The earliest asphalt mix design methods were based primarily on empirical observations and laboratory testing. The two most widely adopted methods were the Marshall and Hveem procedures. The Marshall method evaluated mixtures using stability and flow, whereas the Hveem method emphasized stability and resistance to deformation. Both approaches relied on experience, mixture volumetrics, and laboratory measurements obtained under controlled conditions (1). These methods provided practical and effective tools for asphalt mixture proportioning and established the foundation for modern mix design practice. However, because they were largely empirical, their ability to account for variations in traffic loading, climate, aggregate properties, binder characteristics, and long-term pavement performance was limited (2). Nevertheless, they introduced the fundamental concept that asphalt mixture properties must be properly balanced to achieve satisfactory field performance and laid the basis for subsequent advances in asphalt mix design methodology.

2.1.2 Superpave Mix Design

A major advancement in asphalt mix design occurred with the development of the Superpave system under the Strategic Highway Research Program (SHRP). Superpave represented a significant transition from empirical design methods to a more rational and standardized framework. The system introduced performance-graded (PG) binders, enhanced aggregate requirements, and the Superpave gyratory compactor (SGC) as the basis for mixture design (2,5) Its primary objective was to better relate material selection and mixture design to anticipated traffic loading and climatic conditions, thereby improving pavement performance and extending service life.

In addition to these technical advancements, Superpave established a nationally consistent approach to asphalt mix design by standardizing test procedures, terminology, and acceptance criteria. The use of the gyratory compactor provided a more realistic simulation of field compaction and enabled evaluation of mixture densification characteristics, which are closely related to pavement durability. As a result, Superpave was widely adopted by state highway agencies throughout the United States and remains the predominant asphalt mix design methodology in current practice (3,5).

Despite its widespread adoption, several limitations of the Superpave system became evident with broader implementation. Although the methodology improved material selection and volumetric design, some mixtures that satisfied Superpave criteria still exhibited premature rutting, cracking, and other forms of distress in service. Certain design elements, including gyration levels, VMA requirements, and the restricted zone concept, were not always well suited to local materials, traffic levels, and construction practices. In addition, some coarse-graded mixtures were found to be difficult to compact in the field, increasing the risk of inadequate density, moisture damage, and early deterioration (3).

Another important limitation is that several performance tests originally envisioned as part of the SHRP framework were not incorporated into routine practice. Consequently, Superpave implementation has relied primarily on volumetric criteria rather than direct measurement of mixture performance. To address these shortcomings, many state agencies have modified Superpave criteria to reflect local experience and performance requirements (4,5). While these adjustments improved the practicality of the system, they also demonstrated that volumetric criteria alone do not consistently ensure satisfactory field performance. This recognition has led to increasing use of laboratory performance testing and, more recently, Balanced Mix Design (BMD) approaches to supplement the traditional Superpave methodology.

2.1.3 Emergence of Balanced Mix Design

The original Superpave mix design system envisioned three levels of analysis. Level I relied primarily on volumetric properties for low-traffic pavements, Level II combined volumetric design with a limited set of performance tests for moderate traffic, and Level III incorporated advanced performance testing for high-traffic pavements. In practice, however, the performance tests proposed during the Strategic Highway Research Program (SHRP) were not implemented for routine use because they were too complex and time-consuming for widespread application.

During the early implementation of Superpave, the primary focus was on improving rutting resistance through the use of performance-graded binders, angular aggregates, and increased compaction effort. These measures were largely successful, and rutting is no longer considered the predominant distress in many asphalt pavements. Instead, cracking, including fatigue, thermal, and reflective cracking, has become the most common form of pavement deterioration.

To address these issues, many state highway agencies modified Superpave volumetric requirements in an effort to improve mixture durability and cracking resistance. However, the effectiveness of these adjustments varied considerably because key volumetric parameters, such as air voids and effective binder content, do not directly characterize binder quality, recycled material interactions, or the mechanical response of the mixture.

These limitations highlighted the need for a more performance-based approach to asphalt mixture design. Balanced Mix Design (BMD) was developed to address this need by supplementing traditional volumetric design with laboratory performance tests that directly evaluate rutting and cracking resistance, thereby providing a more reliable link between laboratory design and expected field performance (4,6).

2.2 BALANCED MIX DESIGN CONCEPT

Balanced Mix Design (BMD) is a performance-based asphalt mixture design methodology that integrates conventional volumetric design with laboratory performance testing to achieve an appropriate balance between rutting resistance and cracking resistance. In 2015, the Federal Highway Administration (FHWA) Balanced Mix Design Task Force defined BMD as:

“Asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress, taking into consideration mix aging, traffic, climate, and location within the pavement structure” (4).

The concept of balancing asphalt mixture stability and durability is not new and can be traced back to the Marshall and Hveem mix design methods. Both methods recognized that optimum asphalt binder content should provide adequate resistance to permanent deformation while maintaining sufficient durability and cracking resistance. In particular, Hveem emphasized the importance of providing enough effective binder to satisfy aggregate absorption and maintain an adequate binder film thickness, while also ensuring sufficient shear strength and cohesion (12).

The modern BMD concept was advanced by researchers at the Texas A&M Transportation Institute (TTI), who used the Hamburg Wheel Tracking Test (HWTT) to evaluate rutting resistance and the Overlay Test (OT) to assess cracking resistance (13). In this approach, asphalt binder content and binder grade are selected based on direct measurement of mixture performance rather than volumetric properties alone. Subsequent field evaluations demonstrated that performance criteria should be calibrated to local traffic and climatic conditions (14).

Under the BMD framework, a preliminary optimum binder content is typically established using a conventional volumetric design procedure. Additional specimens are then prepared at binder contents above and below the preliminary value and tested using selected rutting and cracking performance tests. The binder content that satisfies both performance criteria is selected as the balanced asphalt content. This approach provides a more direct relationship between laboratory design and expected field performance than traditional volumetric methods.

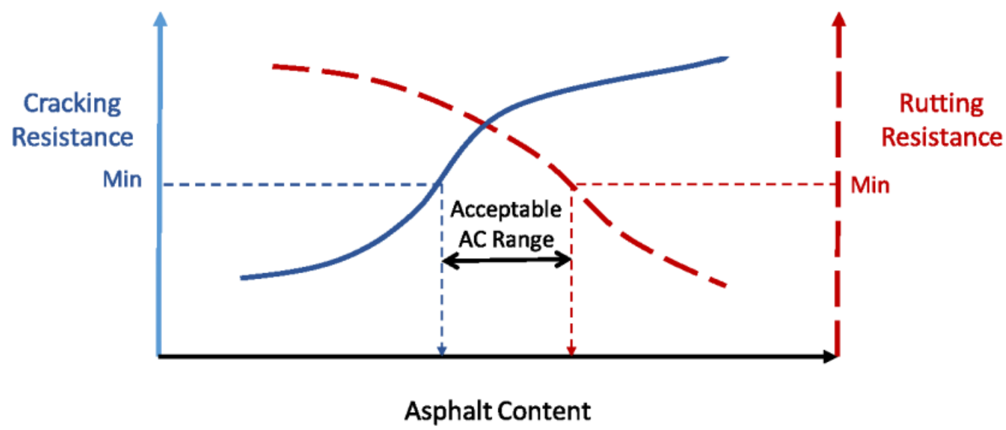


FIGURE 2.73 Balanced Mix Design Concept (15)

2.3 BMD APPROACHES

Balanced Mix Design (BMD) is a flexible methodology that combines traditional volumetric mix design with laboratory performance testing to identify an asphalt mixture that provides an appropriate balance between rutting resistance and cracking resistance. Unlike conventional mix design procedures that rely primarily on volumetric criteria, BMD uses one or more performance tests to directly evaluate the expected field behavior of the mixture under relevant traffic and environmental conditions. This approach allows agencies to optimize asphalt binder content, incorporate recycled materials, and improve pavement performance while maintaining specification flexibility.

The American Association of State Highway and Transportation Officials (AASHTO) formalized the BMD concept in AASHTO MP 46, Balanced Design of Asphalt Mixtures, which defines minimum requirements for implementing performance-based mixture design. The standard permits the use of volumetric properties, performance test results, or a combination of both to establish job-mix formulas for asphalt mixtures. It further recommends that agencies select at least one rutting test and one cracking test and compare the measured results to agency-established criteria. Four different approaches have been proposed and implemented by state highway agencies and researchers for incorporating performance testing into the asphalt mixture design process. These approaches differ primarily in the role of volumetric criteria and the method used to determine the optimum asphalt binder content (4,16)

2.3.1 Approach A: Volumetric Design with Performance Verification

In this approach, the asphalt mixture design begins with a conventional volumetric mix design procedure, such as Superpave, Marshall, or Hveem, to determine an optimum binder content (OBC) that satisfies existing volumetric requirements. The mixture at the selected OBC is then evaluated using one rutting test and one cracking test. If the mixture does not meet the specified performance criteria, the mix design is revised by modifying materials or proportions and the process is repeated until all volumetric and performance requirements are satisfied. After acceptable rutting and cracking performance is achieved, the mixture is tested for moisture susceptibility. If the moisture criterion is not met, anti-strip additives or hydrated lime are incorporated and the mixture is retested until satisfactory performance is obtained. Once all criteria are satisfied, the job mix formula (JMF) is established for production. This approach is the most widely adopted BMD implementation method because it preserves the existing volumetric design framework while incorporating performance verification.

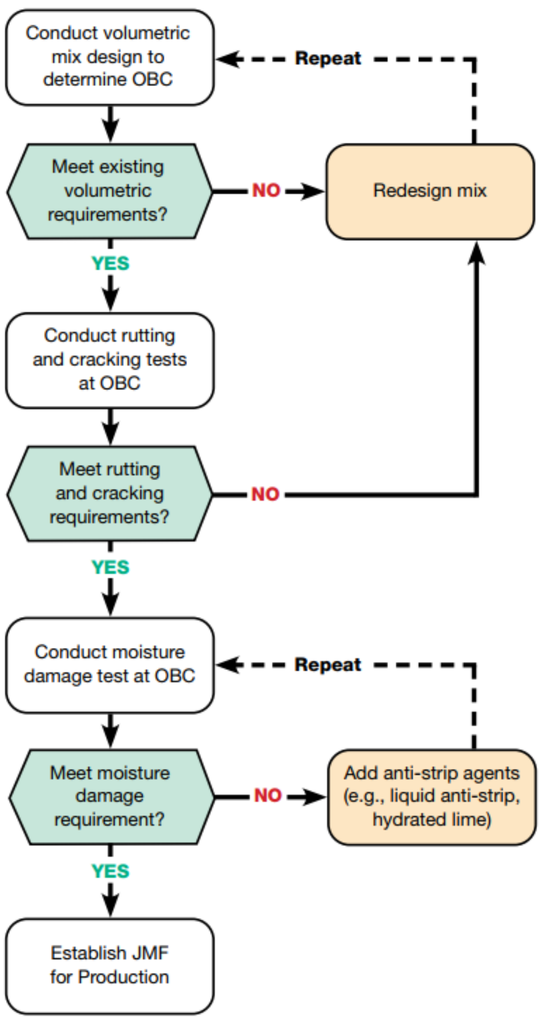


FIGURE 2.74 Volumetric Design with Performance Verification (4)

This approach is the most widely adopted BMD implementation method because it preserves the existing volumetric design framework while incorporating performance verification.

2.3.2 Approach B: Volumetric Design with Performance Verification

This method begins with a conventional volumetric mix design procedure (e.g., Superpave, Marshall, or Hveem) to establish a preliminary optimum binder content (OBC) that satisfies existing volumetric requirements. The mixture is then evaluated at the preliminary OBC and at two or more additional binder contents, typically spaced at intervals of ±0.3 to 0.5 percent, using selected rutting and cracking performance tests. The final OBC is selected as the binder content that satisfies both rutting and cracking criteria, regardless of whether it is the same as the preliminary volumetric OBC. If no binder content meets both performance requirements, the mixture components or proportions are modified and the design process is repeated. After the final OBC is selected, the mixture is evaluated for moisture susceptibility. If the moisture criterion is not met, anti-strip additives or hydrated lime are incorporated and the mixture is retested until satisfactory performance is achieved. This approach allows direct optimization of binder content based on measured performance while maintaining the framework of conventional volumetric design.

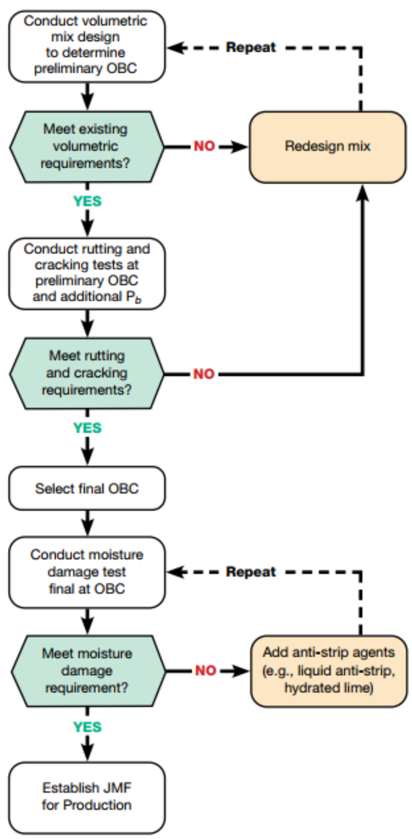


FIGURE 2.75 Volumetric Design with Performance Verification (4)

The final design binder content is selected as the value that provides an acceptable balance between the two competing distress modes. This approach more fully captures the intent of BMD by directly optimizing binder content based on measured mixture performance rather than relying solely on volumetric relationships.

2.3.3 Approach C: Performance Modified Volumetric Design

This approach begins with a conventional volumetric mix design, such as Superpave, Marshall, or Hveem, or with an existing agency-approved mixture. The initial design is evaluated using selected rutting and cracking performance tests. Based on the results, the asphalt binder content and/or other mixture components, including aggregate gradation, binder grade, recycled materials, and additives, are adjusted until both performance criteria are satisfied. Once acceptable rutting and cracking performance is achieved, the mixture is subjected to moisture susceptibility testing. If the moisture requirement is not met, anti-strip additives such as liquid anti-strip agents or hydrated lime are incorporated and the mixture is retested until compliance is achieved. After all performance and moisture criteria are satisfied, key volumetric properties are verified against agency-defined relaxed limits before establishing the final job mix formula (JMF). This approach provides greater flexibility than traditional volumetric design by allowing modifications to both binder content and mixture composition while still retaining volumetric checks as quality-control measures.

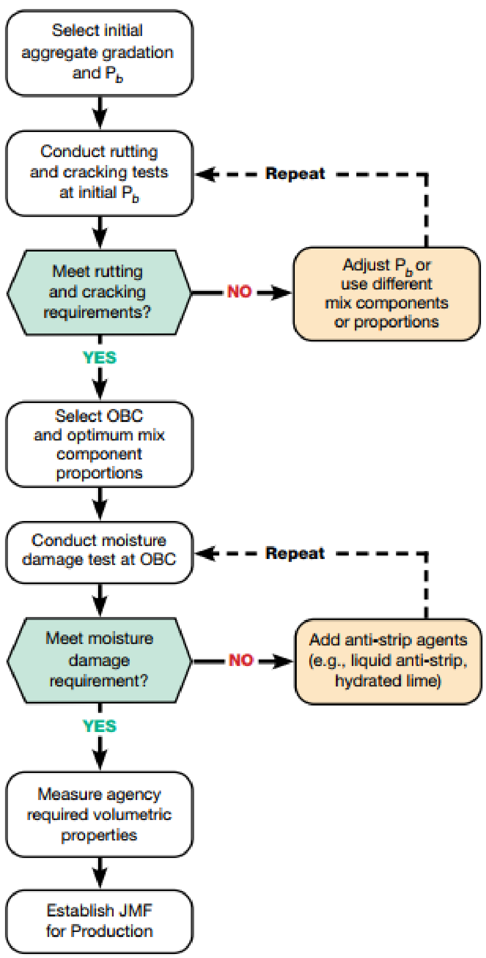


FIGURE 2.76 Performance Modified Volumetric Design (4)

2.3.4 Approach D: Performance Design

This approach begins by selecting an initial aggregate structure, recycled material content, and virgin binder grade, or by using an existing approved mix design. The mixture is then evaluated at three or more asphalt binder contents, typically spaced at intervals of 0.3 to 0.5 percent, using selected rutting and cracking performance tests. The optimum binder content (OBC) is chosen as the binder content that satisfies both performance criteria.

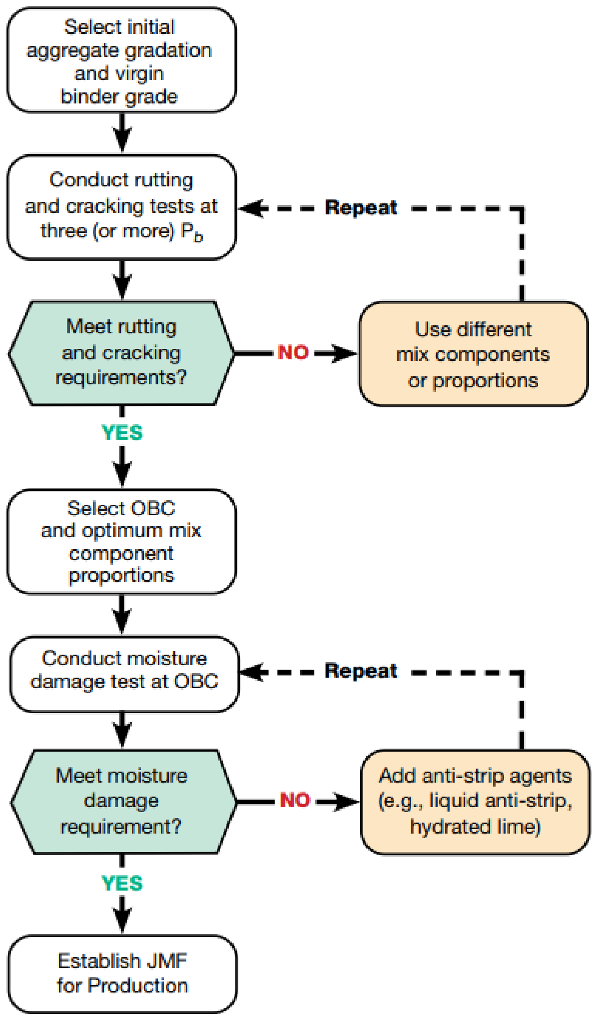


FIGURE 2.77 Performance Design (4)

If no binder content meets the required rutting and cracking thresholds, the mixture components or proportions are adjusted, and the testing process is repeated until acceptable performance is achieved. The selected design is then subjected to moisture susceptibility testing. If the moisture criterion is not met, anti-strip additives such as liquid anti-strip agents or hydrated lime are incorporated, and the mixture is retested until compliance is achieved. Once the mixture satisfies rutting, cracking, and moisture requirements, the job mix formula (JMF) is established for production.

2.4 PERFORMANCE TESTS IN BMD

Performance testing is the foundation of Balanced Mix Design (BMD). Unlike conventional volumetric mix design methods, which rely primarily on aggregate structure and binder content relationships, BMD uses laboratory tests to directly evaluate the resistance of asphalt mixtures to the two principal modes of pavement distress: rutting and cracking. The selected tests provide a mechanistic assessment of mixture behavior and are used to identify an asphalt binder content that achieves an appropriate balance between stability and durability.

AASHTO MP 46, Standard Specification for Balanced Mix Design, identifies several laboratory performance tests that may be used to evaluate asphalt mixtures. For rutting resistance, the commonly recognized tests include the Asphalt Pavement Analyzer (AASHTO T 340), Flow Number Test (AASHTO T 378), Hamburg Wheel Tracking Test (AASHTO T 324), Hveem Stability Test (AASHTO T 246), Superpave Shear Tester (AASHTO T 320), Incremental Repeated Load Permanent Deformation (AASHTO TP 116), and Stress Sweep Rutting (SSR) test using the Asphalt Mixture Performance Tester (AASHTO TP 134) (17).

For cracking resistance, AASHTO MP 46 lists the BBR Mixture Bending Test (AASHTO TP 125), Direct Tension Cyclic Fatigue Test (AASHTO T 400), Flexural Beam Fatigue Test (AASHTO T 321), Illinois Flexibility Index Test (AASHTO T 393), Indirect Tensile Creep and Strength Test (AASHTO T 322), Energy Ratio Test, Overlay Test (Tex-248-F), Semi-Circular Bend (SCB) Test at intermediate temperature (ASTM D8044), SCB Test at low temperature (AASHTO T 394), Cantabro Abrasion Loss Test (AASHTO T 401), and Small Specimen Geometry Cyclic Fatigue Test (AASHTO TP 133) (17).

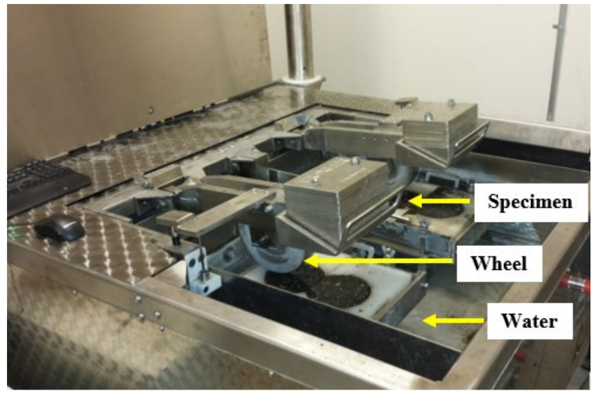
Among these procedures, the Hamburg Wheel Tracking Test (HWTT) and IDEAL Rutting Test (IDEAL-RT) are increasingly used for evaluating rutting resistance, while the Illinois Flexibility Index Test (I-FIT), IDEAL Cracking Test (IDEAL-CT), Overlay Test (OT), and Semi-Circular Bend (SCB) test are among the most commonly adopted methods for assessing cracking resistance in Balanced Mix Design applications.

2.4.1 Hamburg Wheel Tracking Test (HWTT)

The Hamburg Wheel Tracking Test (HWTT), standardized as AASHTO T 324, is widely used in Balanced Mix Design (BMD) to evaluate the rutting and moisture susceptibility of asphalt mixtures. In this test, compacted asphalt specimens are submerged in a temperature-controlled water bath and subjected to repeated loading by a reciprocating steel wheel. The test simulates the combined effects of traffic loading, elevated temperature, and moisture, providing an indication of the mixture's resistance to permanent deformation and stripping.

Laboratory-prepared specimens are typically compacted to a target air void content of 7.0 ± 0.5 percent for gyratory-compacted cylindrical specimens. A standard test consists of four 150-mm-diameter specimens tested as two replicate pairs. Prior to testing, the specimens are conditioned in the water bath at the selected test temperature for 45 minutes. Common test temperatures used by agencies range from 40 to 50°C, although the specific temperature is established by the governing specification. During testing, a steel wheel measuring approximately 203 mm in diameter and 47 mm in width applies to a load of 703 ± 4.5 N (158 ± 1 lb) while traveling across the specimen at a rate of 52 ± 2 passes per minute. Rut depth is automatically recorded at regular intervals, and testing typically continues until 20,000 wheel passes are completed or until a specified maximum rut depth is reached (18).

(a) HWTT Prepared Specimen



(b) HWTT Test Setup

FIGURE 2.78 (a) HWTT Prepared Specimen, (b) HWTT Test Setup

The primary performance parameter is rut depth at a specified number of wheel passes, such as 10,000, 15,000, or 20,000 passes. Additional parameters, including the stripping inflection point (SIP), creep slope, and stripping slope, may be obtained from the rut depth versus number of passes curve. Lower rut depths and delayed stripping inflection indicate better resistance to rutting and moisture damage.

$$\textbf{Stripping inflection point (SIP} = \frac{\textbf{intercept (second portion)} - \textbf{intercept (first portion)}}{\textbf{slope (first portion)} - \textbf{slope (second portion)}} \quad ..(1)$$

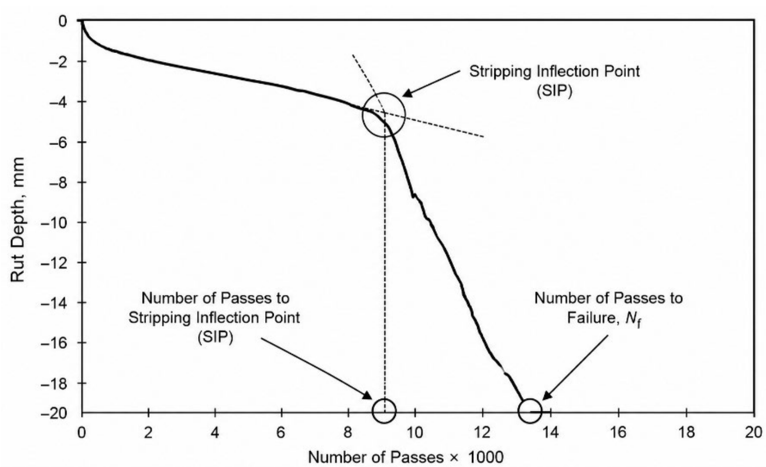


FIGURE 2.79 Hamburg Curve with Test Parameters (18)

Because the test simultaneously evaluates structural stability and moisture susceptibility, the HWTT has become one of the most commonly adopted rutting performance tests in state BMD specifications.

2.4.2 Indirect Tensile Asphalt Rutting Test (IDEAL-RT)

The Indirect Tensile Asphalt Rutting Test (IDEAL-RT) was conducted to assess the rutting resistance of asphalt mixtures at high temperatures using an indirect tensile configuration. Asphalt mixtures were compacted using a Superpave Gyratory Compactor (SGC) to a height of 160 ± 1 mm, and specimens were trimmed to a thickness of 62 ± 2 mm prior to testing. The test was performed under monotonic diametral loading at an elevated temperature, with specimens conditioned at 50 °C for at least two hours before testing. A constant displacement rate of 50 mm/min was applied until failure. A minimum of three specimens was tested for each mixture. Rutting resistance was quantified using the IDEAL-RT rutting index (RTIndex), which reflects the mixture's resistance to permanent deformation based on the measured load–displacement behavior (19). The Ideal-RT test set up is shown in Figure 2.8.

FIGURE 2.80 Ideal-RT test set up

The rutting resistance of the asphalt mixture was quantified using the Rutting Tolerance Index (RTIndex), which is based on the shear strength derived from the measured maximum load. The shear strength τ_f was calculated as:

$$\tau_f = 0.356\frac{P_{max}}{t \cdot w} \text{ .... (2)}$$

Where,

τ_f = shear strength of the asphalt mixture (psi),

$P_{\max}$ = measured maximum load (lb),

t = specimen thickness (in.),

w = width of the upper loading strip (0.75 in.).

$$RT_{Index} = 0.4575\tau_f \text{ ..... (3)}$$

where

RT_{Index} = rutting tolerance index,

τ_f = shear strength obtained from the previous equation (psi).

2.4.3 Semi-Circular Bend (SCB) test

The Semi-Circular Bend (SCB) test is widely used to evaluate the cracking resistance of Hot Mix Asphalt (HMA). This test measures the fracture properties of HMA, such as tensile strength and fracture energy, which are critical for understanding its resistance to cracking. The SCB test provides insights into how well the asphalt mix can withstand stress from traffic loads and environmental factors. By evaluating the mix's ability to resist crack initiation and propagation, the SCB test helps ensure the durability and longevity of pavements made with HMA.

(a) SCB Specimen (b) SCB Test Setup

FIGURE 2.81 SCB test: (a) SCB Specimen, (b) SCB Test Setup

Figure 2.9 depicts the semicircular specimen and the part of the loading frame SCB test, which can be performed in a monotonic or cyclic mode. In this study, a semicircular specimen was loaded monotonically until fracture failure under a constant deformation rate of 0.5 mm/min and at room temperature of 25^{o}C. The load and deformation were continuously recorded. Two semicircular specimens were prepared from a single gyratory compacted cylindrical specimen. Three semicircular specimens were tested at each of the three different notch depths (i.e., 25.0 mm, 32.0 mm, and 38 mm). Critical strain energy (U) and J_c-integral are two important parameters from the test results. The critical strain energy is defined as the work required to produce a crack and is represented by the area under the load versus displacement curve up to peak load. J_c-integral, the critical fracture energy release rate, is used to describe the mixture's resistance to fracture. The higher the value, the mixture is more resistance to fracture or crack propagation. It is determined using the following equation:

$$J_c = -\frac{1}{b}\left(\frac{dU}{da}\right) \ldots\ldots\ldots (4)$$

where, J_c = critical strain energy release rate (kJ/m); b = sample thickness (m); a = notch depth (m); U = strain energy to failure (kJ); and dU/da = change of strain energy with notch depth (kJ/m).

2.4.4 Illinois Flexibility Index Test (I-FIT)

The Illinois Flexibility Index Test (I-FIT) has become popular in determining the fracture resistance of asphalt concrete mixture. The test method is developed based on the work-of-fracture principle, and it uses semicircular bending (SCB) specimen geometry to determine the fracture resistance of the asphalt mixture at an intermediate temperature.

The asphalt concrete mixture is compacted in a Superpave gyratory compactor (SGC) to a height of 160±1 mm. Two cylindrical 50±1 mm thick discs are obtained from the middle of the 160 mm ± 1 mm-tall specimen. Then, each disc is cut into two identical “halves” resulting in four individual I-FIT test specimens. Next, a notch is cut in the base portion of the semicircular specimen—parallel to the loading axis. The notch will be 15±1 mm deep and 1.5 mm wide. A minimum of three individual I-FIT specimens is defined as one I-FIT test. The sample preparation and test setup is shown in Figure 2.10.

(a) IFIT Specimen

(a) IFIT Test Setup

FIGURE 2.82 (a) Prepared I-FIT Specimen, (b) I-FIT Test Setup

Prior to testing, the prepared samples are placed in an environmental chamber for about two hours at 25°C for conditioning. Then the sample is placed inside the test chamber. First, a small contact load of 0.1 ± 0.01 kN is applied to the sample with a loading rate of 0.05 kN/s. After the contact load of 0.1 kN is reached, the test is conducted by applying a displacement rate of 50 mm/min. The load and displacement data are continuously recorded. One of the primary output parameters of I-FIT is the fracture energy (G_f), often expressed as joules per square meter (J/m^2), which represents the energy dissipated by the crack propagation. The (G_f) is calculated by dividing the work of fracture (W_f) by the ligament area (the product of the ligament length and the thickness of the specimen) of the specimen measured prior to testing. Figure 2.11 shows a typical load-displacement plot of the I-FIT test.

$$G_f = \frac{W_f}{Area_{lig}} \quad \ldots\ldots\ldots\ldots (5)$$

Where, G_f = fracture energy (Joules/m^2);

W_f = work of fracture (Joules);
$Area_{lig}$ = ligament area (mm^2).

To assess the cracking resistance of asphalt mixtures more accurately, an additional resistance index parameter, which is known as Flexibility Index (FI), is determined from the test results. The FI is developed based on calculations of the measured fracture energy and load-displacement curve post-peak slope (m) values, as shown in Figure 2.11, and can be calculated using Equation 3.

$$FI = \frac{G_f}{|m|} \times A \quad \ldots\ldots.. (6)$$

Where, FI= Flexibility Index;
|m|= Absolute value of slope (m);
A= a factor used for unit conversion and scaling.

The higher the value of FI, the more ductile the AC mix, which indicates better crack resistance ability of the mixture.

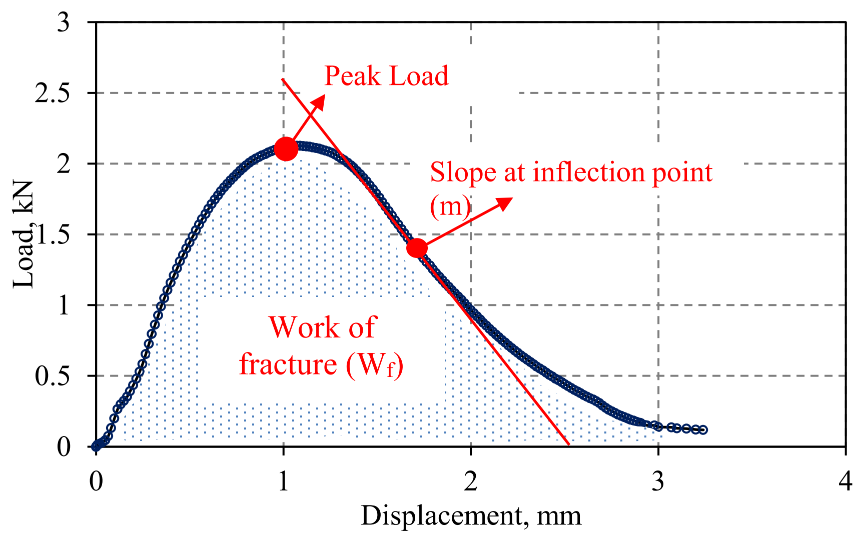


FIGURE 2.83 Load-displacement plot for FIT

2.4.5 IDEAL-CT (Indirect Tensile Asphalt Cracking Test)

The Indirect Tensile Asphalt Cracking Test (IDEAL-CT) was used to evaluate the cracking resistance of asphalt mixtures at intermediate temperatures under monotonic loading. Asphalt mixtures were compacted using a Superpave Gyratory Compactor (SGC) to a target height of 160 ± 1 mm. Cylindrical specimens were then trimmed to a thickness of 62 ± 2 mm for testing. The test was conducted in indirect tension configuration, with specimens loaded diametrically at a constant displacement rate of 50 mm/min until failure. Prior to testing, specimens were conditioned at 25 °C for a minimum of two hours to ensure uniform temperature. A minimum of three replicate specimens was tested for each mixture. Cracking resistance was quantified using the IDEAL-CT cracking index (CTIndex), which is based on the measured load–displacement response and fracture energy (Figure 2.13).

The cracking resistance of asphalt mixtures was quantified using the Indirect Tensile Asphalt Cracking Test (IDEAL-CT). The test is based on the work-of-fracture concept and the post-peak load–displacement response obtained from monotonic indirect tensile loading. The Ideal-CT test set up is shown in Figure 2.12.

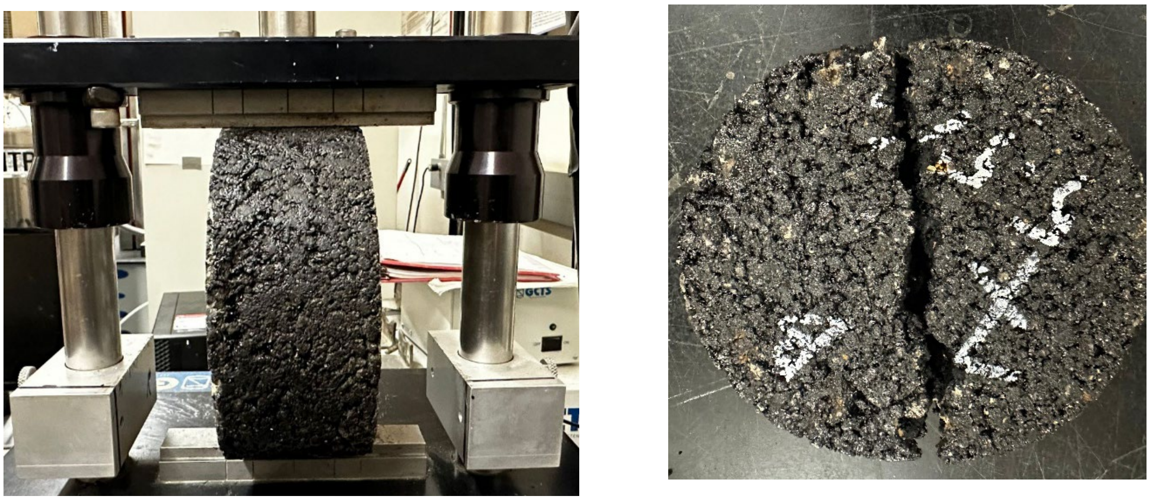


FIGURE 2.84 Ideal-RT test set up

$$W_f = \sum P_i \Delta_i \text{ ………………… (7)}$$

Where,
W_f = work of fracture (J),
P_i = applied load (N) at the i^{th} load step,
Δ_i = corresponding displacement increment (mm).

$$G_f = \frac{W_f}{D \cdot t} \times 10^6 \text{ …………… (8)}$$

where
G_f = fracture energy (J/m^2),
D = specimen diameter (mm),
t = specimen thickness (mm).

$$CT_{Index} = \frac{G_f}{|m_{75}| \cdot \delta_{75}} \cdot \frac{t}{D} \times 10^6 \text{ …(9)}$$

Where,
CT_{Index} = cracking tolerance index,
G_f = fracture energy (J/m^2),
| m_{75} | = absolute value of the post-peak slope at 75% of peak load (N/mm),
δ_{75} = displacement at 75% of peak load after the peak (mm),
t = specimen thickness (mm),
D = specimen diameter (mm).

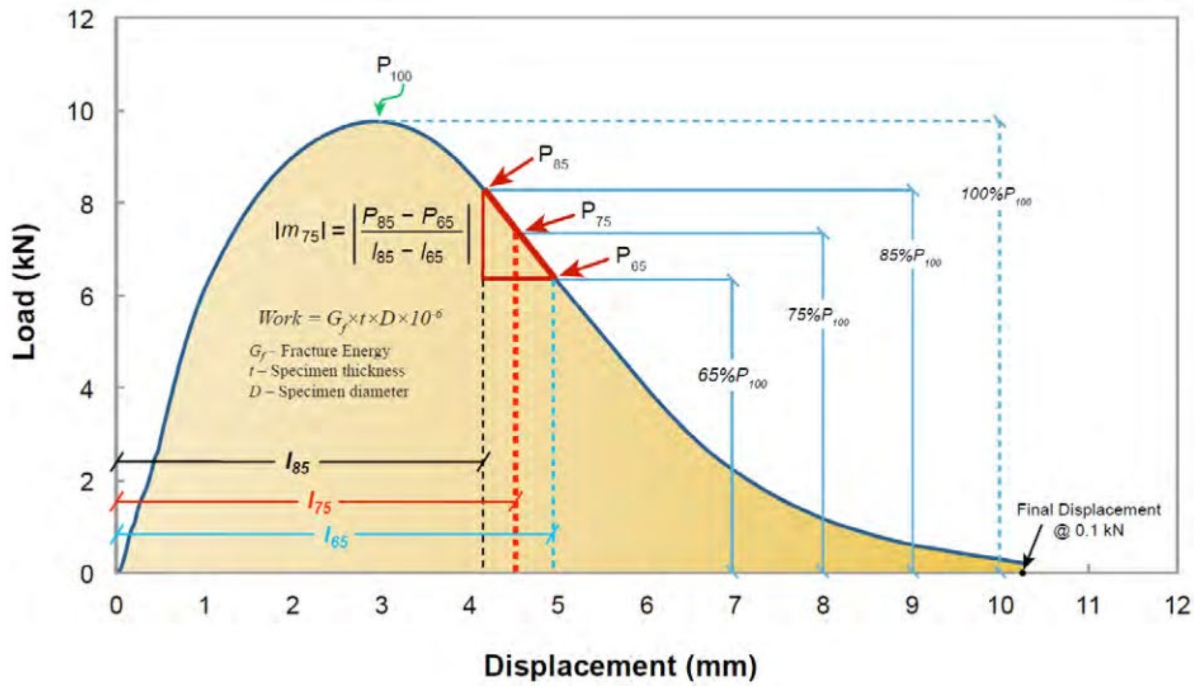


FIGURE 2.85 Load (P) Versus Load-line Displacement Curve of IDEAL-CT Test

2.4.6 OVERLAY TEST (OT)

The Overlay Test (OT) is used to evaluate the reflective cracking potential of the asphalt mix. The overlay tester can effectively differentiate between the reflection cracking resistance of different asphalt mixtures and shows good correlations with field cracking. The test is conducted as per the Tex-248-F procedure. Samples are compacted and trimmed as the dimensions shown in Figure 2. 14.

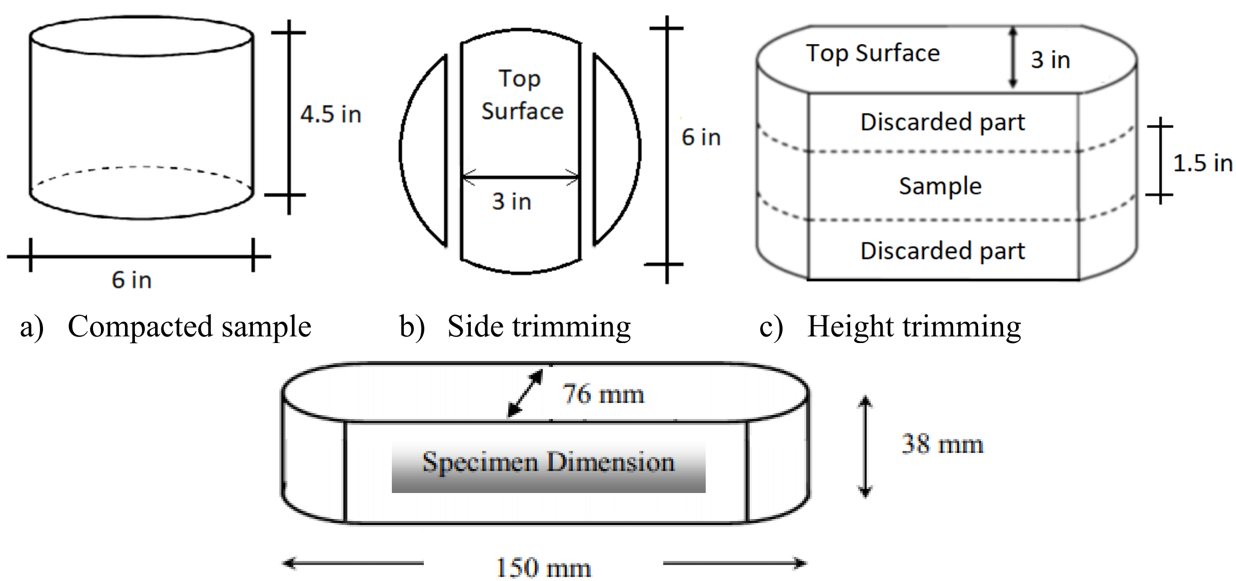
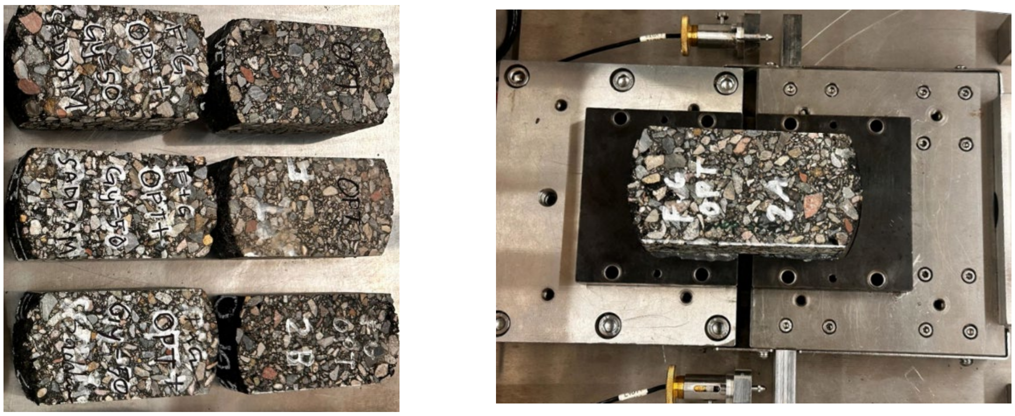


FIGURE 2.86 OT Specimen Preparation

The opening between two metal plates is 2 mm, which is a crack opening. The test temperature is 77±1 ºF. A cyclic displacement with the max magnitude of 0.025 inches is applied at a 10 sec/cycle rate. A total of 0.025 inches is selected based on the displacement experienced by a concrete pavement undergoing 20ºC change in temperature with a 4.5m joint or crack spacing (Zhou et al.). The OT prepared specimen and test setup is shown in Figure 2.15.



(a) Prepared OT Specimen (b) OT Test Setup

FIGURE 2.87 Prepared OT Specimen, (b) OT Test Setup

The Crack Propagation Rate (*CPR*), *β,* is determined by fitting a power equation to the peak load versus the number of cycles curve. To compare the test results, the load reduction curve is normalized by the maximum load of the first cycle.

2.5 CURRENT DOT BMD PRACTICES

Balanced Mix Design (BMD) implementation has advanced significantly across the United States as state transportation agencies seek to improve asphalt mixture durability, address cracking-related distress, and support the use of recycled and innovative materials. Although the fundamental objective of BMD is consistent, the specific implementation practices vary among agencies. These differences reflect variations in climate, traffic level, aggregate sources, binder grades, recycled material use, pavement distress history, and agency experience with performance testing.

Most state DOTs have introduced BMD by supplementing existing Superpave volumetric design procedures with laboratory performance tests. In this approach, mixtures are first designed to satisfy conventional volumetric requirements and are then evaluated using selected rutting and cracking tests. Recent national implementation efforts show that agencies are at different stages of BMD adoption. Some states, such as Texas, Illinois, Louisiana, and Virginia, have incorporated BMD into specifications or pilot programs, while others are conducting benchmarking, shadow testing, and field validation studies. Because performance thresholds are influenced by local materials, traffic, and climate. Most agencies emphasize the need to establish state-specific criteria rather than directly adopting thresholds developed elsewhere.

This section summarizes current BMD practices used by selected state DOTs, including their implementation approaches, selected rutting and cracking performance tests, and reported threshold values.

2.5.1 Illinois Department of Transportation (IDOT)

The Illinois Department of Transportation (IDOT) is one of the leading agencies in implementing Balanced Mix Design using Volumetric Design with Performance Verification. The primary motivation for IDOT's BMD implementation was to improve mixture durability while allowing responsible use of higher RAP/RAS contents. Under this approach, the asphalt binder content is first determined using the Superpave volumetric mix design procedure, and the mixture is then evaluated using laboratory performance tests for rutting, cracking, and moisture susceptibility.

IDOT uses the Hamburg Wheel Tracking Test (HWTT) to evaluate rutting resistance and the Illinois Flexibility Index Test (I-FIT) to evaluate cracking resistance. HWTT is conducted at 50°C in accordance with the Illinois-modified AASHTO T 324 procedure. For plant-produced warm mix asphalt, loose mix reheating for 2 hours at 132 ± 3°C is required prior to HWTT testing. I-FIT is conducted in accordance with the Illinois-modified AASHTO TP 124 procedure. Earlier implementation documents reported an FI threshold of 8.0, while more recent implementation practice includes long-term aging of compacted I-FIT specimens for 3 days at 95°C to better evaluate surface cracking resistance (24-26).

IDOT has advanced beyond the research stage and has implemented performance testing in mix design verification and production start-up. The 2024 FHWA Lead States Peer Exchange reported that IDOT's implementation status is complete for several key tasks, including performance test selection, validation, equipment acquisition, baseline data development, pilot specifications, pilot projects, training, accreditation, and initial implementation (25).

Table 2.1 Illinois DOT BMD Performance Thresholds

Binder PG Grade	HWTT Requirement: Passes to 12.5 mm Rut Depth	I-FIT Requirement	Moisture Susceptibility Requirement
PG 58-xx or lower	> 5,000	FI > 8.0	TSR ≥ 0.85
PG 64-xx	> 7,500		
PG 70-xx	> 15,000		
PG 76-xx or higher	> 20,000		

Additional tensile strength limits include a minimum conditioned tensile strength of 60 psi for non-polymer-modified binder mixtures and 80 psi for polymer-modified binder mixtures, with a maximum unconditioned tensile strength of 200 psi.

2.5.2 Louisiana Department of Transportation and Development (LaDOTD)

The Louisiana Department of Transportation and Development (LaDOTD) was one of the earliest state agencies to implement Balanced Mix Design as part of its routine asphalt mixture design process. The primary motivation for adopting BMD was to improve cracking resistance in asphalt mixtures while maintaining the excellent rutting performance historically achieved under Louisiana's conventional Superpave specifications. Because many Louisiana mixtures already exhibited very good rutting resistance, the agency recognized that modest increases in asphalt binder content could substantially improve cracking resistance without compromising rutting performance.

The Louisiana Department of Transportation and Development (LaDOTD) uses a Volumetric Design with Performance Verification approach for Balanced Mix Design (BMD). In this procedure, the preliminary optimum asphalt binder content is first determined using conventional Superpave mix design methods and then verified through laboratory performance testing. Rutting and moisture susceptibility are evaluated using the Hamburg Wheel Tracking Test (HWTT) in accordance with AASHTO T 324 at 50°C, with rut depth measured after 20,000-wheel passes. Intermediate-temperature cracking resistance is assessed using the Semi-Circular Bend Test (SCB) test at 25°C, and the cracking performance metric is the J-integral (Jc), which represents the strain energy release rate during crack propagation. Performance thresholds vary by traffic level, with more stringent criteria applied to high-volume roadways. LaDOTD has fully implemented BMD statewide for both surface and binder course mixtures. Field and laboratory experience in Louisiana has shown that BMD-designed mixtures can substantially improve cracking resistance while maintaining satisfactory rutting performance (27)

TABLE 4.2 Louisiana DOTD BMD Performance Thresholds

Traffic Level	HWTT Requirement	SCB Cracking Requirement
Level 1 (moderate traffic)	Rut depth ≤ 10 mm at 20,000 passes	$J_c \geq 0.5$ kJ/m²
Level 2 (high traffic)	Rut depth ≤ 6 mm at 20,000 passes	$J_c \geq 0.6$ kJ/m²

In practice, application of these criteria often resulted in slightly higher asphalt binder contents than those selected using conventional Superpave design, thereby improving cracking resistance while maintaining acceptable rutting performance. Louisiana's successful statewide implementation has made LaDOTD one of the most widely cited examples of effective BMD adoption in the United States (6,25).

2.5.3 Texas Department of Transportation (TxDOT)

The Texas Department of Transportation (TxDOT) is widely recognized as the pioneer of the modern Balanced Mix Design (BMD) concept. The original motivation for TxDOT's BMD development was to address premature cracking observed in asphalt overlays while maintaining the excellent rutting resistance traditionally achieved in Texas mixtures. Researchers at the Texas A&M Transportation Institute (TTI) developed a performance-based methodology that directly balanced rutting and cracking resistance by evaluating mixtures at multiple asphalt binder contents and selecting the range that satisfied both criteria (Zhou et al., 2006; Zhou et al., 2014).

The Texas Department of Transportation (TxDOT) employs a performance-modified volumetric design approach in which a conventional Superpave mix design is first developed and then verified using laboratory performance tests. Rutting and moisture susceptibility are evaluated using the Hamburg Wheel Tracking Test (HWTT), while cracking resistance has traditionally been assessed using the Texas Overlay Test (OT); more recently, the Indirect Tensile Asphalt Cracking Test (IDEAL-CT) has been investigated as a simpler alternative. The HWTT is typically conducted at 50°C, and performance is evaluated based on the number of wheel passes required to reach 12.5 mm rut depth. The Overlay Test measures the number of cycles to failure under cyclic opening displacements. TxDOT adjusts performance criteria according to binder grade, traffic level, and mixture type. Texas was one of the earliest agencies to implement BMD, and its methodology served as the foundation for national guidance, including NCHRP Report 900 and AASHTO PP 105. Experience in Texas has demonstrated that performance-based mix optimization can significantly improve cracking resistance while maintaining adequate rutting performance and enabling increased use of recycled materials.

TABLE 2.5 Texas DOT Balanced Mix Design Performance Thresholds

Mixture Type	HWTT Requirement	Overlay Test Requirement
Permeable Friction Course (PFC)	≥ 10,000 passes to 12.5 mm rut depth	≥ 200 cycles
Stone Matrix Asphalt (SMA)	≥ 20,000 passes to 12.5 mm rut depth	≥ 200 cycles
Dense-Graded Surface Mix, PG 64-xx	≥ 10,000 passes to 12.5 mm rut depth	
Dense-Graded Surface Mix, PG 70-xx	≥ 15,000 passes to 12.5 mm rut depth	CFE≥ 1.0 in.lb/in.^{2} CPR ≤ 0.45
Dense-Graded Surface Mix, PG 76-xx	≥ 20,000 passes to 12.5 mm rut depth	
Hot In-Place Recycling (HIR)	≥ 10,000 passes to 12.5 mm rut depth	≥ 150 cycles

Note: Adapted from Texas Department of Transportation specifications, NCHRP Report 900 (West et al., 2018), and the NAPA Balanced Mix Design Resource Guide (NAPA, 2021).

2.5.4 Oklahoma Department of Transportation (ODOT)

The Oklahoma Department of Transportation (ODOT) has incorporated performance testing into its asphalt mixture design procedures to improve pavement durability and to support increased use of reclaimed asphalt pavement (RAP). ODOT's implementation efforts were motivated by the need to supplement traditional volumetric design with direct measures of rutting and cracking performance and to establish criteria appropriate for Oklahoma's climatic conditions and traffic levels (West et al., 2018; NAPA, 2021).

ODOT has primarily adopted Volumetric Design with Performance Verification approach. Under this methodology, mixtures are first designed using the Superpave volumetric procedure and then evaluated using laboratory performance tests. The principal rutting test is the Hamburg Wheel Tracking Test (HWTT), which is used to assess both rutting resistance and moisture susceptibility. For cracking evaluation, ODOT has investigated tests such as the Indirect Tensile Asphalt Cracking Test (IDEAL-CT) and the Illinois Flexibility Index Test (I-FIT), although early implementation efforts focused mainly on rutting and moisture performance (West et al., 2018).

The HWTT is typically conducted at 50°C in accordance with AASHTO T 324. Performance is evaluated based on the number of wheel passes required to reach 12.5 mm of rut depth. ODOT uses binder-grade-dependent criteria, requiring progressively higher resistance for mixtures containing stiffer or polymer-modified binders. Moisture susceptibility is also evaluated using a tensile strength ratio (TSR) criterion (NCHRP 20-07/Task 406).

TABLE 2.6 Oklahoma DOT BMD Performance Thresholds

Binder PG Grade	HWTT Requirement	Moisture Susceptibility Requirement	Ideal-CT
PG 64-xx	≥ 10,000 passes to 12.5 mm rut depth	TSR ≥ 80%	CT_{Index} ≥80
PG 70-xx	≥ 15,000 passes to 12.5 mm rut depth		
PG 76-xx	≥ 20,000 passes to 12.5 mm rut depth		

Note: Adapted from West et al. (2018), NCHRP Project 20-07/Task 406, and NAPA (2021).

2.5.5 Virginia Department of Transportation (VDOT)

The Virginia Department of Transportation (VDOT) has adopted Balanced Mix Design (BMD) to improve asphalt mixture durability, address premature surface cracking, and support the increased use of reclaimed asphalt pavement (RAP). VDOT's implementation was motivated by concerns that conventional Superpave volumetric requirements did not consistently provide adequate asphalt binder contents to achieve long-term cracking resistance, particularly in dense-graded surface mixtures. The agency also recognized that performance testing could provide greater flexibility in optimizing mixtures containing higher RAP contents and modified binders (NAPA, 2021; FHWA, 2024).

The Virginia Department of Transportation (VDOT) adopted a Volumetric Design with Performance Verification approach for Balanced Mix Design (BMD). In this framework, the preliminary optimum binder content is determined using conventional Superpave procedures and then verified through laboratory performance tests. Rutting resistance is evaluated using the Asphalt Pavement Analyzer (APA) in accordance with AASHTO T 340, typically at 64°C, with performance assessed based on rut depth after a specified number of loading cycles. Cracking resistance is assessed using the Indirect Tensile Asphalt Cracking Test (IDEAL-CT) in accordance with ASTM D8225 at 25°C, and performance is quantified using the CT_{Index} parameter. Earlier VDOT studies also considered the Cantabro Test to evaluate durability and resistance to raveling. VDOT's implementation demonstrated that performance testing can effectively supplement volumetric design procedures and improve mixture resistance to rutting and cracking.

TABLE 2.7 Virginia DOT Representative BMD Performance Criteria

Test	Performance Parameter	Representative Threshold*
APA	Rut depth@8000 passes	≤ 8 mm
IDEAL-CT	CT_{Index}	≥ 70
Cantabro	Mass loss	≤ 20%

*Thresholds shown are representative values reported in implementation studies and may vary by mixture type, traffic level, and specification version.

Note: Adapted from West et al. (2018), NAPA (2021), and FHWA (2024).

VDOT has progressed beyond research and pilot testing and is considered one of the leading state agencies in BMD implementation. According to the 2024 FHWA Lead States Peer Exchange, Virginia has completed most key implementation activities, including test selection, equipment acquisition, baseline data development, pilot projects, and training. The agency continues to refine performance thresholds and quality assurance procedures based on field performance and contractor experience (FHWA, 2024).

2.6 SUMMARY OF BMD PRACTICES

Figure 2.16 summarizes the Balanced Mix Design (BMD) implementation practices adopted by selected state Departments of Transportation (DOTs). Table 2.6 identifies the BMD design approach used by each agency and the laboratory performance tests employed to evaluate rutting and cracking resistance. This comparison highlights the diversity of test methods and implementation strategies currently used across the United States.

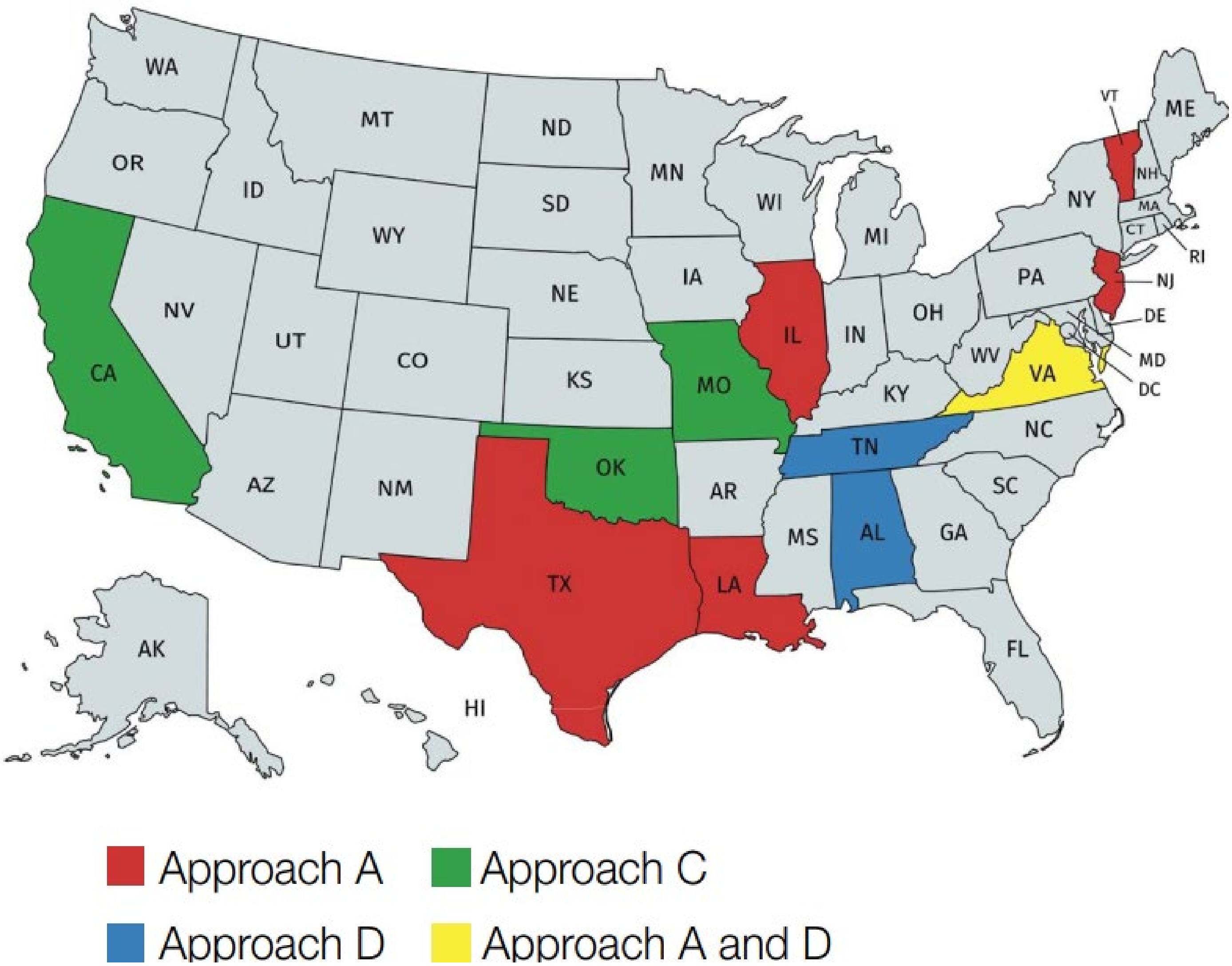


FIGURE 2.88 State-of-The-Practice on Bmd Implementation (4)

Table 2.7 summarizes the rutting and cracking performance thresholds currently used by selected state DOTs in their Balanced Mix Design (BMD) programs. The criteria include maximum allowable rut depths and minimum cracking indices obtained from commonly used performance tests. These thresholds provide a useful benchmark for comparing agency practices and for developing performance criteria for New Mexico.

TABLE 2.6 Summary of Balanced Mix Design (BMD) Implementation Practices Adopted by Selected State DOTs

BMD Approach	State	Applicable Mixture Type	Rutting Test	Cracking Test	Performance Testing for Production Acceptance?
Approach A	Illinois	High ESAL mixtures	HWTT	I-FIT	Yes, HWTT for "Pass/Fail"
Approach A	Louisiana	Wearing and binder course mixtures	HWTT	SCB-Jc	Yes, "Pass/Fail"
Approach A	New Jersey	Specialty mixtures	APA	OT, BBF	Yes, "Pass/Fail" or Pay Adjustment
Approach A	Texas	Surface mixtures	HWTT	OT, IDEAL-CT	Yes, "Pass/Fail"
Approach A	Vermont	Superpave Type IVS mixtures	HWTT	I-FIT	Yes, PWL
Approach A and D	Virginia	Surface mixtures	APA	Cantabro, IDEAL-CT	Yes, "Pass/Fail"
Approach C	California	Long-life pavement mixtures	FN, HWTT	BBF, I-FIT	Yes, HWTT for "Pass/Fail"
Approach C	Missouri	Mainline pavement mixtures	HWTT	I-FIT, IDEAL-CT	Yes, HWTT for "Pass/Fail"; I-FIT and IDEAL-CT for Pay Adjustment
Approach C	Oklahoma	Superpave mixtures	HWTT	IDEAL-CT	No
Approach D	Alabama	Superpave mixtures	HT-IDT	AL-CT	Yes, "Pass/Fail"
Approach D	Tennessee	All mixtures	HWTT	IDEAL-CT	To be determined

TABLE 2.7 Current BMD Mix Performance Criteria Adopted by State DOTs

<table>
<tr><th>DOTS</th><th colspan="2">Rutting</th><th colspan="3">Cracking</th></tr>
<tr><td rowspan="5">TxDOT</td><td colspan="2">HWTT@50°C</td><td colspan="3">OT</td></tr>
<tr><td>PG grade</td><td>HWTT passes to 12.5 mm rut depth</td><td colspan="3" rowspan="4">CFE≥ 1.0 in.lb/in.^{2}
CPR ≤ 0.45</td></tr>
<tr><td>PG64</td><td>10,000</td></tr>
<tr><td>PG70</td><td>15,000</td></tr>
<tr><td>PG76 (or higher)</td><td>20,000</td></tr>
<tr><td rowspan="5">ODOT</td><td colspan="2">HWTT@50°C (STA)</td><td colspan="3">IDEAL-CT@25°C (STA)</td></tr>
<tr><td>PG grade</td><td>HWTT passes to 12.5 mm rut depth</td><td colspan="3" rowspan="4">CT_{Index} ≥80</td></tr>
<tr><td>PG 64-xx</td><td>≤10,000</td></tr>
<tr><td>PG 70-xx</td><td>≤15,000</td></tr>
<tr><td>PG 76-xx</td><td>≤20,000</td></tr>
<tr><td rowspan="6">IDOT</td><td colspan="2">HWTT@50°C</td><td colspan="3">I-FIT@25°C</td></tr>
<tr><td>PG grade</td><td>HWTT passes to 12.5 mm rut depth</td><td colspan="3" rowspan="5">FI≥8 (STA)
FI≥5 (LTA)</td></tr>
<tr><td>PG 58-xx (or lower)</td><td>≤5,000</td></tr>
<tr><td>PG 64-xx</td><td>≤7,500</td></tr>
<tr><td>PG 70-xx</td><td>≤15,000</td></tr>
<tr><td>PG 76-xx (or higher)</td><td>≤20,000</td></tr>
<tr><td rowspan="5">ALDOT</td><td colspan="2">HT-IDT</td><td colspan="3">CT_{Index}@25°C (STA)</td></tr>
<tr><td colspan="2" rowspan="4">$IDT_{strength}$ ≥20 psi</td><td>Design Traffic (ESALs)</td><td>Mix Design Approval</td><td>Production Acceptance</td></tr>
<tr><td>< 1 million</td><td>≥ 55</td><td>≥ 50</td></tr>
<tr><td>1 to 10 million</td><td>≥83</td><td>≥ 75</td></tr>
<tr><td>10 to 30 million</td><td>≥110</td><td>≥ 100</td></tr>
</table>

Caltrans	**HWTT@50°C**		**I-FIT@25°C**	
	Number of passes ≥ 20,000 to 12.5 mm rut depth		FI≥3	
LaDOTD	**HWTT@50°C (STA)**		**SCB-J_c@25°C (STA)**	
	Traffic	Max. Rut @20,000 passes	Traffic	J-integral (J_c)
	Level 1	10 mm	Level 1	0.5 kJ/m^2
	Level 2	6mm	Level 2	0.6 kJ/m^2
MoDOT	**HWTT@50°C (STA)**		**I-FIT@25°C**	
	PG grade	HWTT passes to 12.5 mm rut depth	FI≥2 (STA)	
	PG58S-xx	5,000		
	PG64S-22	7,500		
	PG64H-22	15,000		
	PG64V-22	20,000		
NJDOT	**APA@64°C (STA)**		**Overlay Test@25°C**	
	Mix type	APA rut depth	Mix type	Cycles to failure
	HPTO	≤ 5mm	HPTO	≥600
	HRAP Surface (64S-22)	≤ 7mm	HRAP Surface (64S-22)	≥200
	HRAP Surface (64E-22	≤ 4mm	HRAP Surface (64E-22	≥275
TDOT	**HWTT@50°C (STA)**		**CT_{Index}@25°C (STA)**	
	Road type	HWTT passes to 12.5 mm rut depth	Road type	CT_{Index}
	State Routes < 10,000 ADT	≤10,000	State Routes < 10,000 ADT	≥50
		SIP (≥10,000)		
	State Routes > 10,000 ADT	≤15,000	State Routes > 10,000 ADT	≥ 75
	Interstates	≤20,000	Interstates	≥ 100

VTrans	**HWTT@45°C (STA)** Number of passes ≥ 20,000 to 10 mm rut depth	SIP (≥15,000)	**I-FIT@25°C** FI≥10
VDOT	**APA@64°C (STA)** APA rut depth ≤8 mm @8,000 passes		**IDEAL-CT@25°C (STA)** CT_{Index} ≥70

2.7 NEED FOR NEW MEXICO-SPECIFIC PERFORMANCE CRITERIA

Several state Departments of Transportation (DOTs) have successfully implemented Balanced Mix Design (BMD) by establishing rutting and cracking performance thresholds based on local materials, climatic conditions, traffic demands, and historical field performance. Although these agency-specific criteria provide valuable guidance, the threshold values developed by other DOTs cannot be directly adopted for New Mexico because of the state's unique environmental conditions, aggregate sources, binder selection practices, and mixture characteristics.

To address this need, the present study was undertaken to develop a BMD framework tailored to New Mexico conditions. A comprehensive review of national BMD practices was conducted to identify commonly used performance tests and benchmark threshold values for rutting and cracking resistance. These benchmarks served as an initial reference for evaluating the performance of asphalt mixtures representative of New Mexico practice.

The benchmark criteria identified through the literature review were used in conjunction with laboratory performance results from New Mexico mixtures to develop preliminary rutting and cracking thresholds for the state. The methodology used to establish these thresholds, along with the supporting performance test data and recommended criteria, is presented in Chapter 5.

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CHAPTER 3
DEVELOPMENT OF BALANCED MIX DESIGN PROCEDURES

3.1 INTRODUCTION

This section describes the methodology developed in this study to determine the balanced asphalt binder content for New Mexico asphalt mixtures. The procedure is based on a performance-modified volumetric design approach in which an initial Superpave mix design is used as the starting point, and the optimum binder content is subsequently adjusted using laboratory performance tests to achieve an appropriate balance between rutting resistance and cracking resistance. This approach was selected because it preserves the established Superpave mix design framework, which is widely used and well understood by practitioners, while incorporating direct performance testing to provide a more reliable assessment of mixture rutting and cracking resistance.

3.2 METHODOLOGY

The methodology developed in this study for determining the balanced asphalt binder content is illustrated in Figure 3.1. The procedure follows a performance-modified volumetric design approach in which a conventional Superpave mix design is used as the starting point, and the optimum asphalt content is subsequently refined using laboratory performance tests and performance indices developed in this research.

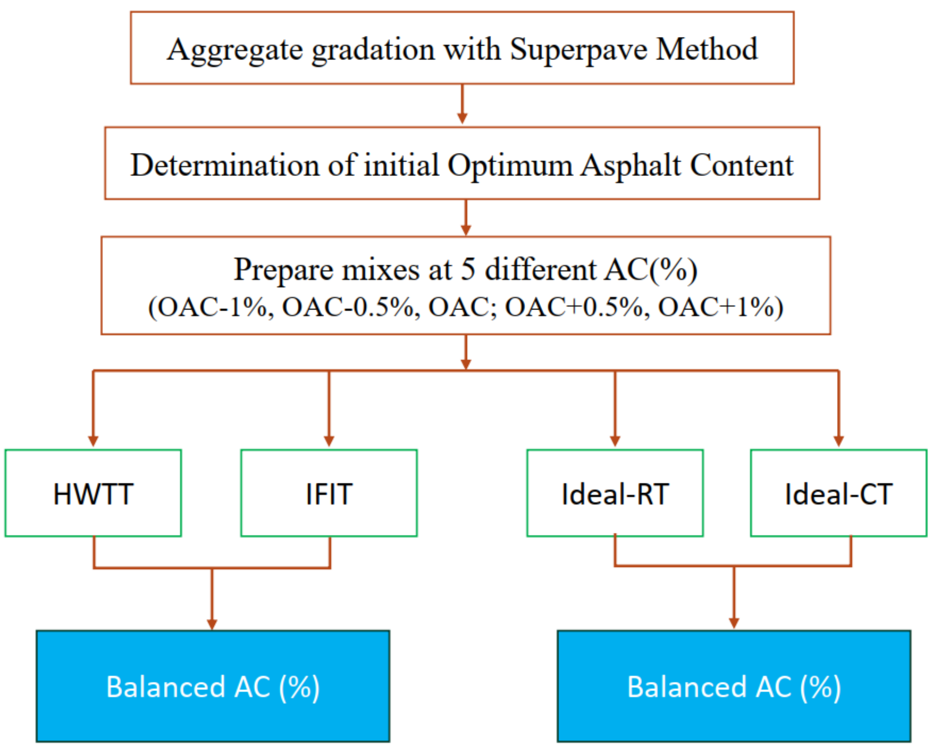

FIGURE 3.1 BMD Development Methodology

The process begins with the selection of an aggregate gradation and asphalt binder grade, followed by the development of an initial Superpave mix design to determine the volumetric optimum asphalt content (OAC). To evaluate the influence of binder content on mixture performance, five trial mixtures are prepared at asphalt contents corresponding to OAC-1.0%, OAC-0.5%, OAC, OAC+0.5%, and OAC+1.0%.

Three performance index-based methods were proposed to determine the balanced asphalt content. The first method uses the Hamburg Wheel Tracking Test (HWTT) and the Illinois Flexibility Index Test (I-FIT) to develop normalized rutting and cracking performance indices. The second method uses the Indirect Tensile Asphalt Rutting Test (IDEAL-RT) and the Indirect Tensile Asphalt Cracking Test (IDEAL-CT) to establish a second set of performance indices. The third method is a combined performance approach that integrates the results from all four tests into a unified framework.

The methodology was applied to both laboratory-designed and plant-produced asphalt mixtures representing aggregate sources, binder grades, and RAP contents commonly used in New Mexico. The resulting procedure provides a rational and practical framework for selecting optimum asphalt binder content based on direct measurements of mixture performance rather than volumetric properties alone and forms the basis for the proposed Balanced Mix Design procedure for NMDOT.

3.3 PREPARATION OF ASPHALT MIXES

Asphalt mixtures were prepared in the laboratory using established Superpave method (28,29). Virgin aggregates were combined according to the designated blend proportions, and asphalt binder was added based on the selected design asphalt contents. Mixing and conditioning procedures were carefully controlled to ensure uniform coating, proper blending of materials, and reproducible specimen preparation for subsequent volumetric and performance testing.

3.3.1 Aggregate

The aggregates used in this study were obtained from a local source and are representative of materials commonly used in New Mexico asphalt mixtures. The mixture selected for detailed Balanced Mix Design evaluation was the NMDOT SP-IV dense-graded surface mixture designated as M12. The M12 mixture utilizes an alluvial limestone aggregate produced from the Brantley Pit. The physical properties of the M12 aggregates are summarized in Table 3.1, and the aggregate gradation used in the mix design is presented in the following section.

TABLE 3.1 Properties of M12 aggregates

Combination Used		Bulk Sp. Gravities	Abs. %
3/4"	15%	2.695	1.1
1/2"	40%	2.6668	1.6
ASCF	45%	2.660	1.5

The combined gradation for the M12 aggregates is shown in Figure 3.2. The NMAS for gradation is 12.5mm and the gradation lies below the primary control sieve (PCS) is 4.75 mm. The percentage passing the PCS control point is 35.3% < 39%, so the combined gradation for M12 is classified as coarse graded.

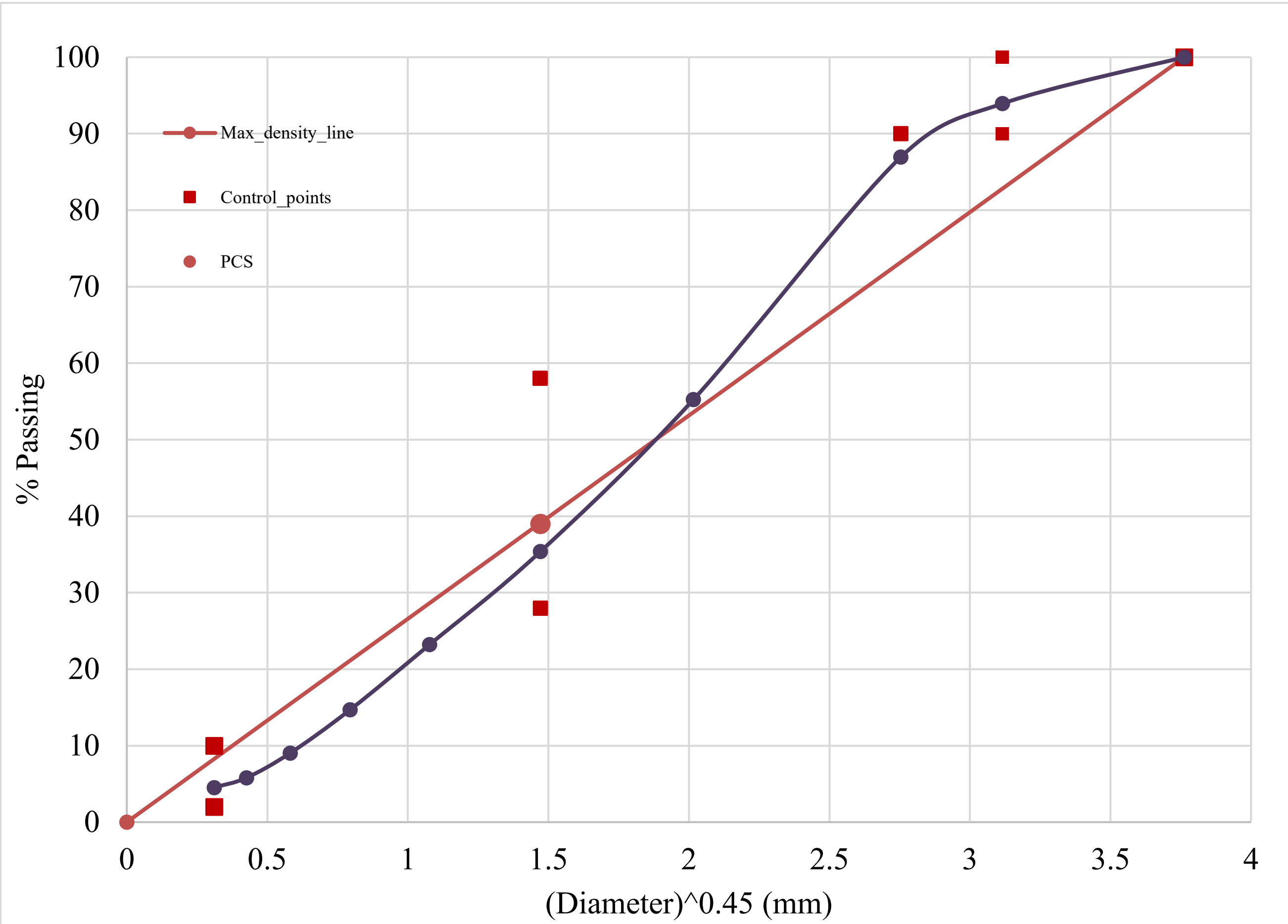

FIGURE 3.2 Combined gradation for the M12 aggregates

3.3.2 Asphalt Binder

Three asphalt binder grades were used in this study: PG 64-22, PG 70-22, and PG 76-22. These binders were selected to represent the range of performance grades commonly used by the New Mexico Department of Transportation (NMDOT) for asphalt mixtures subjected to different traffic levels and climatic conditions.

All binders satisfied the applicable Superpave performance grading requirements for high-temperature rutting resistance, intermediate-temperature fatigue cracking, and low-temperature thermal cracking. Mixing and compaction temperatures were determined in accordance with the binder supplier recommendations and are summarized in Table 3.2.

TABLE 3.2 Mixing and Compaction Temperature of Binders

Binder grade	Mixing Temperature (°C)	Compaction Temperature (°C)
PG 64-22	155	145
PG 70-22	160	150
PG 76-22	165	155

3.3.3 Mix Preparation

Asphalt mixtures were prepared at five asphalt binder contents to evaluate mixture performance over a range of asphalt contents and to identify the balanced asphalt content. The mixtures were produced using the M12 virgin aggregate structure with PG 64-22, PG 70-22, and PG 76-22 binders. No recycled materials, such as reclaimed asphalt pavement (RAP) or recycled asphalt shingles (RAS), were included in these laboratory-designed mixtures.

The selected binder contents were 5.4%, 5.7%, 6.0%, 6.3%, and 6.6% by total mixture mass. This range was chosen to bracket the volumetric optimum asphalt content and to capture the transition from cracking-controlled behavior at lower binder contents to rutting-controlled behavior at higher binder contents. For each binder content, loose mixtures were prepared at the designated mixing temperature of 155°C and subjected to short-term oven aging (STOA) in accordance with AASHTO R 30 by conditioning the loose mix at 135°C for 4 hours (30). Following aging, the mixtures heated to reach specified compaction temperature and compacted using the Superpave Gyratory Compactor (SGC). Specimens were compacted to achieve a target air void content of 7.0 ± 0.5%, consistent with the specimen preparation requirements for the selected performance tests.

3.4 PERFORMANCE TESTS

Performance testing was conducted on specimens prepared at each binder content to evaluate both rutting and cracking resistance. Rutting performance was assessed using the Hamburg Wheel Tracking Test (HWTT) and the IDEAL Rutting Test (IDEAL-RT), while cracking performance was evaluated using the IDEAL Cracking Test (IDEAL-CT) and the Illinois Flexibility Index Test (I-FIT). The results were used to quantify the rutting–cracking tradeoff and to identify the binder content corresponding to balanced performance.

3.4.1 HWTT Test

The Hamburg Wheel-Tracking Device (HWTD) test was performed to evaluate the stripping and rutting susceptibility of the asphalt mixture in accordance with AASHTO T 324-11 (AASHTO, 2011). The specimens were subjected to 20,000-wheel passes, and the resulting rut depth was continuously monitored using a linear variable displacement transducer (LVDT).

HWTT specimens for M12-6422 virgin mixes were prepared at five binder contents 5.4%, 5.7%, 6%,6.3% and 6.6% to evaluate the rutting potential of the mix at different AC (%). The test results are shown in Figure 3.3 and summarized in Table 3.3.

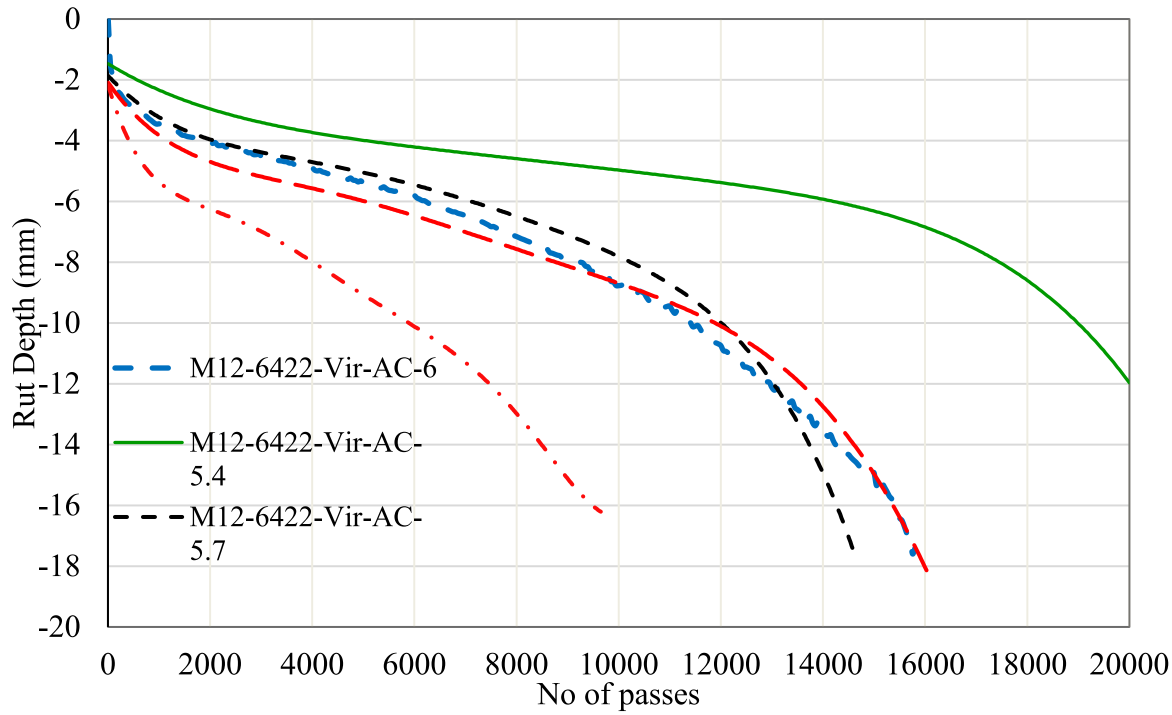

FIGURE 3.3 HWTT Rut Depth for M12 Virgin Mixture with PG 64-22 Binder

TABLE 3.3 Summary of HWTT Rut Depth for M12 Virgin Mixture (PG 64-22)

AC (%)	Rut Depth @ 10,000 Passes (mm)	Rut Depth @ 15,000 Passes (mm)	Rut Depth @ 20,000 Passes (mm)
5.4	5.1	6.21	12
5.7	7.9	9.8	>20
6	8.5	14.9	>20
6.3	8.7	15	>20
6.6	17.8	>20	>20

The HWTT results demonstrate a clear and progressive increase in rut depth with increasing binder content for the M12 virgin mixture with PG 64-22 binder. At lower binder contents (5.4% and 5.7%), rut depths of approximately 5.0 mm and 7.5 mm, respectively, indicate strong rutting resistance and remain well below the commonly adopted threshold of 12.5 mm at 10,000 passes. As the binder content increases to 6.0% and 6.3%, rut depths increase to about 8.5 mm and 9.0 mm, respectively, reflecting a reduction in mixture stiffness and shear resistance, although still within acceptable performance limits. However, at 6.6% binder content, the rut depth exceeds 12.5 mm, indicating failure to meet the rutting criterion and suggesting excessive binder leading to reduced aggregate interlock and stability. Overall, the results highlight that rutting susceptibility increases with binder content, and based on the 12.5 mm threshold, the maximum allowable binder content for acceptable rutting performance lies between 6.3% and 6.6%, establishing an upper bound for balanced mix design.

HWTT specimens for M12-7022 virgin mixes were prepared at five binder contents 5.4%, 5.7%, 6%,6.3% and 6.6% to evaluate the rutting potential of the mix at different AC (%).

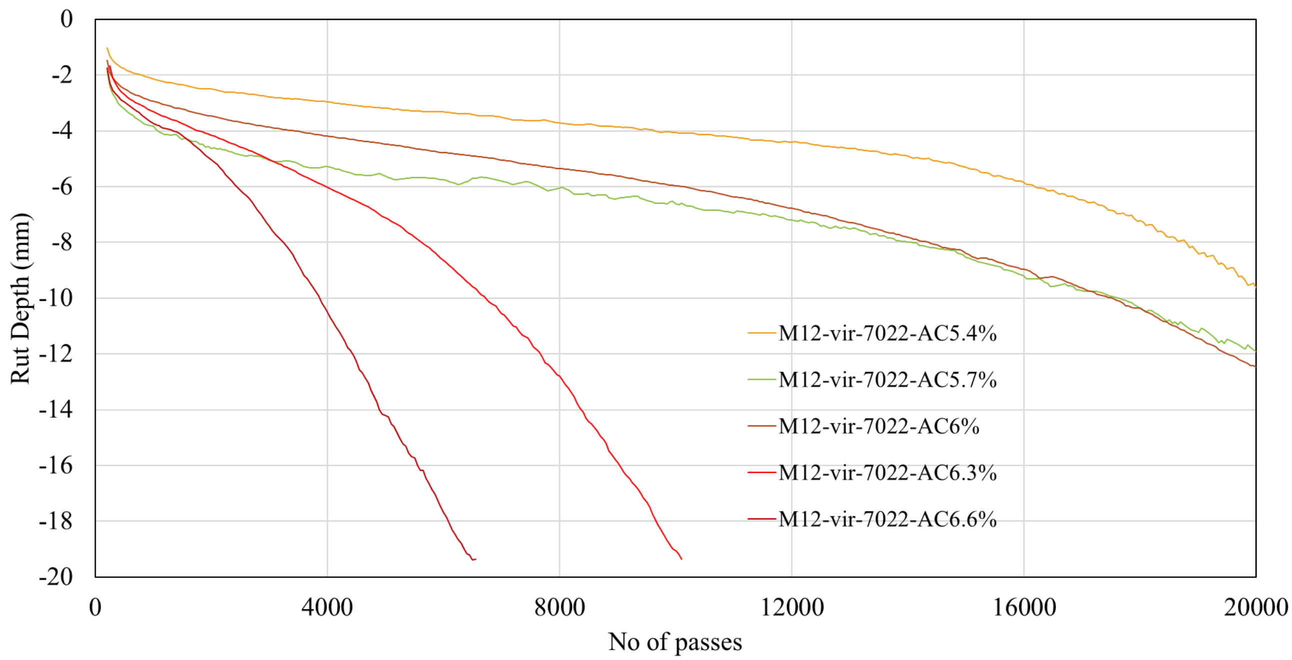

FIGURE 3.4 HWTT Rut Depth for M12 Virgin Mixture with PG 70-22 Binder

TABLE 3.4 HWTT rut depth result for M12 Virgin mixes (PG 70-22 Binder)

AC (%)	Rut Depth @ 10,000 Passes (mm)	Rut Depth @ 15,000 Passes (mm)	Rut Depth @ 20,000 Passes (mm)
5.4	4.11	5.25	9.7
5.7	5.9	8.4	11.8
6	6.7	8.5	12.4
6.3	19.2	>20	>20
6.6	>20	>20	>20

Figure 3.4 and Table 3.4 present the Hamburg Wheel Tracking Test (HWTT) results for the M12 virgin mixtures prepared with PG 70-22 binder at five asphalt binder contents. The results show a clear increase in rut depth with increasing binder content. The mixture containing 5.4% asphalt binder exhibited the best rutting resistance, with rut depths of 4.11 mm, 5.25 mm, and 9.7 mm at

10,000, 15,000, and 20,000 passes, respectively. Increasing the binder content to 5.7% and 6.0% resulted in progressively higher rut depths; however, both mixtures remained below the 12.5 mm criterion at 20,000 passes, with final rut depths of 11.8 mm and 12.4 mm, respectively.

A substantial loss in rutting resistance was observed at binder contents of 6.3% and 6.6%. The 6.3% mixture reached approximately 19.2 mm rut depth by 10,000 passes and exceeded 20 mm before completion of the test, while the 6.6% mixture failed before reaching 10,000 passes. These results indicate that rutting performance deteriorated rapidly when the binder content exceeded approximately 6.0%.

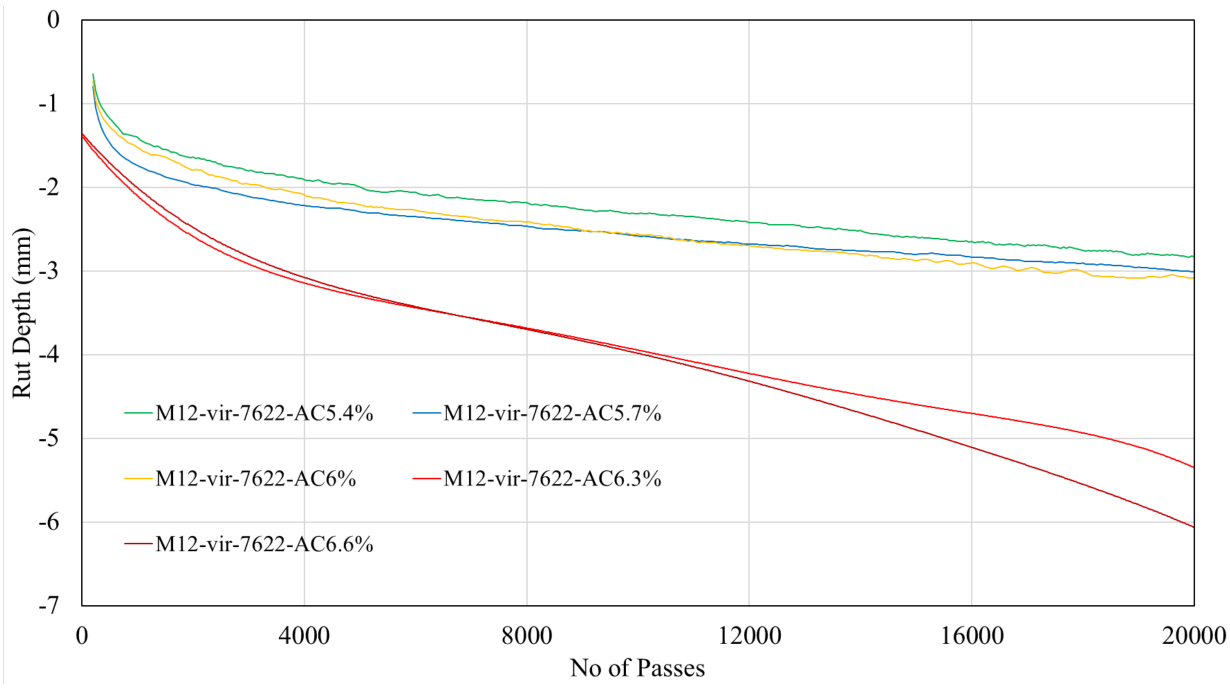

FIGURE 3.5 HWTT Rut Depth for M12 Virgin Mixture with PG 76-22 Binder

TABLE 3.5 HWTT rut depth result for M12 Virgin mixes (PG 76-22 Binder)

AC (%)	Rut Depth @ 10,000 Passes (mm)	Rut Depth @ 15,000 Passes (mm)	Rut Depth @ 20,000 Passes (mm)
5.4	2.31	2.5	2.83
5.7	2.5	2.79	3
6	2.6	2.84	3.1
6.3	3.98	4.59	5.31
6.6	4.3	4.9	6

Figure 3.5 and Table 3.5 present the Hamburg Wheel Tracking Test (HWTT) results for the M12 virgin mixtures prepared with PG 76-22 binder. Compared with the PG 64-22 and PG 70-22 mixtures, the PG 76-22 mixtures exhibited substantially improved rutting resistance across the entire range of asphalt binder contents evaluated. Rut depths at 20,000 passes ranged from 2.83 mm at 5.4% binder content to 6.0 mm at 6.6% binder content, all of which were well below the 12.5 mm failure criterion.

The results indicate a gradual increase in rut depth with increasing binder content; however, the effect of binder content on rutting performance was significantly less pronounced than that observed for the PG 70-22 mixtures. Even at the highest binder content of 6.6%, the measured rut depth at 20,000 passes was only 6.0 mm, demonstrating excellent resistance to permanent deformation.

3.4.2 Binder Sensitivity to Rutting

Figures 3.6 through 24 illustrate the effect of asphalt binder content on HWTT rut depth at 10,000, 15,000, and 20,000 wheel passes for the M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders. In general, rut depth increased with increasing asphalt binder content for all three binder grades, confirming that higher binder contents improve cracking resistance but reduce resistance to permanent deformation.

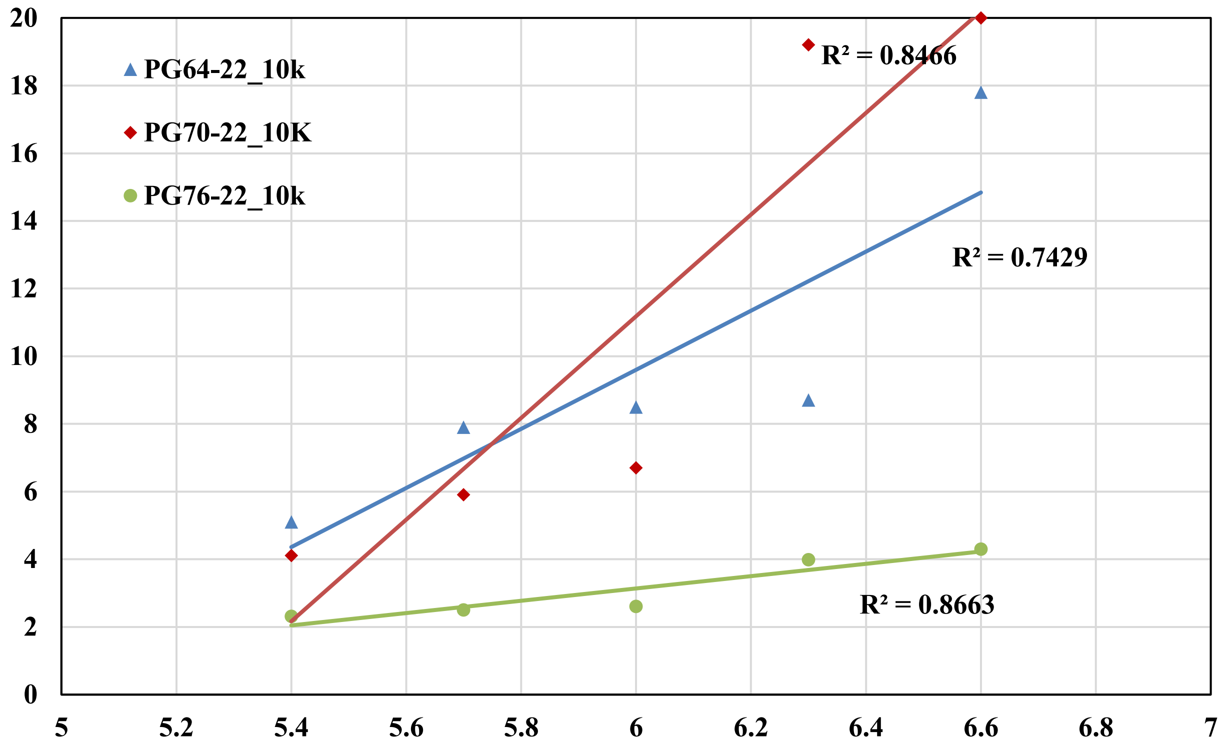

FIGURE 3.6 Binder Sensitivity to rutting @10,000 passes

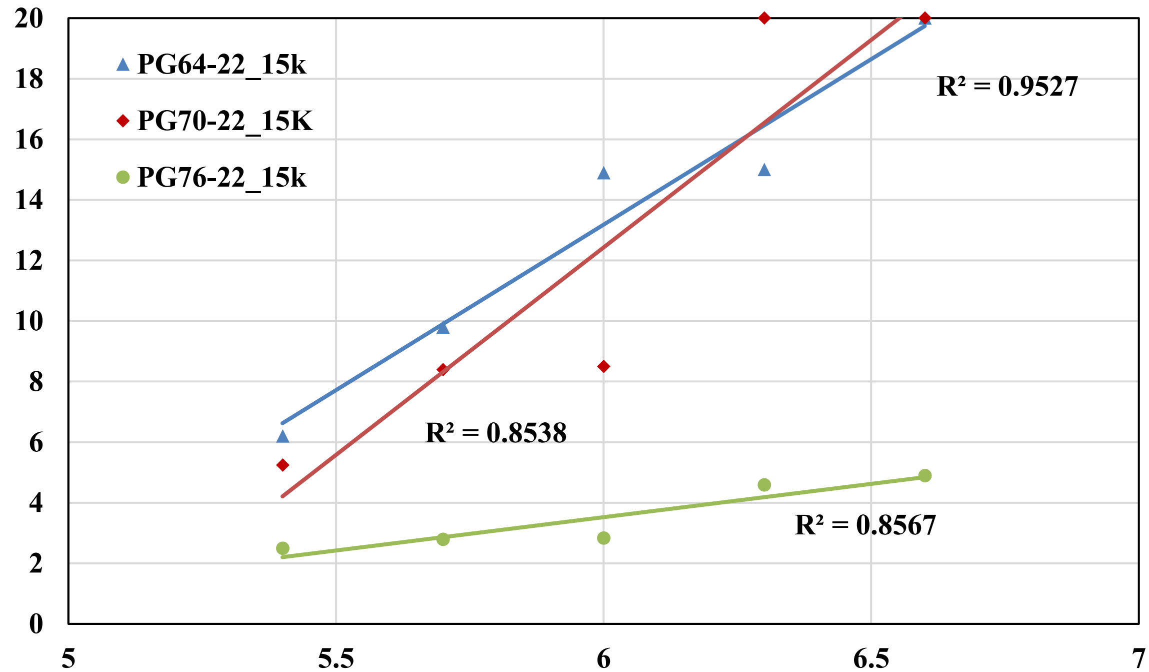

FIGURE 3.7 Binder Sensitivity to rutting @15,000 passes

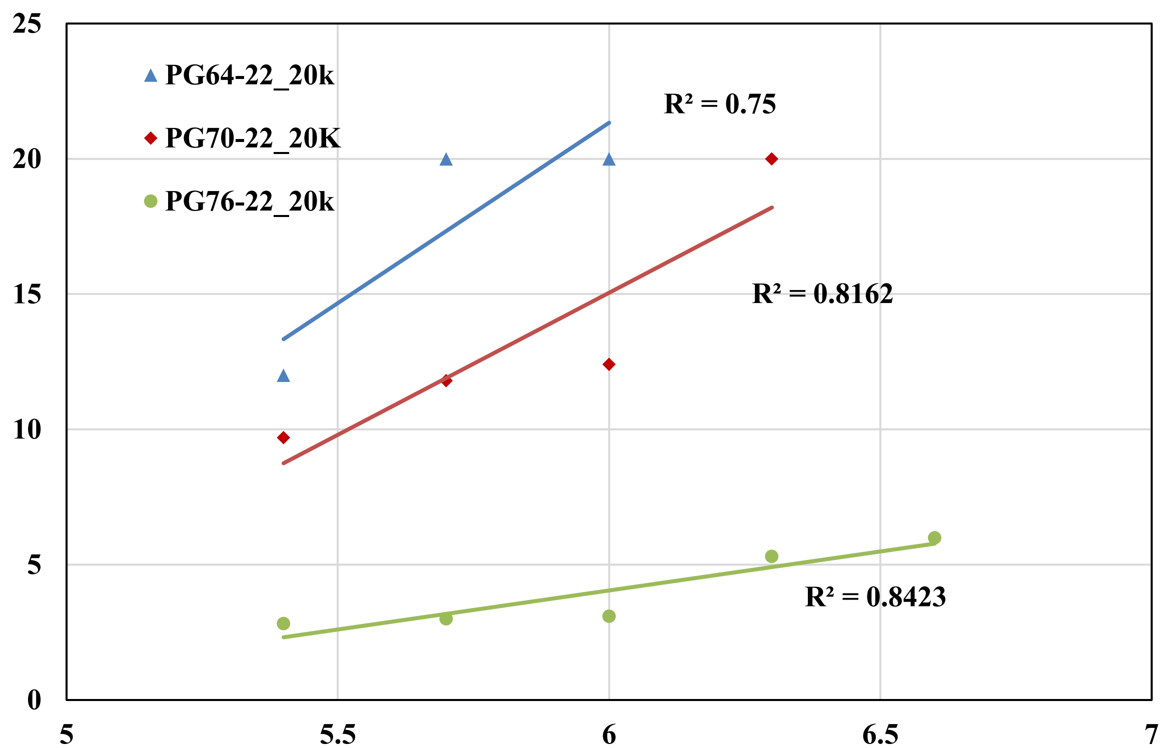

FIGURE 3.8 Binder Sensitivity to rutting @20,000 passes

The PG 64-22 mixtures exhibited a progressive increase in rut depth with increasing asphalt binder content. At lower binder contents, the mixtures demonstrated satisfactory rutting resistance; however, rut depth increased markedly when the binder content exceeded approximately 6.0%. At both 15,000, and 20,000 wheel passes, mixtures containing 6.3% and 6.6% binder exceeded the 12.5 mm rut depth criterion, indicating that rutting became the governing distress at higher asphalt contents.

The PG 70-22 mixtures exhibited a similar trend but showed greater sensitivity to increases in binder content than the PG 64-22 mixtures. While rutting performance at lower binder contents was comparable to the PG 64-22 mixtures, rut depth increased more rapidly as binder content increased. Consequently, the PG 70-22 mixtures experienced a more pronounced reduction in rutting resistance beyond approximately 6.0% binder content, with the 6.3% and 6.6% mixtures exceeding the HWTT criterion at an earlier stage of testing.

In contrast, the PG 76-22 mixtures exhibited substantially lower rut depths and the least sensitivity to changes in binder content. Although rut depth increased gradually with increasing asphalt content, all mixtures remained well below the 12.5 mm criterion after 20,000 wheel passes. This behavior demonstrates the superior rutting resistance provided by the PG 76-22 binder.

Overall, the results indicate that rutting susceptibility increased with increasing binder content for all three binder grades; however, the magnitude of this effect was strongly dependent on binder grade. Among the binders evaluated, PG 76-22 provided the highest resistance to permanent deformation and permitted the use of higher asphalt contents without exceeding the selected rutting threshold. These findings underscore the significant role of binder grade in governing the rutting–cracking trade-off and, consequently, in determining the balanced asphalt content.

3.4.3 Illinois Flexibility Index Test (IFIT)

The Illinois Flexibility Index Test (I-FIT) was used in this study to evaluate the intermediate-temperature cracking resistance of asphalt mixtures. The test is performed on semi-circular bend (SCB) specimens and provides two primary parameters: fracture energy and flexibility index (FI). The flexibility index combines the energy required to initiate cracking with the post-peak slope of the load-displacement curve and serves as an indicator of the mixture's resistance to crack propagation. Higher FI values indicate greater cracking tolerance and improved resistance to fatigue and reflective cracking.

I-FIT testing was conducted on M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders at five asphalt binder contents ranging from 5.4% to 6.6%. The objective was to quantify the effect of binder content and binder grade on cracking performance and to identify the content of the binder at which the mixtures satisfied the selected cracking criterion. The I-FIT results for the M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders at different asphalt binder contents are presented in Figures 3.9 through 3.11. Summary statistics, including average Flexibility Index (FI), fracture energy, post-peak slope, and indirect tensile strength, are provided in Tables 3.6 through 3.8.

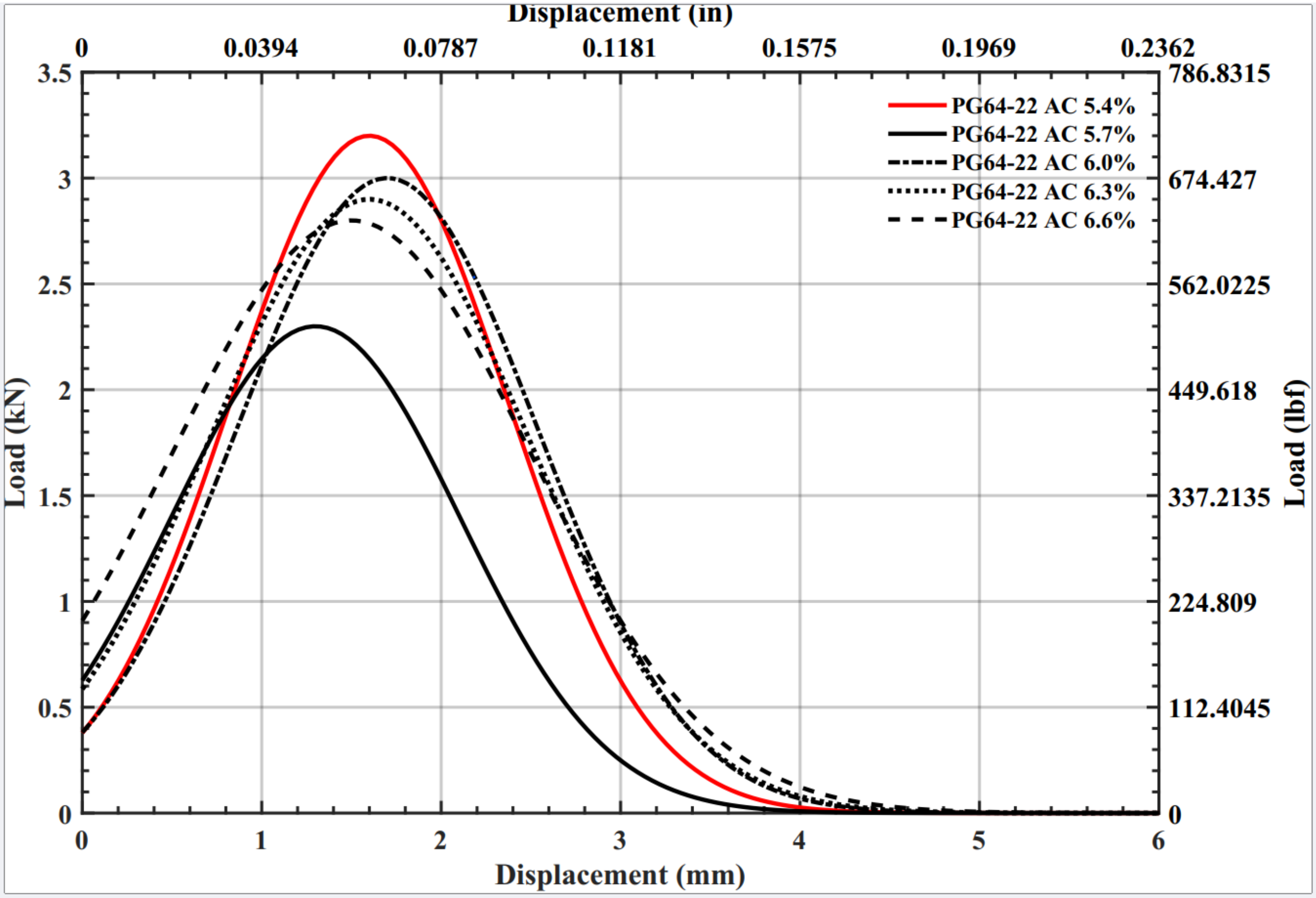

FIGURE 3.9 I-FIT Results for M12 Virgin Mix (PG 64-22)

TABLE 3.6 I-FIT Summary Results for M12 Virgin Mix (PG 64-22)

AC (%)	Avg FI	Cov (%)	Avg Gf	Cov (%)	Avg slope	Cov (%)	Avg Strength	Cov (%)
5.4	7.27	18.6	2096	3.8	2.95	22.3	61.83	1.9
5.7	11.60	14.9	1626	16.0	1.44	25.4	43.42	16.2
6.0	16.21	—	2577	—	1.59	—	58.25	—
6.3	17.98	6.6	2966	17.0	1.66	16.7	59.57	6.9
6.6	22.25	16.0	2928	1.5	1.34	17.4	56.52	6.3

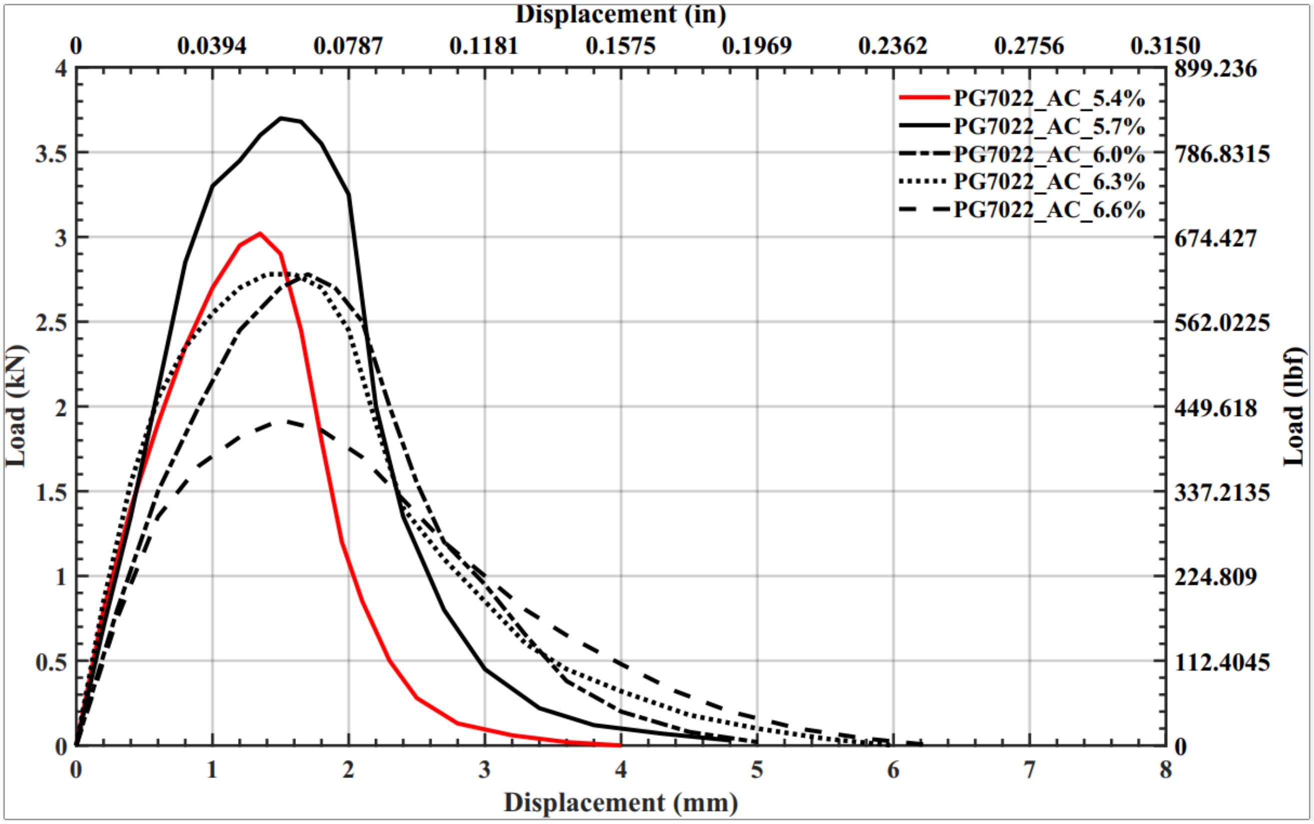

FIGURE 3.10 I-FIT Results for M12 Virgin Mix (PG 70-22)

TABLE 3.7 I-FIT Summary Results for M12 Virgin Mix (PG 70-22)

AC (%)	Avg FI	COV (%)	Avg Gf (J/m²)	COV (%)	Avg Slope (kN/mm)	COV (%)	Avg Strength (psi)	COV (%)
5.4	3.54	31.5	2218	19.2	6.73	32.2	72.10	13.6
5.7	4.04	25.2	2283	13.2	5.79	14.8	71.24	4.6
6.0	9.63	12.5	1905	11.8	2.01	22.2	52.79	8.0
6.3	10.09	10.7	1991	34.2	1.99	38.8	51.79	26.4
6.6	10.76	76.8	2342	15.1	3.32	56.8	59.76	25.6

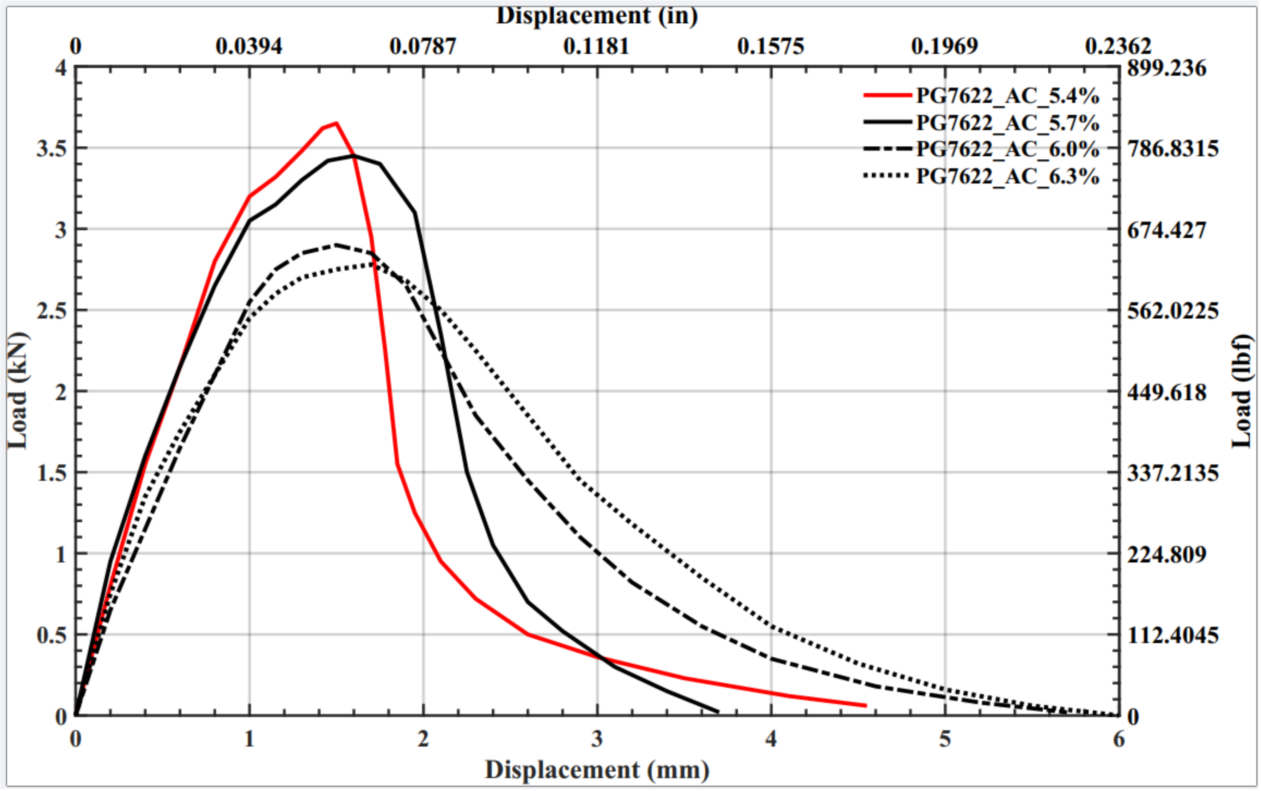

FIGURE 3.11 I-FIT Results for M12 Virgin Mix (PG 76-22)

TABLE 3.8 I-FIT Summary Results for M12 Virgin Mix (PG 76-22)

AC (%)	Avg FI	COV (%)	Avg Gf (J/m²)	COV (%)	Avg Slope (kN/mm)	COV (%)	Avg Strength (psi)	COV (%)
5.4	3.19	11.6	2211	11.5	6.94	0.4	76.89	14.8
5.7	4.70	18.6	2622	6.7	5.69	17.7	75.98	12.0
6.0	12.43	12.0	3075	24.4	2.53	29.7	66.91	16.8
6.3	18.25	12.7	2154	13.1	1.20	20.0	46.97	11.0

The I-FIT results demonstrated that cracking resistance improved with increasing asphalt binder content for all three binder grades, as indicated by the corresponding increase in Flexibility Index (FI). For the PG 64-22 mixtures, the average FI increased from 7.27 at 5.4% binder content to 22.25 at 6.6%. The PG 70-22 mixtures showed a more gradual increase, with FI values ranging from 3.54 to 10.76, while the PG 76-22 mixtures exhibited a substantial improvement, increasing from 3.19 at 5.4% to 18.25 at 6.3%. In general, the increase in FI was accompanied by a reduction in post-peak slope, indicating improved resistance to crack propagation. Mixtures at lower binder contents often failed to meet the commonly accepted FI threshold of 8.0, whereas mixtures with higher binder content consistently exceeded this criterion. Overall, the results confirm that increasing asphalt binder content significantly enhances cracking resistance, although the magnitude of improvement varies with binder grade.

3.4.4 Binder Sensitivity to Cracking Resistance

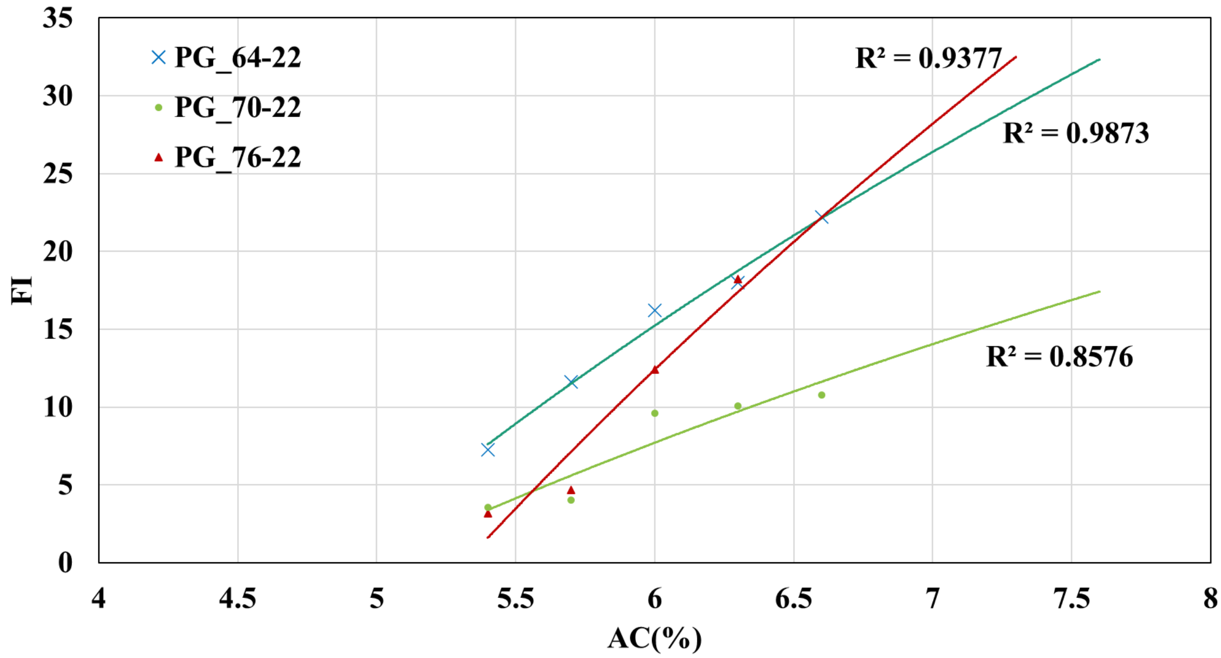

FIGURE 3.12 Binder Sensitivity to FI (Cracking Resistance)

Figure 3.12 illustrates the sensitivity of cracking resistance, expressed in terms of Flexibility Index (FI), to asphalt binder content for the M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders. For all three binder grades, FI increased with increasing asphalt binder content, confirming that higher binder contents improve mixture flexibility and resistance to crack propagation.

The PG 64-22 mixtures exhibited a strong positive relationship between binder content and FI, with values increasing from approximately 7 at 5.4% binder content to more than 22 at 6.6%. The PG 70-22 mixtures showed a more gradual increase, with FI values remaining comparatively lower over the same binder content range. In contrast, the PG 76-22 mixtures demonstrated the highest sensitivity to binder content, with FI increasing rapidly from approximately 3 at 5.4% binder content to more than 18 at 6.3%.

The high coefficients of determination (R^2) values ranging from 0.86 to 0.99 indicate a strong linear relationship between binder content and cracking resistance for all three binder grades. Overall, the results demonstrate that increasing asphalt binder content significantly enhances cracking resistance, although the rate of improvement depends on binder grade. The PG 64-22 and PG 76-22 mixtures exhibited the most pronounced gains in FI, whereas the PG 70-22 mixtures showed a more moderate response. These findings highlight the beneficial effect of increased effective binder content on cracking performance and underscore the importance of balancing this improvement against the accompanying reduction in rutting resistance when determining the balanced asphalt content.

3.4.5 Ideal Rutting Test (IDEAL-RT)

The Indirect Tensile Asphalt Rutting Test (IDEAL-RT) was used in this study to evaluate the rutting resistance of asphalt mixtures using a simple and practical monotonic loading test. Conducted on standard 150-mm diameter gyratory-compacted specimens, IDEAL-RT provides the RT_{Index}, a parameter that reflects the mixture's resistance to permanent deformation under compressive loading. Higher RT_{Index} values indicate greater resistance to rutting.

IDEAL-RT testing was performed on the M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders at five asphalt binder contents ranging from 5.4% to 6.6%. The objective was to quantify the influence of binder content and binder grade on rutting performance and to evaluate the applicability of IDEAL-RT as a surrogate rutting test within the proposed Balanced Mix Design framework. The IDEAL-RT results for the M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders at different asphalt binder contents are presented in Figures 3.13 through 3.15. Summary statistics, including average RT_{Index}, coefficient of variation (COV), average shear strength, and average peak load, are provided in Tables 3.9 through 3.11.

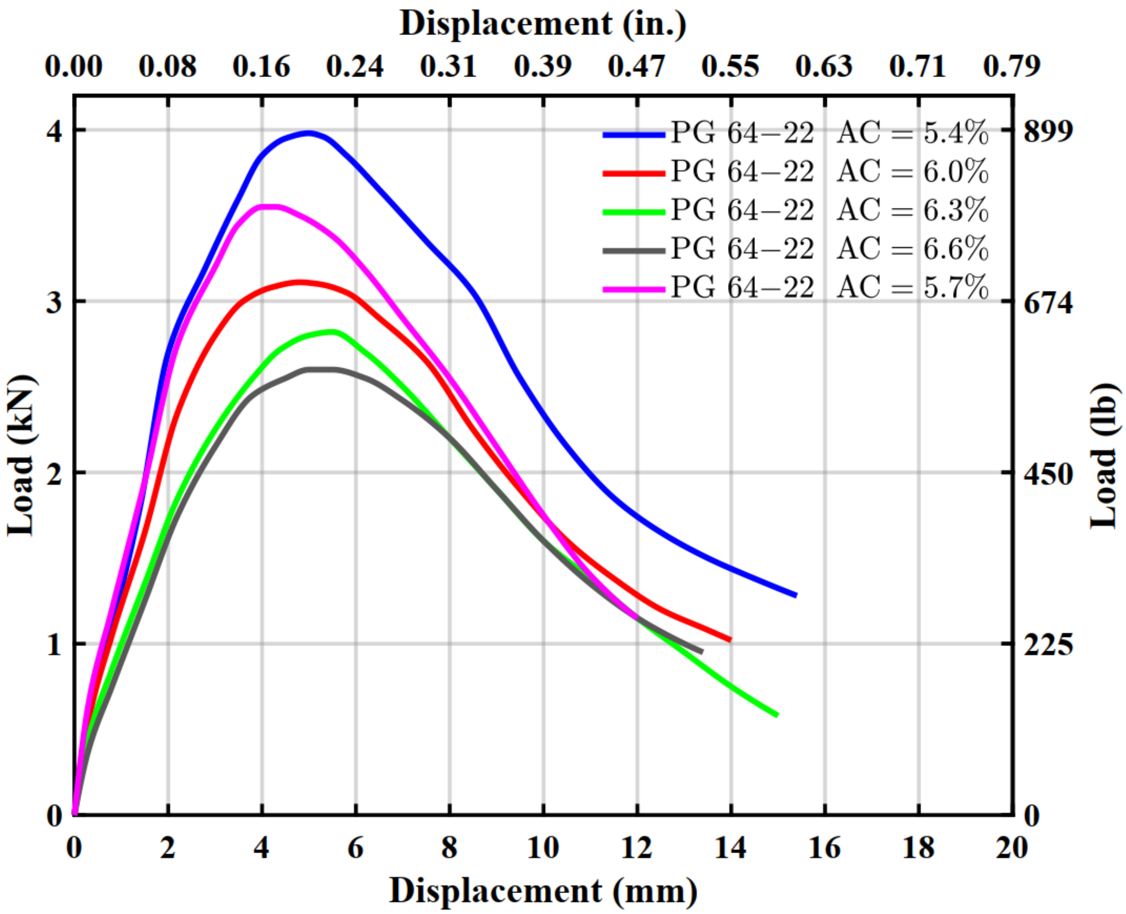

FIGURE 3.13 RT_{Index} of M12 Virgin Mix (PG 64-22 Mixes)

TABLE 3.9 Summary of IDEAL-RT M12 Virgin Mix (PG 64-22)

AC (%)	Avg RT_{Index}	COV (%)	Avg Shear Strength (MPa)	Avg Peak Load (N)
5.4	81.9	2.5	1.24	4105
5.7	78.4	16.4	1.17	3769
6.0	66.9	6.4	1.01	3354
6.3	62.7	6.6	0.95	3141
6.6	52.6	13.2	0.79	2636

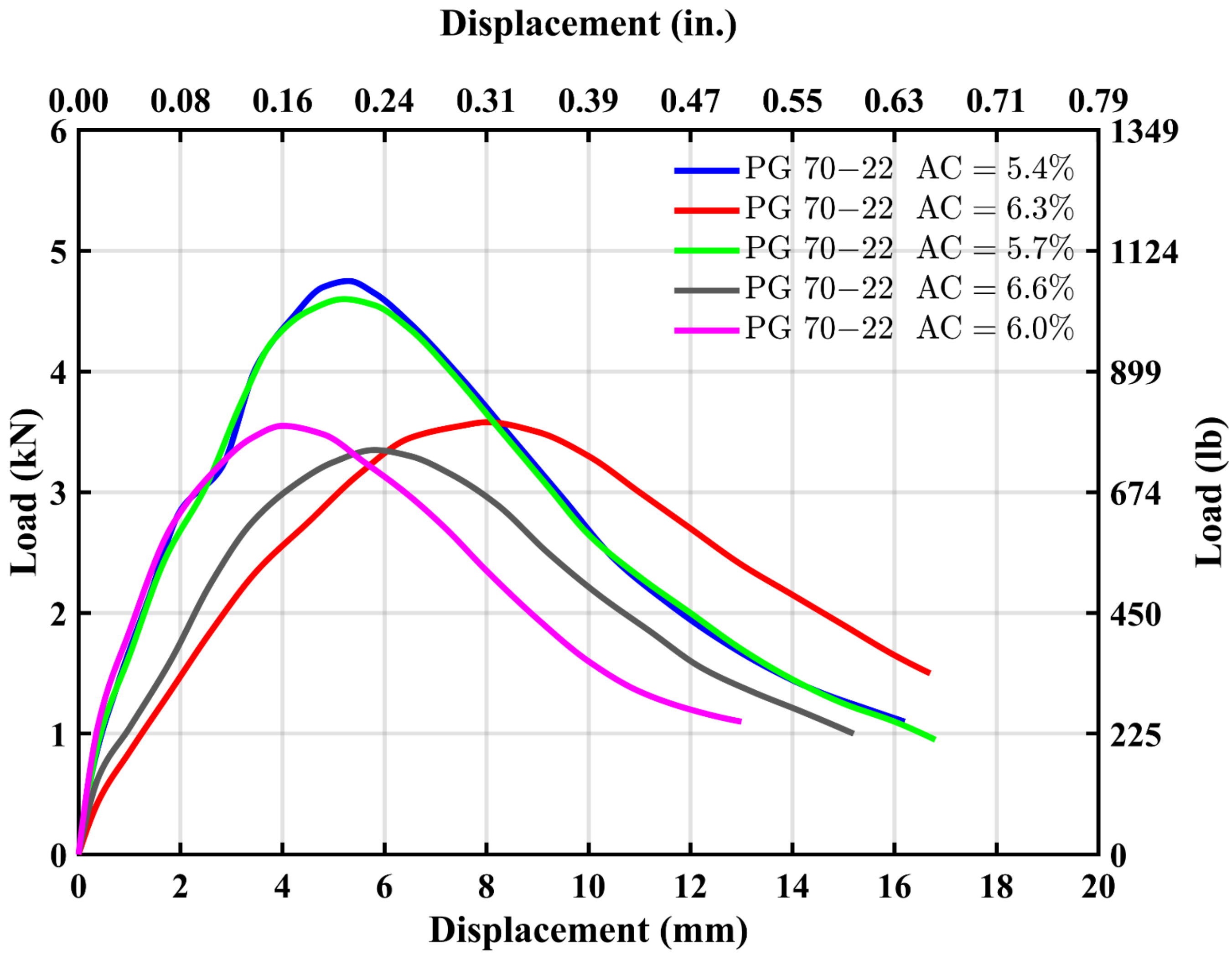

FIGURE 3.14 RT$_{Index}$ of M12 Virgin Mix (PG 70-22 Mixes)

TABLE 3.10 Summary of IDEAL-RT M12 Virgin Mix (PG 70-22)

AC (%)	Avg RT$_{Index}$	COV (%)	Avg Shear Strength (MPa)	Avg Peak Load (N)
5.4	110.2	12.5	1.66	5523
5.7	101.0	9.6	1.53	5062
6.0	66.2	11.2	1.00	3317
6.3	77.0	11.3	1.16	3859
6.6	64.4	4.7	0.96	3227

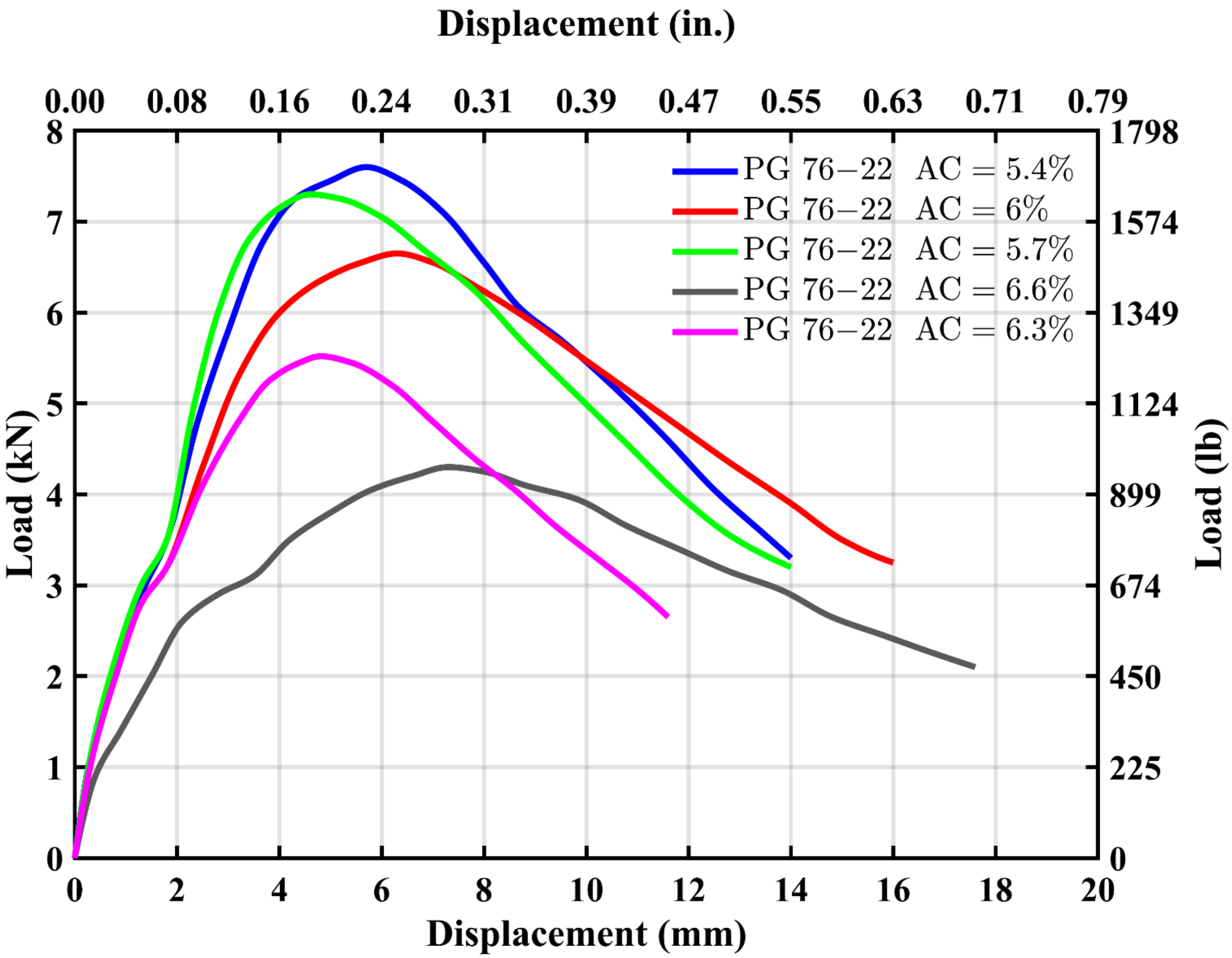

FIGURE 3.15 RT_{Index} of M12 Virgin Mix (PG 76-22 Mixes)

TABLE 3.11 Summary of IDEAL-RT M12 Virgin Mix (PG 76-22)

AC (%)	Avg RT_{Index}	COV (%)	Avg Shear Strength (MPa)	Avg Peak Load (N)
5.4	160	9.2	2.30	7615
5.7	153	7.6	2.00	6653
6.0	145	9.0	2.61	8649
6.3	127	14.5	2.17	7208
6.6	96	6.3	1.42	4714

The IDEAL-RT results demonstrated that rutting resistance generally decreased with increasing asphalt binder content for all three binder grades, as reflected by the reduction in RT_{Index} values. For the PG 64-22 mixtures, the average RT_{Index} decreased from 81.9 at 5.4% binder content to 52.6 at 6.6%, indicating a progressive loss in resistance to permanent deformation as the mixture became richer in binder. A similar trend was observed for the PG 70-22 mixtures, where the RT_{Index}

decreased from 110.2 to 64.4 over the same binder content range, although a slight increase was observed at 6.3% binder content. The PG 76-22 mixtures exhibited the highest RT_{Index} values at all binder contents, decreasing from 160 at 5.4% to 96 at 6.6%, and consistently demonstrated superior rutting resistance compared with the PG 64-22 and PG 70-22 mixtures. In general, the reduction in RT_{Index} was accompanied by decreases in shear strength and peak load, confirming the expected reduction in rutting resistance with increasing binder content. Overall, the results indicate that rutting susceptibility increased with asphalt binder content, while higher-performance binders provided substantially greater resistance to permanent deformation and allowed the use of higher asphalt contents without compromising rutting performance.

3.4.6 Ideal-RT binder sensitivity

Figure 3.16 illustrates the effect of asphalt binder content on IDEAL-RT rutting performance for the M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders. For all binder grades, RTindex decreased with increasing binder content, indicating a reduction in rutting resistance as the mixtures became richer in asphalt binder. The PG 64-22 mixtures exhibited the lowest RTindex values, followed by PG 70-22, while the PG 76-22 mixtures consistently produced the highest RTindex values across the full range of binder contents. The fitted trend lines showed strong linear relationships (R^2 =0.90 to 0.94), confirming that IDEAL-RT is sensitive to both binder content and binder grade. Overall, the results demonstrate that rutting susceptibility increased with asphalt binder content, whereas the use of stiffer binders significantly improved resistance to permanent deformation.

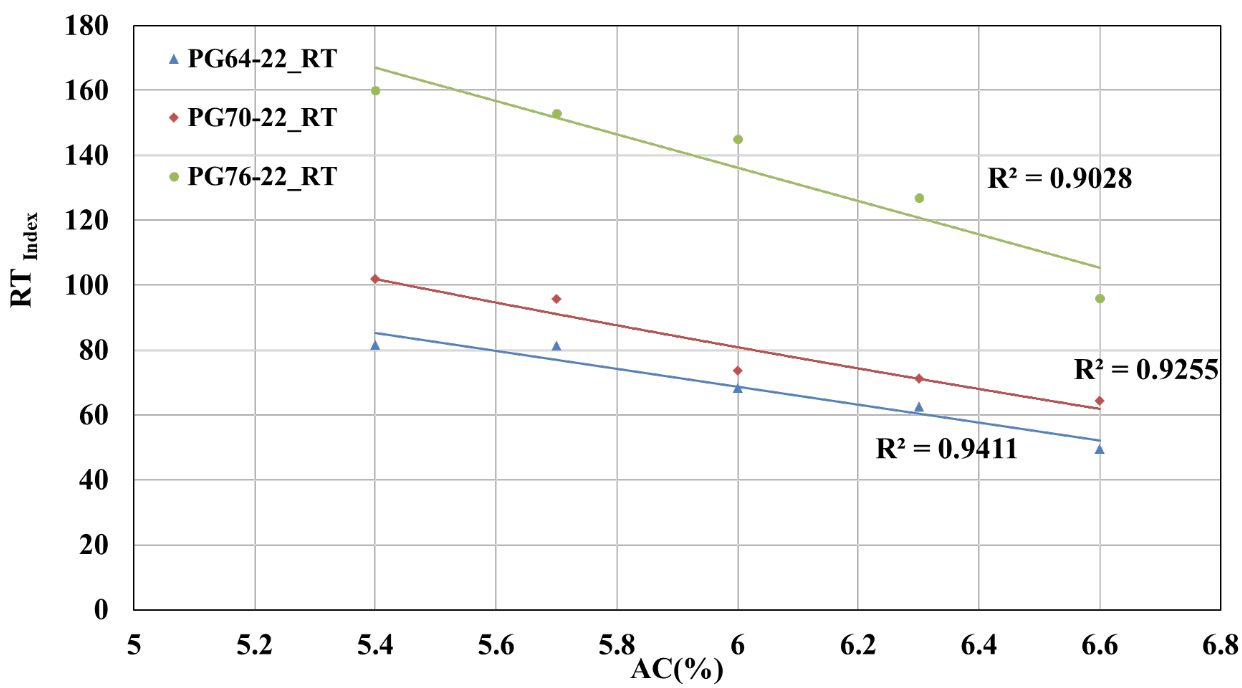

FIGURE 3.16 Ideal-RT binder sensitivity

3.4.7 The Indirect Tensile Asphalt Cracking Test (IDEAL-CT)

The Indirect Tensile Asphalt Cracking Test (IDEAL-CT) was used in this study to evaluate the cracking resistance of asphalt mixtures under monotonic loading at intermediate temperature. The test is performed on standard 150-mm diameter gyratory-compacted specimens and provides the CT_{Index}, a parameter that characterizes the mixture's resistance to crack propagation after peak load. Higher CT_{Index} values indicate greater cracking tolerance and improved resistance to fatigue and reflective cracking.

IDEAL-CT testing was conducted on the M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders at five asphalt binder contents ranging from 5.4% to 6.6%. The objective was to quantify the influence of asphalt binder content and binder grade on cracking performance and to assess the applicability of IDEAL-CT as a practical cracking test within the proposed Balanced Mix Design framework.

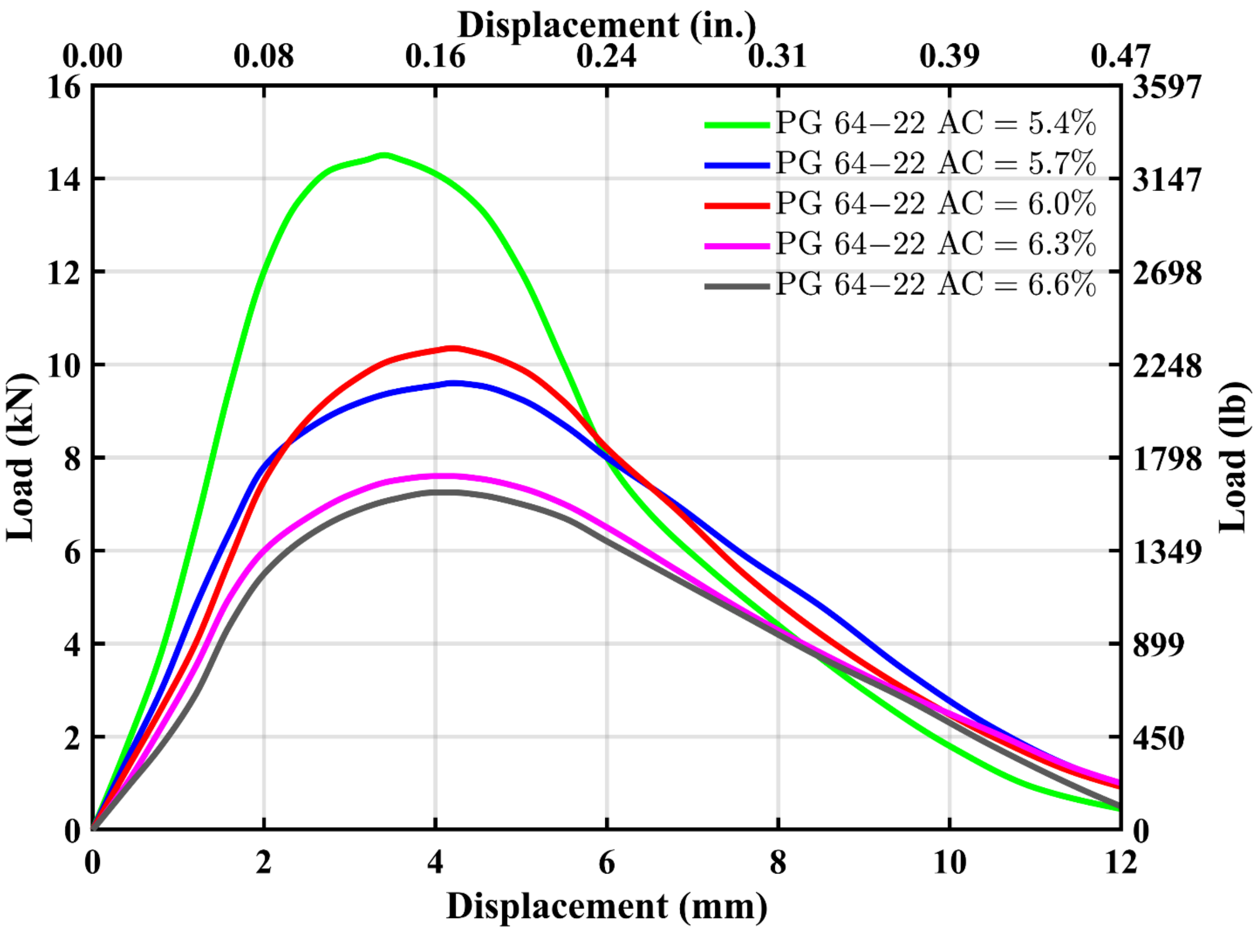

FIGURE 3.17 CT_{Index} of M12 Virgin Mix (PG 64-22 Mixes)

TABLE 3.12 Summary of IDEAL-CT Results for M12 Virgin Mix (PG 64-22)

AC (%)	Avg CT_{Index}	COV (%)	Avg Post-Peak Slope (N/m)	Avg Failure Energy (J/m²)	Avg IDT Strength (kPa)
5.4	123.8	6.6	2.76×10^6	9,370.3	965.7
5.7	176.0	8.9	1.99×10^6	8,599.6	804.1
6.0	267.5	7.6	1.48×10^6	8,576.7	719.4
6.3	257.4	19.5	9.63×10^5	5,301.1	460.9
6.6	295.8	10.9	1.06×10^6	6,529.7	536.8

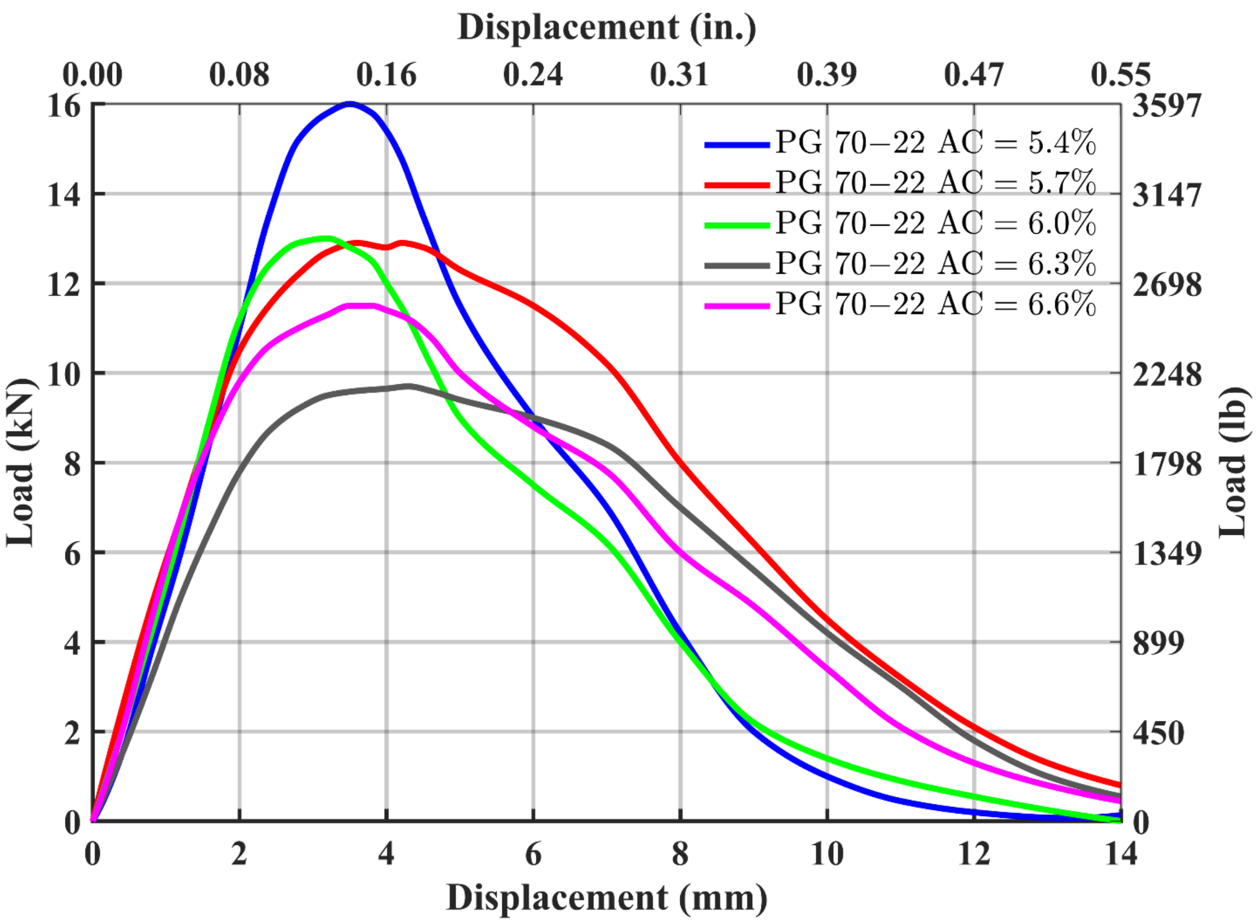

FIGURE 89 CT_{Index} of M12 Virgin Mix (PG 70-22 Mixes)

TABLE 3.13 Summary of IDEAL-CT Results for M12 Virgin Mix (PG 70-22)

AC (%)	Avg CT_{Index}	COV (%)	Avg Post-Peak Slope (N/m)	Avg Failure Energy (J/m²)	Avg IDT Strength (kPa)
5.4	72.3	22.6	4.68×10^6	9,707.6	1,184.8
5.7	153.1	11.3	2.32×10^6	8,836.0	873.0
6.0	209.0	7.2	1.86×10^6	9,142.3	828.4
6.3	135.7	26.8	3.08×10^6	10,314.4	1,007.6
6.6	340.5	5.9	1.25×10^6	8,370.9	639.7

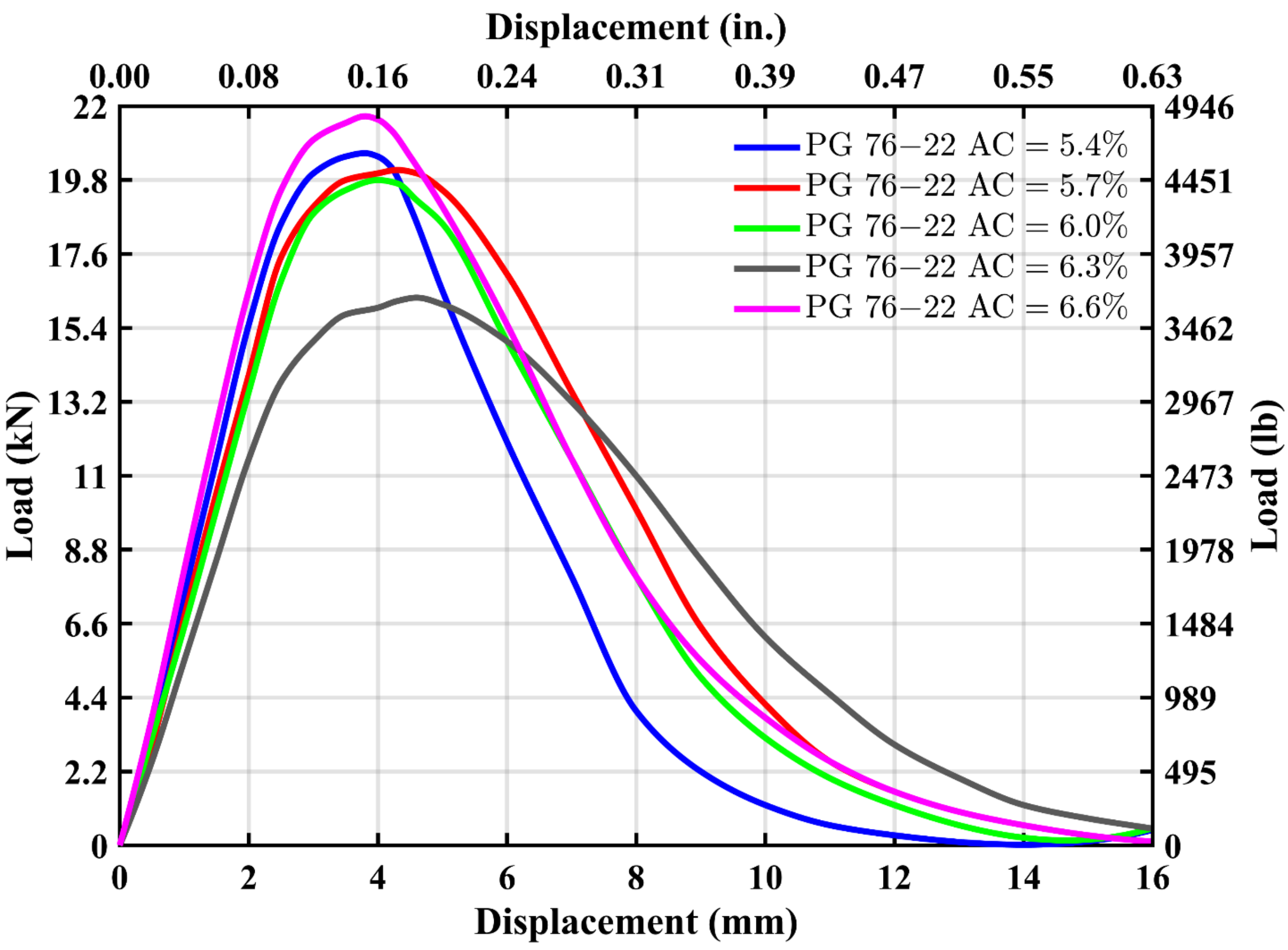

FIGURE 3.19 CT_{Index} of M12 Virgin Mix (PG 76-22 Mixes)

TABLE 3.14 Summary of IDEAL-CT Results for M12 Virgin Mix (PG 76-22)

AC (%)	Avg CT_{Index}	COV (%)	Avg Post-Peak Slope (N/m)	Avg Failure Energy (J/m²)	Avg IDT Strength (kPa)
5.4	79.1	7.4	4.93×10^6	10,834.9	1,287.6
5.7	116.6	24.2	4.48×10^6	12,692.9	1,329.1
6.0	82.0	14.9	5.83×10^6	12,310.9	1,423.8
6.3	84.8	2.1	5.52×10^6	12,046.3	1,381.6
6.6	337.8	19.9	2.35×10^6	14,314.6	1,099.5

The IDEAL-CT results indicate that cracking resistance generally improved with increasing asphalt binder content for all three binder grades, as reflected by the increase in CT_{Index} values. For the PG 64-22 mixtures, the average CT_{Index} increased from 123.8 at 5.4% binder content to 295.8 at 6.6%, with a substantial increase observed up to 6.0% binder content and consistently high values thereafter. The PG 70-22 mixtures showed a similar overall trend, increasing from 72.3 at 5.4% to 340.5 at 6.6%, although a temporary reduction was observed at 6.3% binder content. The PG 76-22 mixtures exhibited lower CT_{Index} values at intermediate binder contents but showed a pronounced increase at 6.6%, where the CT_{Index} reached 337.8. In general, higher CT_{Index} values were associated with lower post-peak slopes, indicating improved resistance to crack propagation. Overall, the results confirm that increasing asphalt binder content significantly enhances cracking resistance, although the magnitude and consistency of improvement depend on binder grade. At the highest binder contents, the PG 70-22 and PG 76-22 mixtures exhibited the highest CT_{Index} values, demonstrating excellent cracking tolerance.

3.4.8 Ideal-CT binder sensitivity

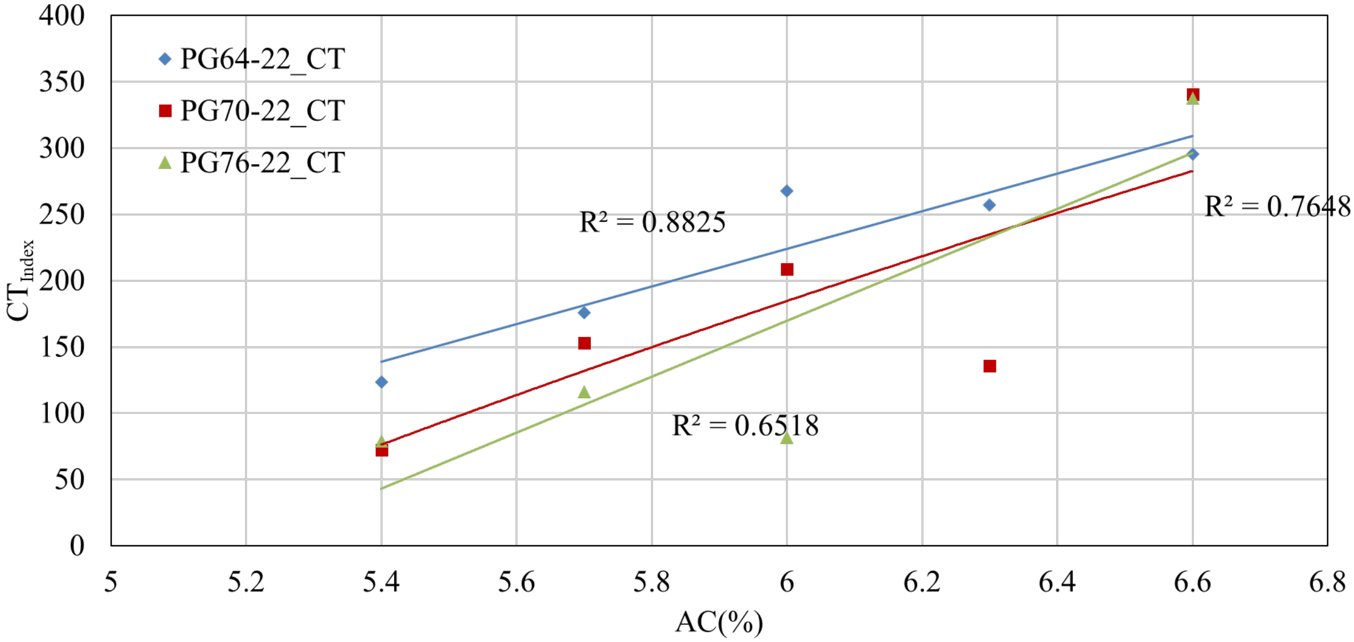

FIGURE 3.20 IDEAL-CT Binder Sensitivity

Figure 3.20 illustrates the influence of binder grade on IDEAL-CT cracking performance as a function of asphalt binder content for the M12 virgin mixtures. At lower asphalt contents (5.4–5.7%), the PG 64-22 mixtures exhibited higher CT_{Index} values than the PG 70-22 and PG 76-22 mixtures, indicating greater cracking resistance in the leaner mixtures. However, as asphalt binder content increased, the effect of binder grade became more pronounced. The PG 70-22 and PG 76-22 mixtures exhibited steeper increases in CT_{Index}. These results indicate that although all binder grades benefited from increased asphalt content, the modified binders demonstrated a greater improvement in cracking resistance and provided superior performance at higher binder contents.

3.5 BALANCED ASPHALT CONTENT DETERMINATION USING THE HWTT–IFIT APPROACH

The first method developed in this study for determining the balanced asphalt content combines the Hamburg Wheel Tracking Test (HWTT) and the Illinois Flexibility Index Test (I-FIT). To directly compare rutting and cracking performance, the measured test results were converted into normalized relative performance indices referenced to selected threshold values.

The relative rutting performance index based on HWTT was defined as:

$$RI_{HWTT}:\ 100 \times \left(\frac{RT_{thresold}(12.5mm)}{Rut(mm)}\right) \ldots\ldots.(10)$$

where:

RI_{HWTT}= HWTT rutting performance index

$RT_{\text{threshold}}$= Commonly accepted rut depth criterion (12.5 mm),

Rut= measured HWTT rut depth (mm)

Because lower rut depths indicate better rutting resistance, the threshold value is divided by the measured rut depth so that higher index values correspond to better performance.

The relative cracking performance index based on I-FIT was defined as:

$$CI_{FI}:\ 100 \times \left(\frac{FI}{FI_{thresold}(8)}\right) \ldots\ldots\ldots\ldots\ldots.\ (11)$$

where:

CI_{FI}= I-FIT cracking performance index

FI= measured Flexibility Index

$FI_{\text{threshold}}$= commonly accepted FI criterion (8.0)

Because higher FI values indicate improved cracking resistance, the measured FI is divided by the threshold value.

The balanced asphalt content is defined as the binder content at which the two indices are equal:

$$\text{Balanced AC (\%)}:\quad RI_{HWTT} = CI_{FI} \ldots\ldots.(12)$$

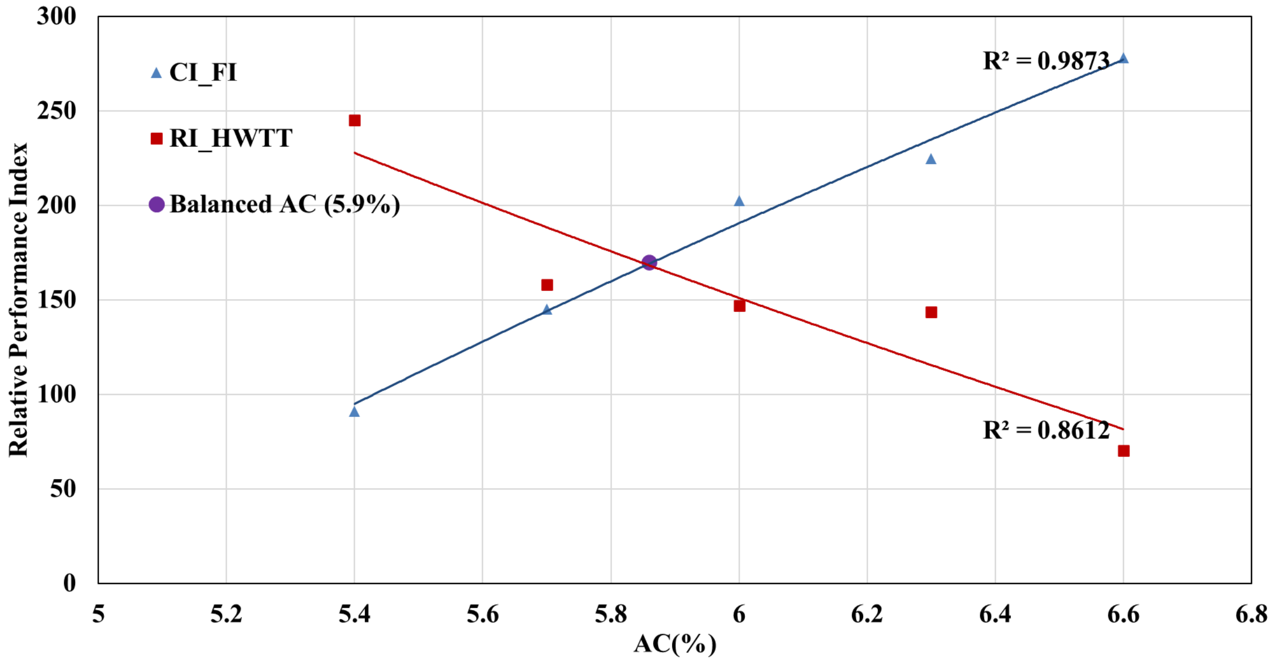

FIGURE 3.21 Balanced AC (%) for PG6422 Mix (HWTT-IFIT Approach)

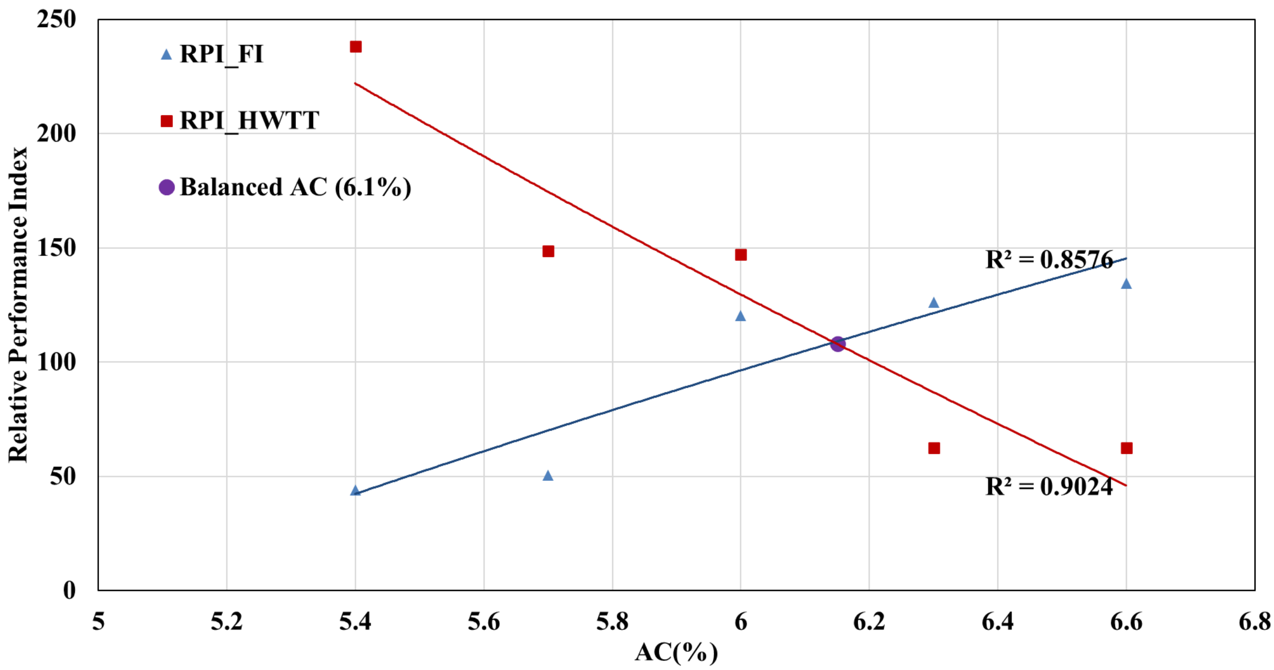

FIGURE 3.22 Balanced AC (%) for PG7022 Mix (HWTT-IFIT Approach)

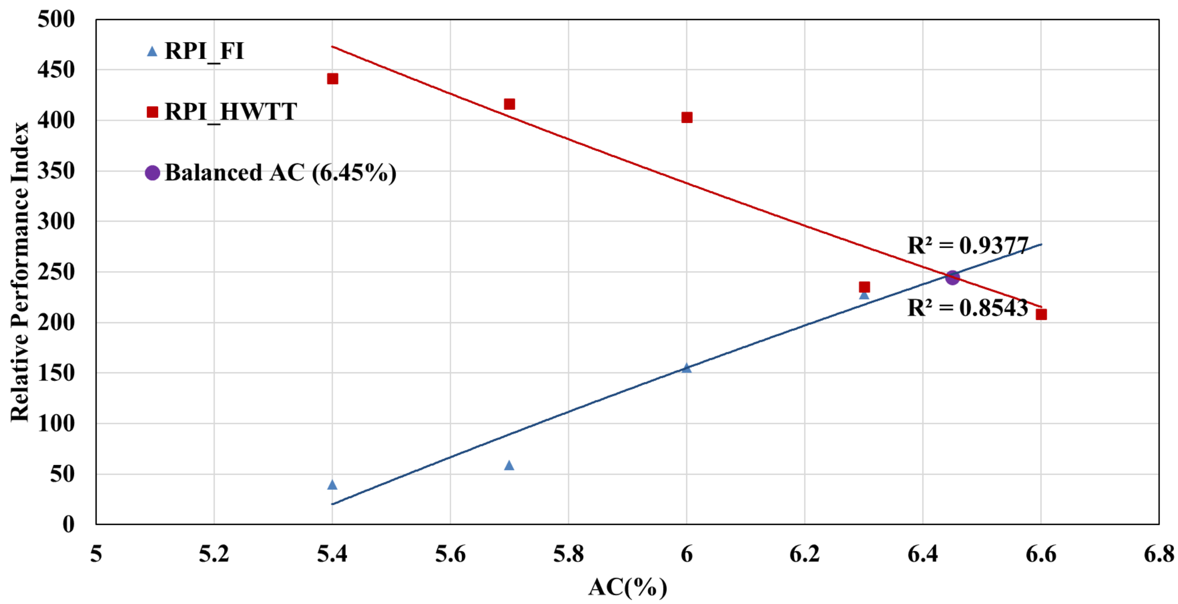

FIGURE 90 Balanced AC (%) for PG7622 Mix (HWTT-IFIT Approach)

Figures 3.21 through 3.23 present the determination of balanced asphalt content using the HWTT–I-FIT performance index approach for the M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders. In each case, the relative rutting performance index (RI_{HWTT}) decreased with increasing asphalt binder content, while the relative cracking performance index (CI_{FI}) increased. The balanced asphalt content was identified as the intersection of these two index curves.

For the PG 64-22 mixture, the balanced asphalt content was determined to be approximately 5.9%. The PG 70-22 mixture yielded a balanced asphalt content of approximately 6.1%, while the PG 76-22 mixture produced the highest balanced asphalt content at approximately 6.45%. The coefficients of determination for the fitted trend lines were generally high, indicating that the proposed performance indices provided a consistent and reliable representation of the rutting–cracking relationship.

The results demonstrate a clear increase in balanced asphalt content with increasing binder grade. Relative to PG 64-22, the use of PG 70-22 increased the balanced asphalt content by approximately 0.2%, while PG 76-22 increased the balanced asphalt content by approximately 0.55%. This trend reflects the improved rutting resistance provided by stiffer and polymer-modified binders, which allows higher asphalt binder contents to be used while still satisfying the selected rutting criterion.

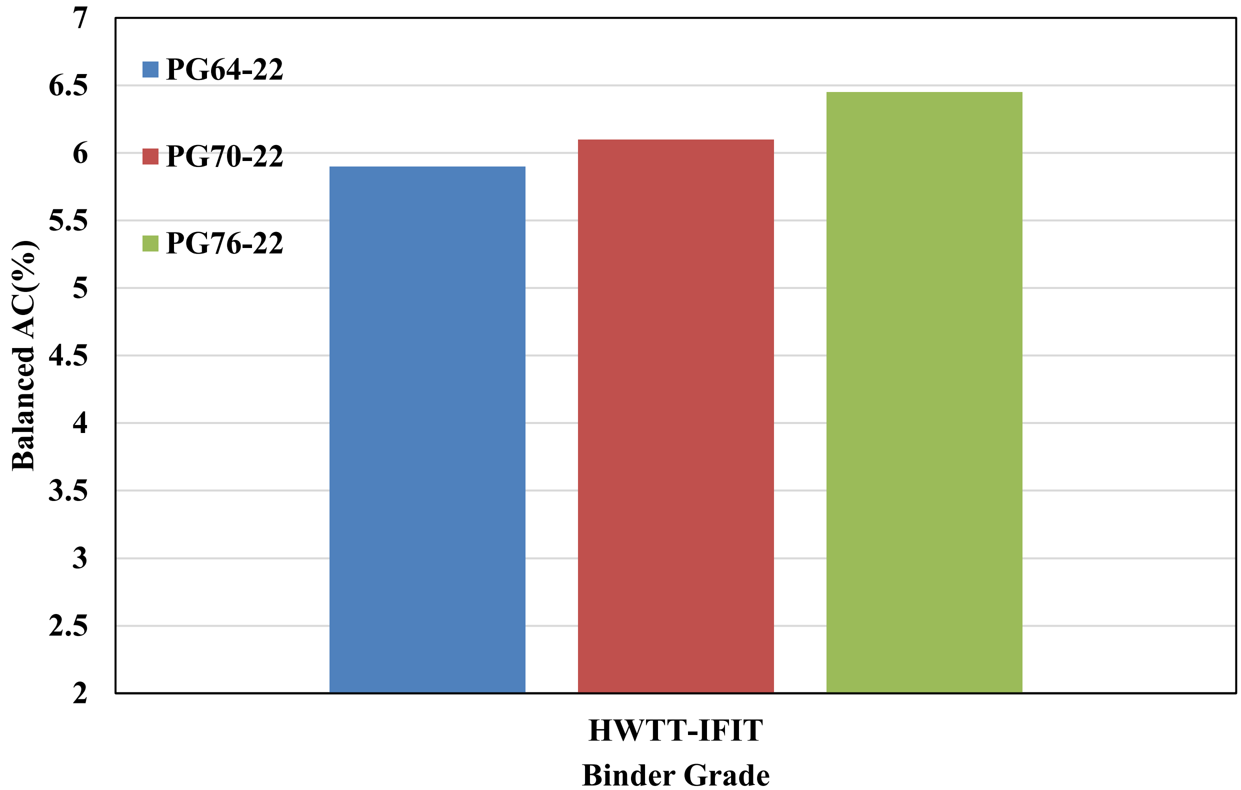

FIGURE 91 Summary Balanced AC (%) (HWTT-IFIT Approach)

The summary shown in Figure 3.24 confirms that higher-performance binders permit richer mixtures that offer improved cracking resistance without compromising rutting performance. These findings highlight the strong influence of binder grade on the balanced asphalt content and demonstrate the effectiveness of the HWTT–I-FIT performance index approach as a practical method for selecting performance-based optimum asphalt binder contents.

3.6 BALANCED ASPHALT CONTENT DETERMINATION USING THE IDEAL-RT–IDEAL-CT APPROACH

The second method developed in this study for determining balanced asphalt content combines the Indirect Tensile Asphalt Rutting Test (IDEAL-RT) and the Indirect Tensile Asphalt Cracking Test (IDEAL-CT). This approach provides a practical framework for evaluating rutting and cracking resistance using monotonic indirect tensile tests conducted on gyratory-compacted specimens.

To compare rutting and cracking performance on a common scale, the IDEAL-RT and IDEAL-CT results were converted into relative performance indices. The cracking index based on IDEAL-CT was defined as:

$$CI_{CT} = \frac{CT_{Index}}{CT_{thresold}(100)} \ldots\ldots\ldots (13)$$

where $CI_{CT} =$ the cracking performance index,

CT_{Index} =the measured IDEAL-CT index,
$CT_{threshold}$ =the commonly accepted cracking threshold (100).

The rutting index based on IDEAL-RT was defined as:

$$RI_{RT} = 100\left(\frac{RT_{Index}}{RT_{threshold}\,(85)}\right) \ldots\ldots\ldots (14)$$

Where,
RI_{RT} = the rutting performance index,
RT_{Index} = the measured IDEAL-RT index,
$RT_{threshold}$ = the selected rutting threshold of 85.

Both indices are expressed on a common scale, where a value of 100 represents the minimum acceptable performance threshold. Values greater than 100 indicate performance exceeding the threshold, whereas values less than 100 indicate that the mixture does not satisfy the selected criterion.

The balanced asphalt content is determined as the binder content at which:

$$CI_{CT} = RI_{RT} \ldots\ldots\ldots\ldots (15)$$

Graphically, this point corresponds to the intersection of the IDEAL-CT cracking index curve and the IDEAL-RT rutting index curve plotted as a function of asphalt binder content. At this intersection, the mixture provides an equivalent relative level of rutting and cracking resistance and is considered balanced according to the IDEAL-RT–IDEAL-CT approach.

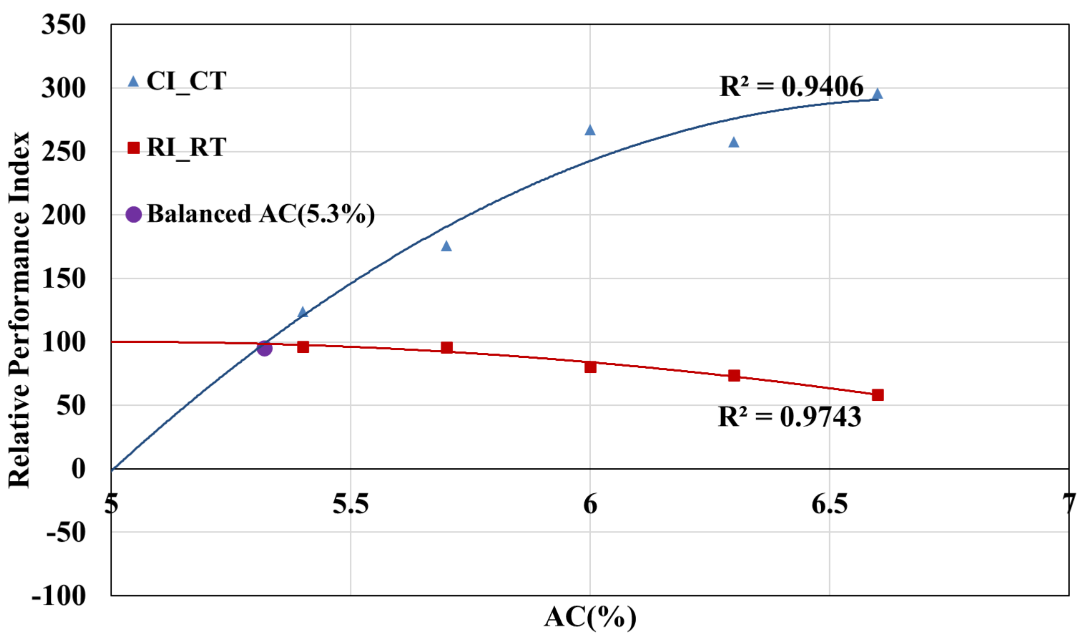

FIGURE 3.25 Balanced AC (%) for PG 64-22 Mix (IDEAL-CT-IDEAL-RT Approach)

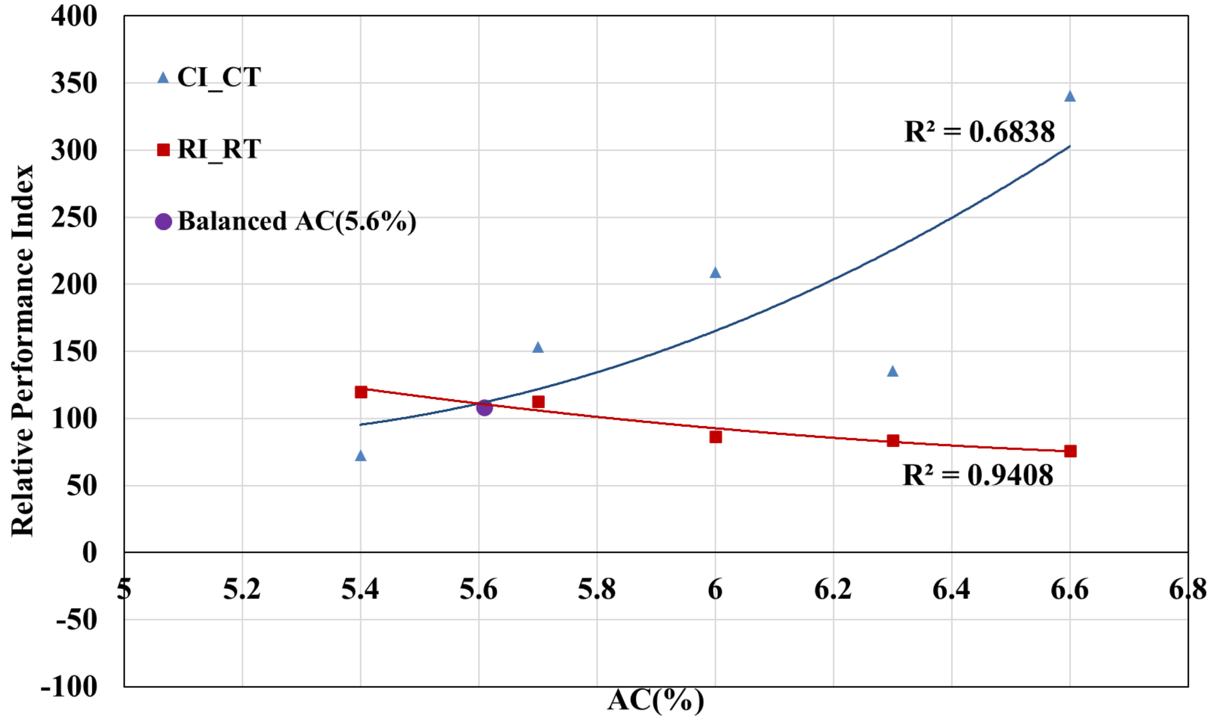

FIGURE 3.26 Balanced AC (%) for PG 70-22 Mix (IDEAL-CT-IDEAL-RT Approach)

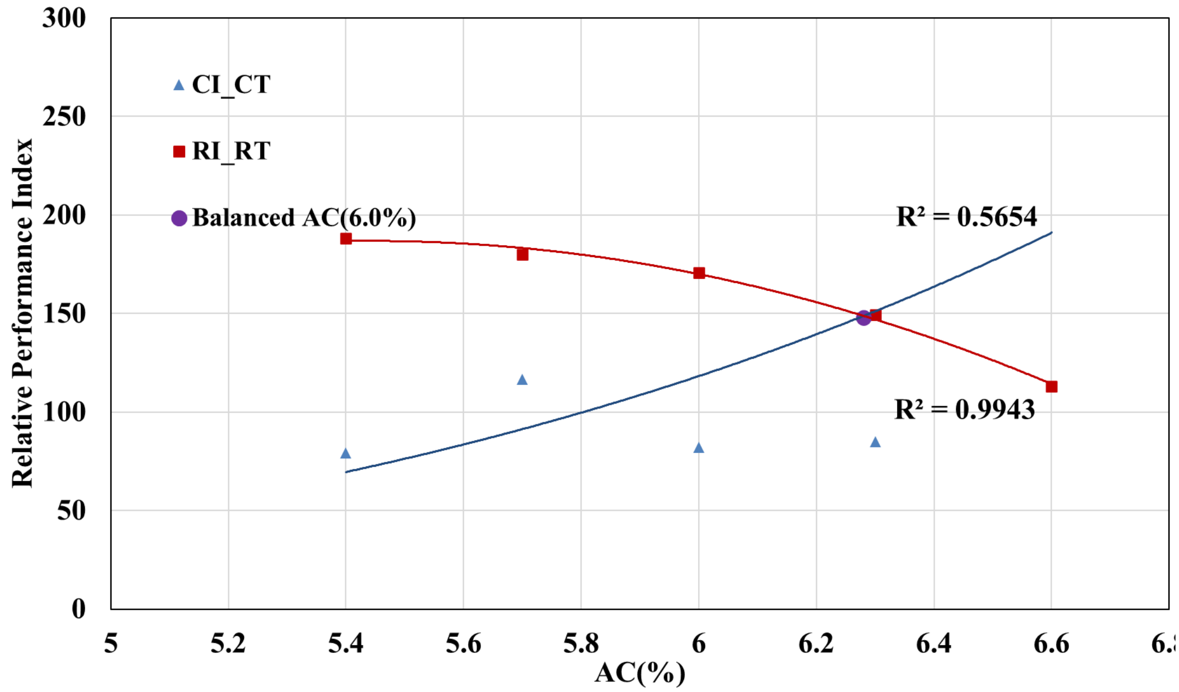

FIGURE 92 Balanced AC (%) for PG 76-22 Mix (IDEAL-CT-IDEAL-RT Approach)

Figures 3.25 through 3.27 present the determination of balanced asphalt content using the IDEAL-RT–IDEAL-CT performance index approach for the M12 virgin mixtures prepared with PG 64-22, PG 70-22, and PG 76-22 binders. In this approach, the relative rutting performance index (RI_{RT}) decreased with increasing asphalt binder content, whereas the relative cracking performance index (CI_{CT}) increased. The balanced asphalt content was identified as the asphalt binder content corresponding to the intersection of these two performance index curves.

Using this method, the balanced asphalt content was determined to be approximately 5.3% for the PG 64-22 mixture, 5.6% for the PG 70-22 mixture, and 6.0% for the PG 76-22 mixture, as summarized in Figure 3.28. The results indicate a clear increase in balanced asphalt content with increasing binder grade. This trend reflects the improved rutting resistance provided by stiffer and polymer-modified binders, which permits the use of higher asphalt contents while maintaining acceptable cracking performance.

The increase in balanced asphalt content from PG 64-22 to PG 76-22 was approximately 0.7%, demonstrating the significant influence of binder modification on the rutting–cracking relationship. Overall, the IDEAL-RT–IDEAL-CT approach provided a consistent and practical method for selecting performance-based optimum asphalt binder content using two relatively simple and efficient laboratory tests.

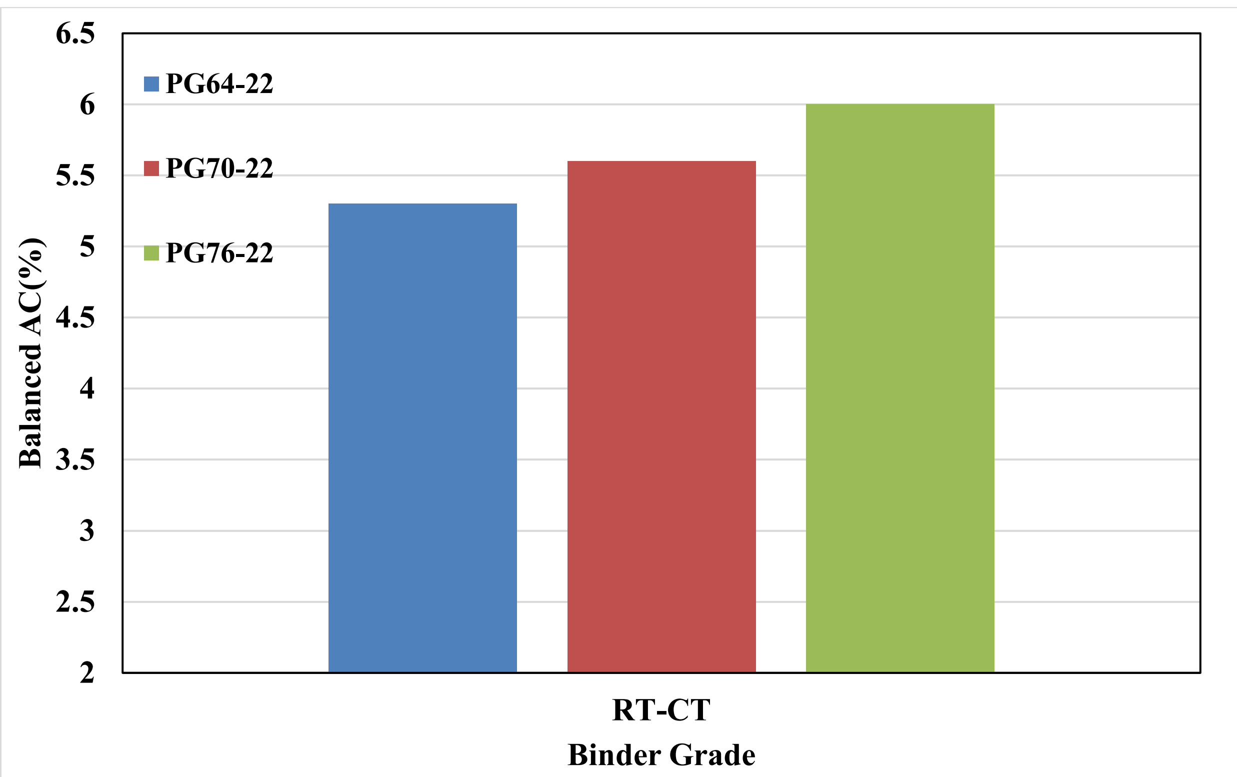

FIGURE 3.28 Summary Balanced AC (%) (IDEAL-CT-IDEAL-RT) Approach)

The summary shown in Figure 3.28 indicates that the IDEAL-RT–IDEAL-CT approach produced the same overall trend observed with the HWTT–I-FIT method, with balanced asphalt content increasing systematically from PG 64-22 to PG 76-22. This consistency suggests that the IDEAL tests capture the fundamental rutting–cracking relationship in a manner comparable to the more established performance tests. Because IDEAL-RT and IDEAL-CT are simpler and less time-consuming to conduct, these results demonstrate their potential as practical surrogate tests for Balanced Mix Design implementation. These findings further highlight the strong influence of binder grade on balanced asphalt content and support the use of the IDEAL-RT–IDEAL-CT approach as an efficient performance-based method for selecting optimum asphalt binder content.

3.7 BALANCED ASPHALT CONTENT DETERMINATION USING THE COMBINED PERFORMANCE APPROACH

The third method proposed in this study is the combined performance approach, which integrates the results from both rutting tests and both cracking tests into a single framework. This approach was proposed to provide a more comprehensive assessment of mixture performance by considering HWTT, IDEAL-RT, I-FIT, and IDEAL-CT simultaneously.

The combined rutting index was defined as:

$$CRI_{rutting} = \frac{RI_{HWTT} + RI_{RT}}{2} \quad \ldots\ldots\ldots\ldots (16)$$

where $CRI_{rutting}$ is the combined rutting performance index, RI_{HWTT} is the rutting index obtained from the Hamburg Wheel Tracking Test, and RI_{RT} is the rutting index obtained from IDEAL-RT.

Similarly, the combined cracking index was defined as:

$$CCI_{cracking} = \frac{CI_{FI} + CI_{CT}}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

where $CCI_{cracking}$ is the combined cracking performance index, CI_{FI} is the cracking index obtained from I-FIT, and CI_{CT} is the cracking index obtained from IDEAL-CT.

Both combined indices are expressed on the same normalized scale, where a value of 100 represents the minimum acceptable performance threshold. Values greater than 100 indicate performance exceeding the selected criteria, while values below 100 indicate inadequate performance.

The balanced asphalt content is determined as the binder content at which:

$$CRI_{rutting} = CCI_{cracking} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

Graphically, this point corresponds to the intersection of the combined rutting and combined cracking index curves plotted as a function of asphalt binder content. This approach provides a broader evaluation of the rutting–cracking trade-off because it incorporates multiple performance indicators rather than relying on a single rutting and cracking test pair. Therefore, the combined performance approach can be used as a more comprehensive method for selecting balanced asphalt content.

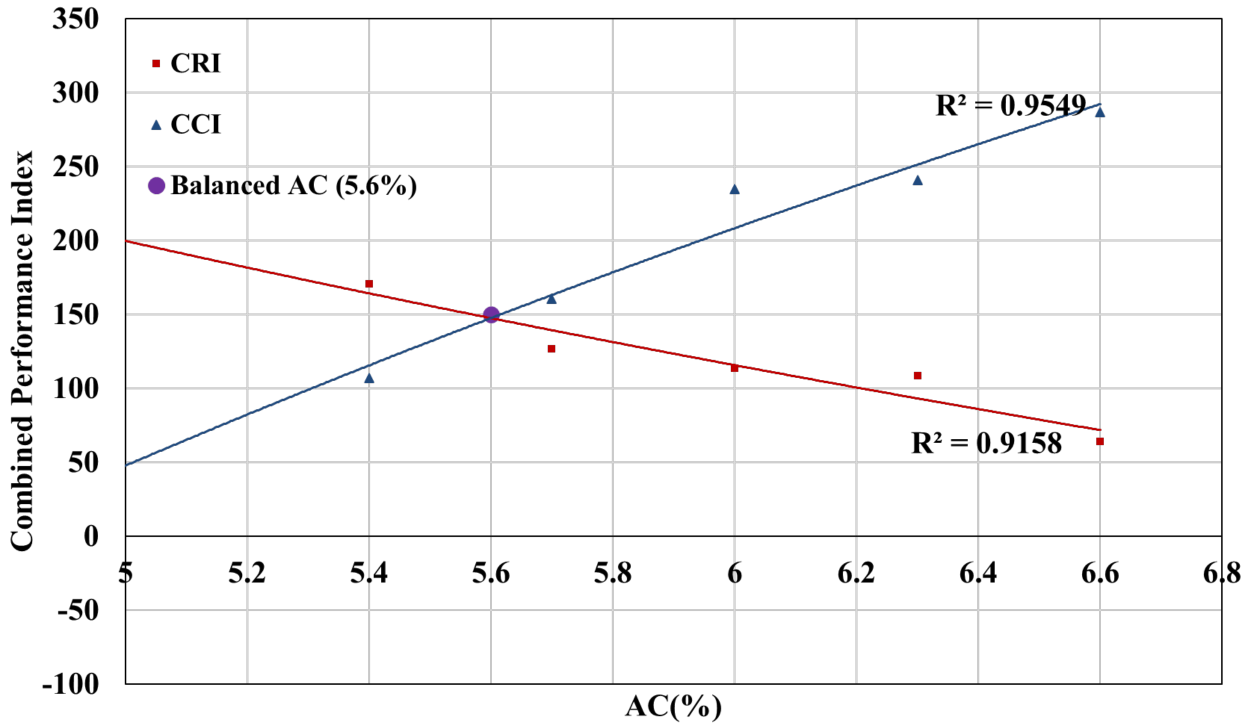

FIGURE 93 Balanced AC (%) for PG 64-22 Mix (Combined Approach)

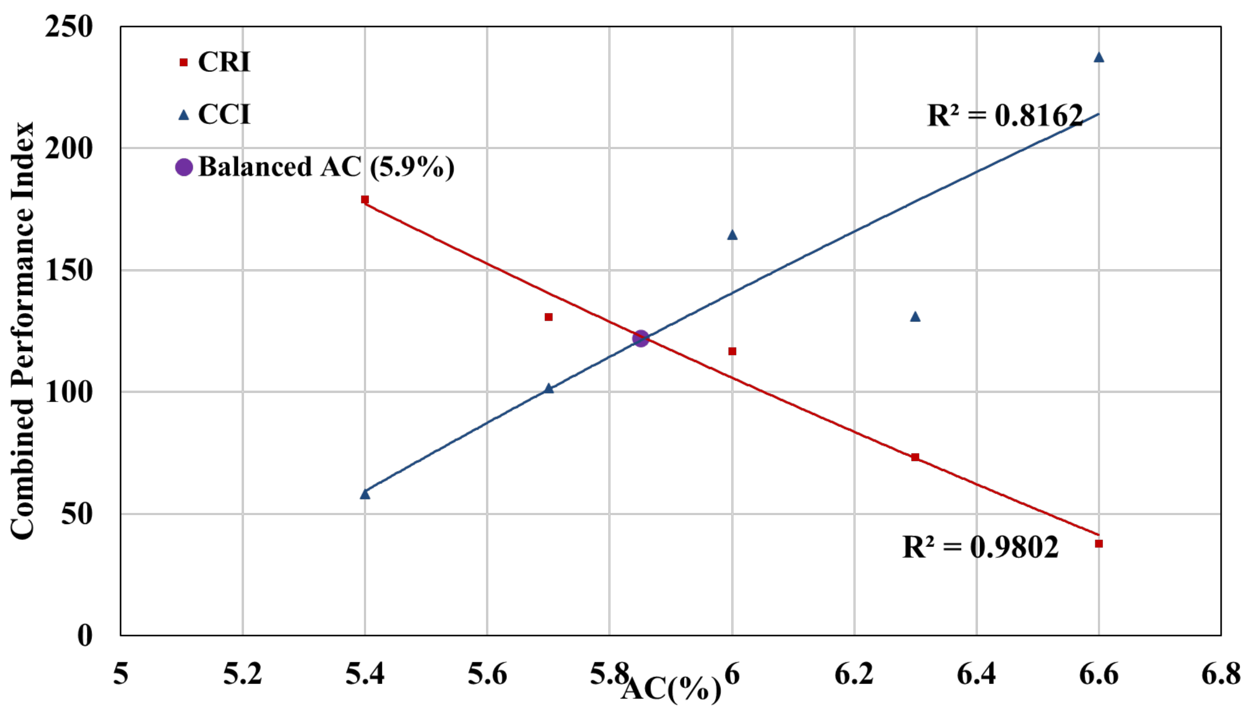

FIGURE 94 Balanced AC (%) for PG 70-22 Mix (Combined Approach)

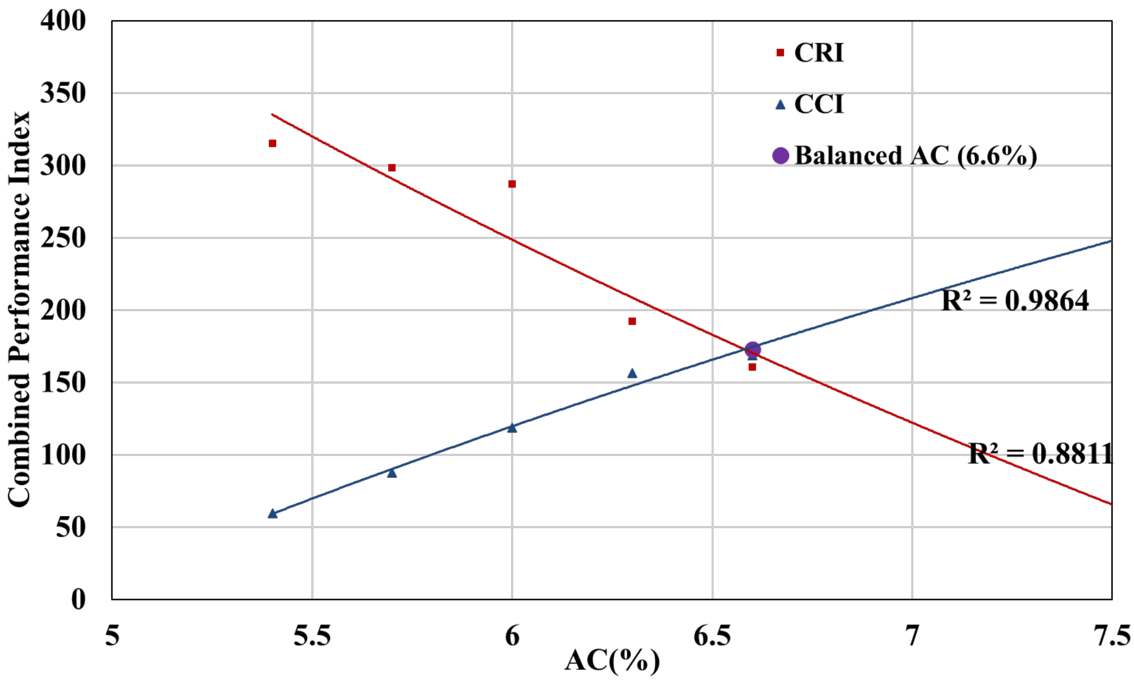

FIGURE 95 Balanced AC (%) for PG 76-22 Mix (Combined Approach)

Figures 3.29 through 3.31 present the determination of balanced asphalt content using the combined performance approach, in which the combined rutting index (CRI) and combined cracking index (CCI) were calculated by averaging the normalized rutting and cracking indices from all four performance tests. In this approach, the CRI decreased with increasing asphalt binder content, whereas the CCI increased. The balanced asphalt content was identified as the asphalt binder content corresponding to the intersection of the two combined index curves.

Using this approach, the balanced asphalt content was determined to be approximately 5.6% for the PG 64-22 mixture, 5.9% for the PG 70-22 mixture, and 6.6% for the PG 76-22 mixture. The results show a systematic increase in balanced asphalt content with increasing binder grade, reflecting the improved rutting resistance provided by stiffer and polymer-modified binders and their ability to accommodate higher asphalt contents while maintaining adequate cracking resistance.

Overall, the combined performance approach confirmed the strong influence of binder grade on balanced asphalt content and provided a comprehensive framework for selecting performance-based optimum asphalt binder content by integrating multiple rutting and cracking performance indicators.

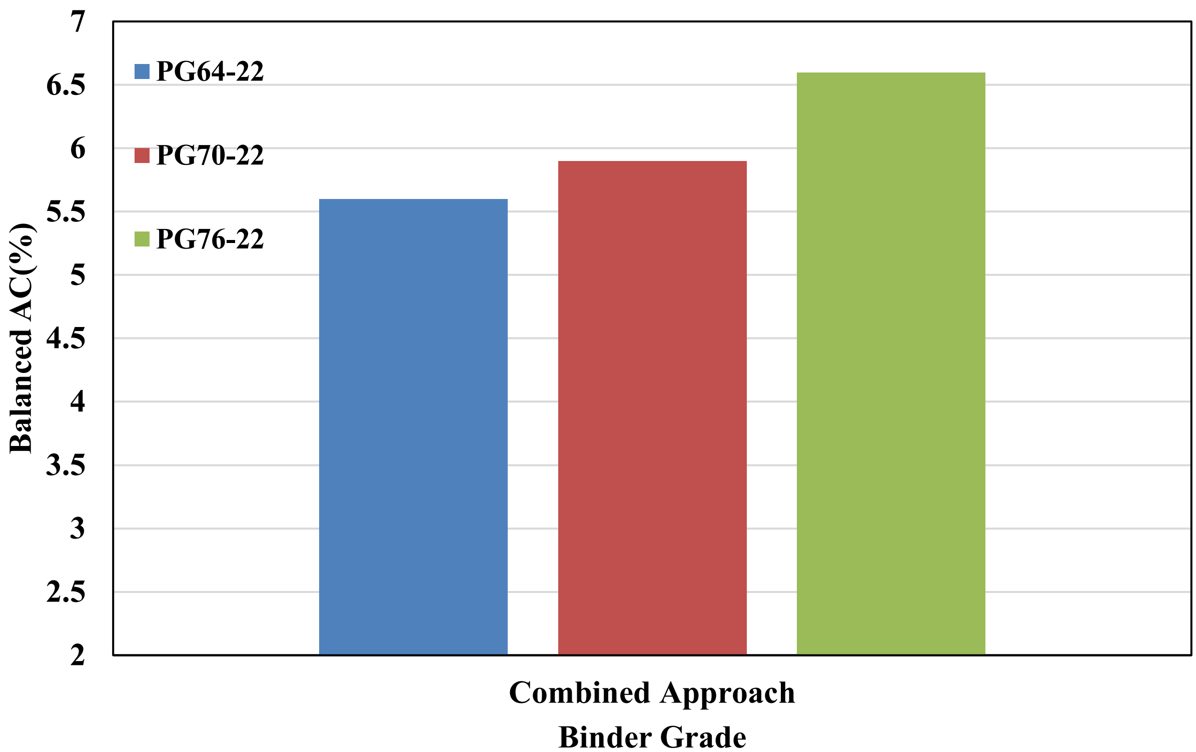

FIGURE 96 Summary Balanced AC (%) (Combined Approach)

The summary shown in Figure 3.32 confirms that the balanced asphalt content increased systematically with binder grade, from approximately 5.6% for PG 64-22 to 5.9% for PG 70-22 and 6.6% for PG 76-22. This trend demonstrates that higher-performance binders permit the use of richer mixtures while maintaining an acceptable balance between rutting and cracking resistance. The results further indicate that the combined performance approach provides a comprehensive and robust method for determining performance-based optimum asphalt binder content by integrating multiple rutting and cracking performance indicators.

3.8 COMPARISON OF PROPOSED METHODS

To evaluate the robustness of the proposed Balanced Mix Design methodology, three performance-based approaches were developed to determine balanced asphalt content: (1) the HWTT–I-FIT approach, (2) the IDEAL-RT–IDEAL-CT approach, and (3) the combined performance approach. The HWTT–I-FIT method was considered the reference approach because it uses performance tests that are widely adopted by state transportation agencies for BMD implementation. The IDEAL-RT–IDEAL-CT approach was developed to assess whether simpler and more rapid laboratory tests could provide comparable results. The combined performance approach integrated the results from all four tests to provide a more comprehensive assessment of the rutting–cracking relationship.

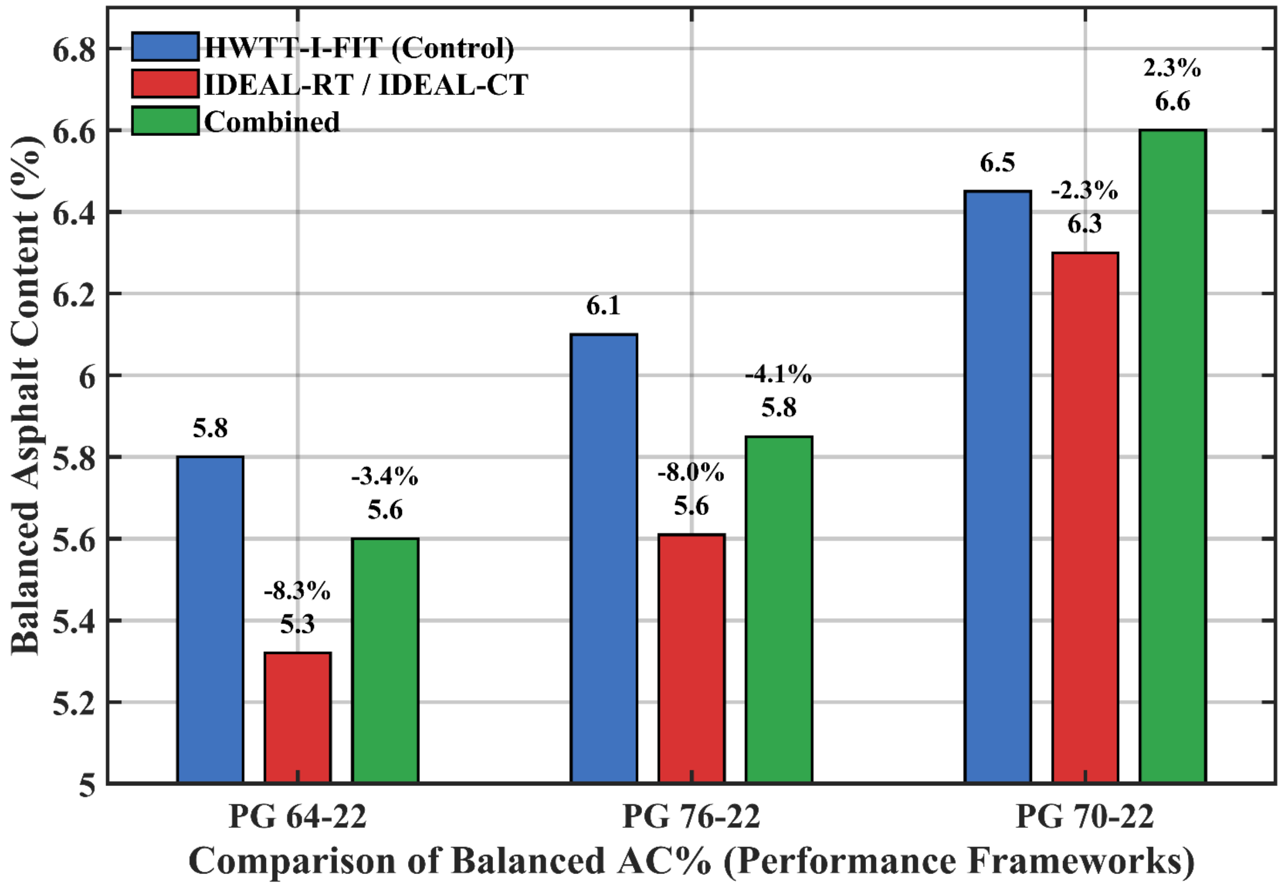

FIGURE 3.33 Comparison of Methods for Determining Balanced AC (%)

Figure 3.33 compares the Balanced Asphalt contents determined using the three proposed performance-based approaches: HWTT–I-FIT, IDEAL-RT–IDEAL-CT, and the combined performance approach. All three methods produced consistent trends, with balanced asphalt content increasing systematically with binder grade from PG 64-22 to PG 76-22. This consistency demonstrates that each approach effectively captured the underlying trade-off between rutting resistance and cracking resistance and can be used to determine a rational performance-based optimum asphalt binder content.

The IDEAL-RT–IDEAL-CT approach yielded slightly lower balanced asphalt contents than the HWTT–I-FIT approach, with differences of approximately -8.3%, -8.0%, and -2.3% for the PG 64-22, PG 70-22, and PG 76-22 mixtures, respectively. In contrast, the combined performance approach produced values that were closer to the HWTT–I-FIT results, with differences of approximately -3.4%, -4.1%, and +2.3% for the same mixtures. These relatively small differences indicate that the three approaches provide comparable estimates of balanced asphalt content, although the absolute values are influenced by the specific test methods and performance thresholds employed.

Among the approaches evaluated, the HWTT–I-FIT method could be considered the most appropriate framework for mix design because it is based on well-established performance tests that are widely used by state transportation agencies for Balanced Mix Design implementation. The IDEAL-RT–IDEAL-CT approach produced the same overall trends and comparable balanced asphalt contents while relying on simpler and faster laboratory tests. Therefore, this approach shows strong potential as a surrogate method for routine quality assurance and quality control applications. The combined performance approach provides an additional level of confidence by integrating multiple rutting and cracking indicators into a single framework.

Overall, the results demonstrate that the proposed methodologies are robust and consistent. While the balanced asphalt content is somewhat method-dependent, all three approaches yielded similar and technically reasonable results, confirming that each can be used to support Balanced Mix Design implementation depending on the intended application and available testing resources.

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CHAPTER 4
DETERMINATION OF PERFORMANCE BASED DESIGN

4.1 OVERVIEW OF EVALUATED NEW MEXICO ASPHALT MIXES

This chapter presents the development of preliminary performance-based design criteria for Balanced Mix Design (BMD) implementation in New Mexico. A total of nineteen asphalt mixtures representative of materials, binder types, and production practices used throughout the state were evaluated to assess their rutting and cracking performance. The dataset consisted of eleven laboratory-compacted short-term aged (LCSTA) mixtures, and eight field mix reheated (FMRH) mixtures.

Each mixture was evaluated using one or more rutting performance tests, including the Hamburg Wheel Tracking Test (HWTT) and the IDEAL Rutting Test (IDEAL-RT), and one or more cracking performance tests, including the Illinois Flexibility Index Test (I-FIT), Semi-Circular Bend (SCB) test, and Texas Overlay Test (OT). The performance results were evaluated using threshold criteria commonly adopted by state Departments of Transportation (DOTs), and each mixture was subsequently classified as either balanced or unbalanced based on the applicable rutting and cracking requirements.

The objective of this chapter is to evaluate the New Mexico asphalt mixtures perform relative to established performance benchmarks and to assess the applicability of these criteria to local materials and conditions. The results provide the basis for developing preliminary New Mexico-specific performance thresholds and refining a practical Balanced Mix Design framework for statewide implementation.

4.2 Evaluation of Mix#1a, Mix#1b, Mix#1c

Locally available aggregates were used to design SP-IV asphalt mixtures with three binder grades commonly used in New Mexico: PG 58-28, PG 64-22, and PG 76-28. Based on these materials, three laboratory-produced mixtures, designated as Mix #1a, Mix #1b, and Mix #1c, were prepared. The mixtures were subjected to short-term aging in accordance with Superpave procedures to simulate plant production and construction conditions. Following aging, the mixtures were evaluated for rutting and cracking performance using the Hamburg Wheel Tracking Test (HWTT) and the Illinois Flexibility Index Test (I-FIT), respectively. The performance results were used to assess the influence of binder grade on mixture rutting resistance and cracking susceptibility and to determine whether each mixture satisfied the selected Balanced Mix Design (BMD) criteria.

The properties of Aggregates and proportions of final blends are presented in Table 4.1 and Table 4.2. The aggregate gradation of the final blend for Mix#1a, Mix#1b, Mix#1c is presented in Figure 4.1. The mix design volumetric properties for Mix#1a, Mix#1b, Mix#1c are presented in Table 4.3.

TABLE 4.1 Properties of Aggregates Used for Mix#1a, Mix#1b, Mix#1c

Material	Blend Percentage (%)	Bulk Specific Gravity (Gsb)	Absorption (%)
5/8 in. Aggregate	28.0	2.644	0.8
3/8 in. Aggregate	27.0	2.616	1.1
CF (Crusher Fines)	45.0	2.622	1.0
Liquid Antistrip	0.35	1.000	—

TABLE 4.2 Gradation of Blended Aggregates Used for Mix#1a, Mix#1b, Mix#1c

Gradation		1.5 in.	1in.	3/4in.	1/2in.	3/8in.	No. 4	No. 8	No.16	No.30	No.50	No.100	No.200
Passing (%)		100	100	100	96	82	47	31	22	17	12	9	5.7
Specification		100	100	100	90-100	Max 90		28-28					2-10
Acceptable Tolerances	Max				100	90	54						7.1
	Min				91	74	40						4.3

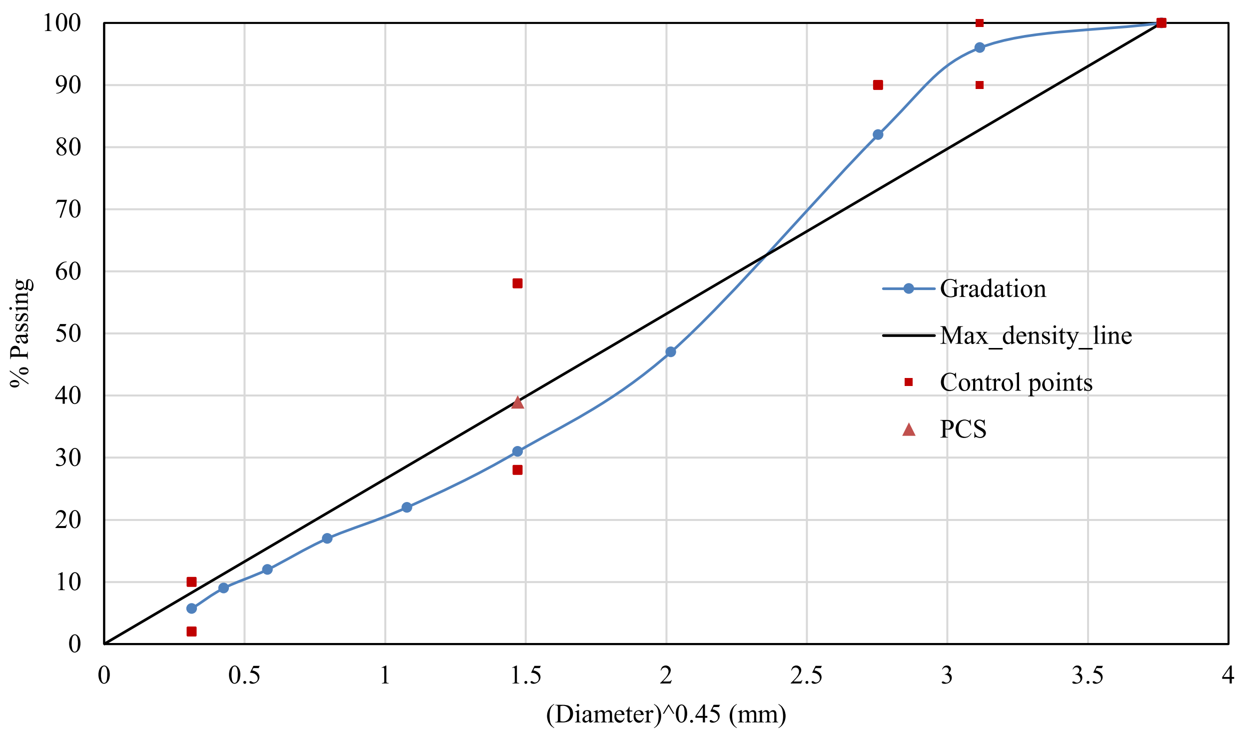


FIGURE 4.1 Aggregate gradation of the final blend for Mix#1a, Mix#1b, Mix#1c

TABLE 4.3 Mix Design Volumetric Properties for Mix#1a, Mix#1b, Mix#1c

Mix ID	Binder	AC (%)	Gmm	Gmb	Air voids (%)	VMA (%)	VFA (%)	Dust proportion
M#1a	58-28	4.5	2.360	2.251	4.6	14.4	67.9	1.36
		5	2.349	2.276	3.1	13.9	77.7	1.24
		5.5	2.335	2.289	2	13.8	85.9	1.14
		6	2.323	2.294	1.3	14.1	91	1.05
M#1b	64-22	4.6	2.483	2.320	6.6	15.8	58.1	1.41
		5.1	2.465	2.365	4.1	14.5	72.2	1.25
		5.6	2.447	2.388	2.4	14.2	83.1	1.13
		6.1	2.429	2.398	1.3	14.3	91	1.03
M#1c	76-28	4.5	2.658	2.505	5.7	14	59	1.59
		5	2.636	2.529	4.1	13.6	70.2	1.39
		5.5	2.614	2.557	2.2	13.1	83.3	1.23
		6	2.593	2.582	0.4	12.7	96.7	1.1

The optimum binder contents for the M#1a, M#1b, and M#1c mixtures were determined to be 4.7%, 5.0%, and 5.1%, respectively.

4.2.1 Performance of Mix#1a, Mix#1b, Mix#1c

Rutting Performance

The Hamburg Wheel Tracking Test (HWTT) was conducted on Mix #1a, Mix #1b, and Mix #1c to evaluate the rutting resistance of these laboratory-produced mixtures. Figures 4.2 through 4.3 present the rut depth versus wheel pass curves for the three mixtures, and Table 4.4 summarizes the corresponding rut depth results and performance evaluation relative to the selected rutting criterion.

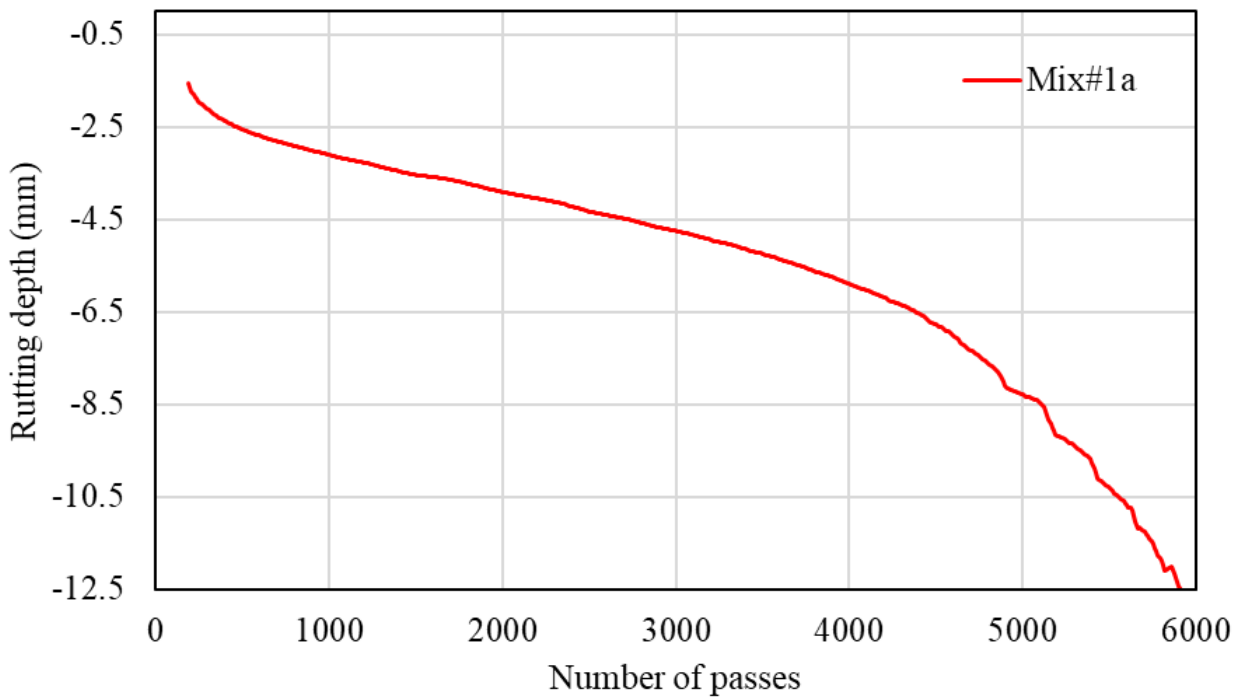


FIGURE 4.2 (a) HWTT of Mix#1a (SPIV-PG58-28)

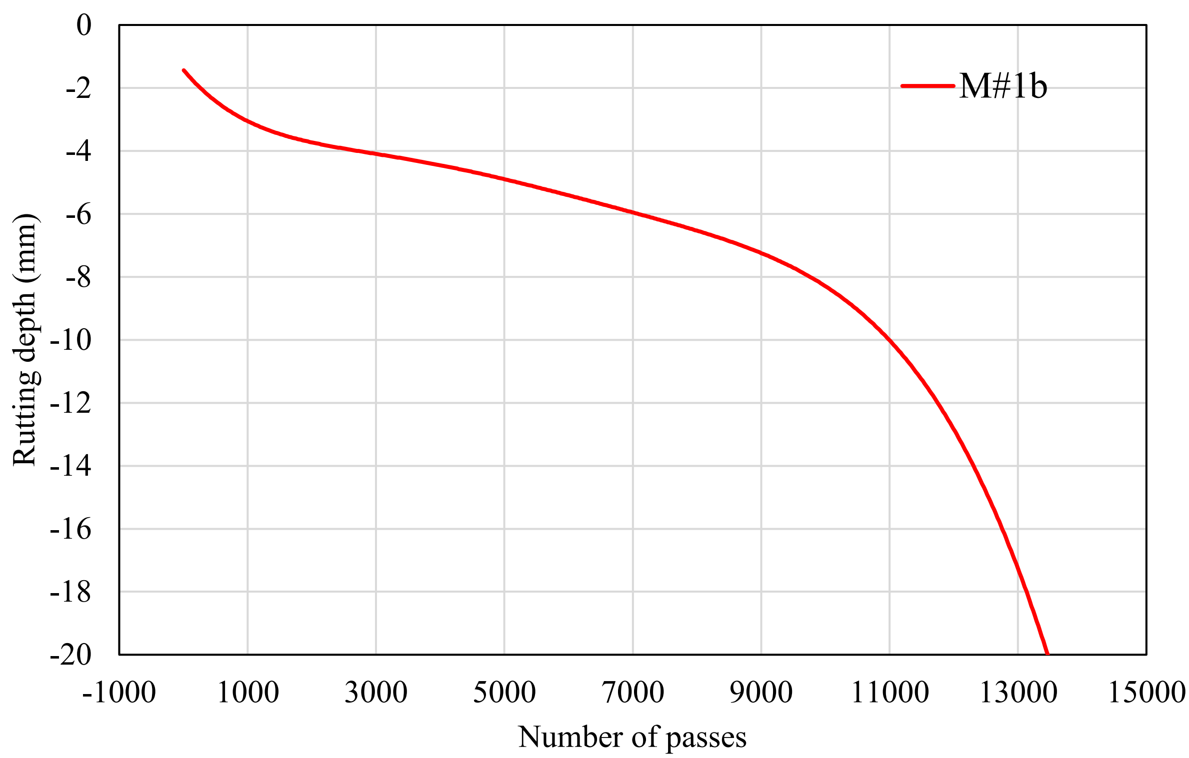


FIGURE 97 (b) HWTT of Mix#1b (SPIV-PG64-22)

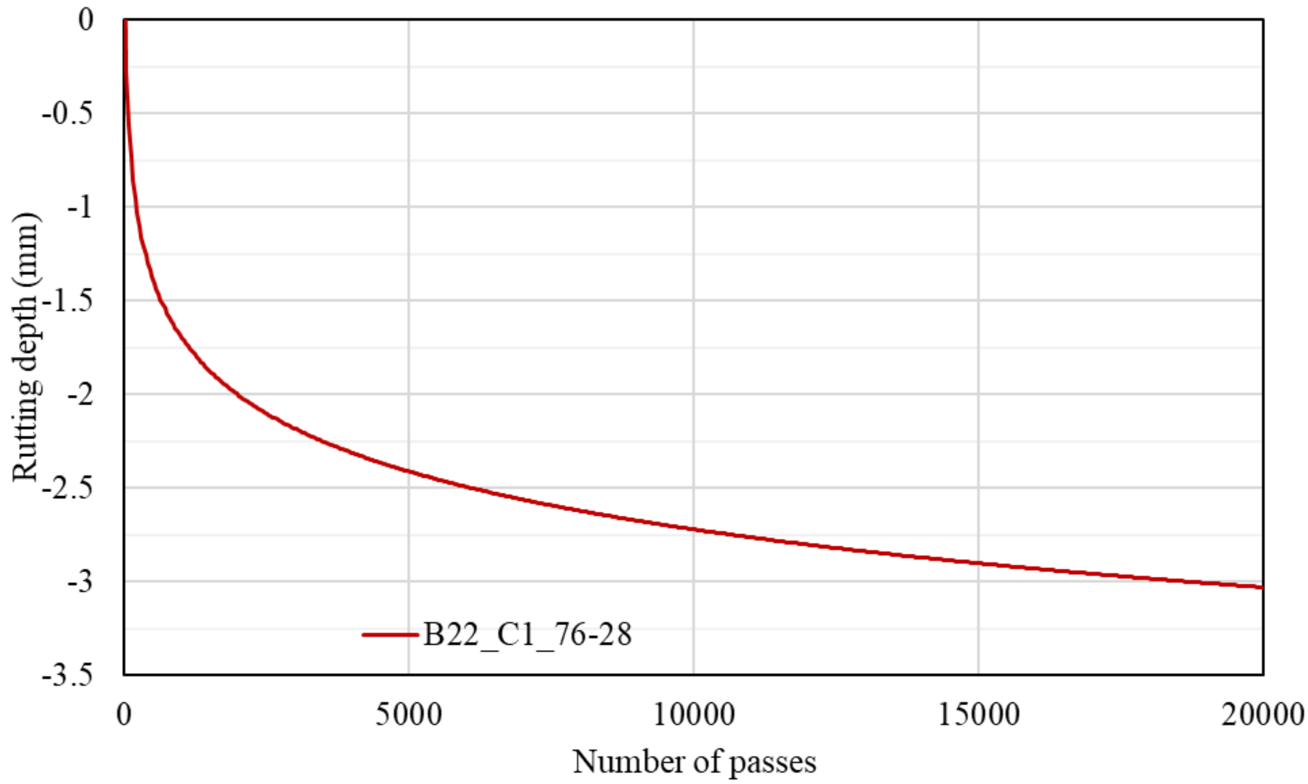


FIGURE 98 HWTT of Mix#1c (SPIV-PG76-28)

Cracking Performance

The Illinois Flexibility Index Test (I-FIT) was conducted on Mix #1a, Mix #1b, and Mix #1c to evaluate the cracking resistance of these laboratory-produced mixtures. Figures 4.4 presents the load–displacement curves and corresponding Flexibility Index (FI) results, and Table 4.4 summarizes the average FI values and performance evaluation relative to the selected cracking criterion.

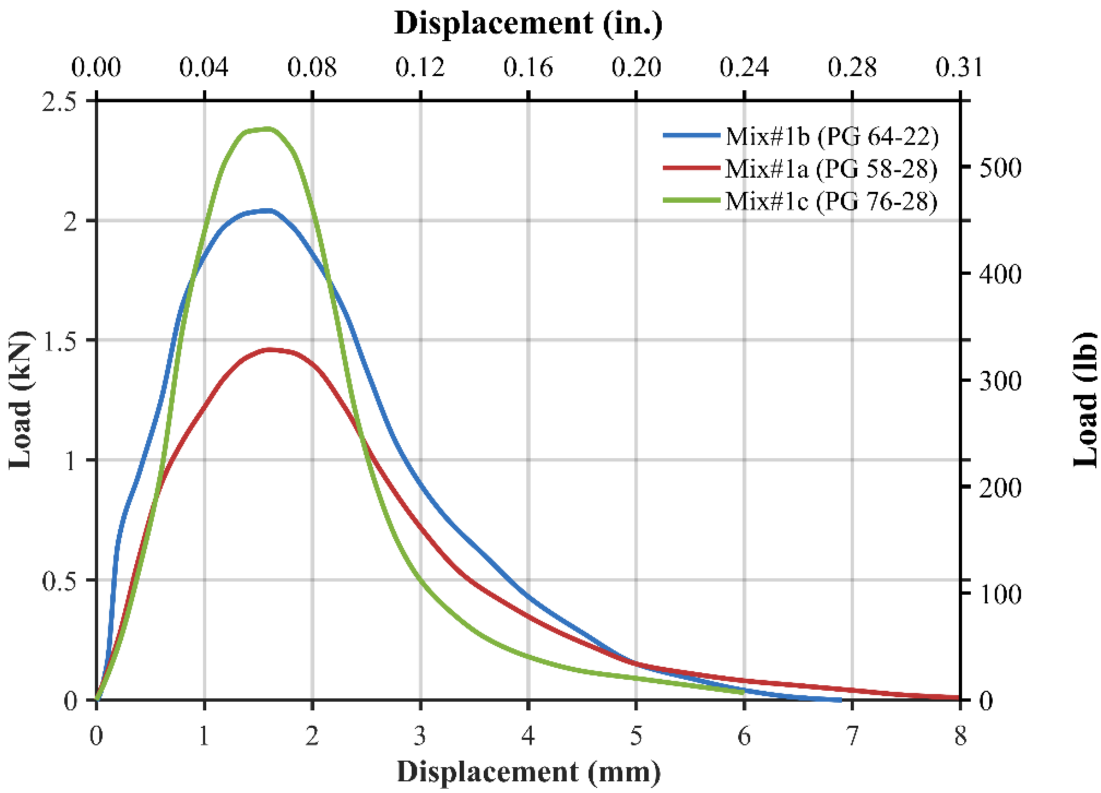


FIGURE 99 IFIT of Mix#1a, Mix#1b, Mix#1c

TABLE 4.4 Summary of Performance Tests of Mix#1a, Mix#1b, Mix#1c

Mix ID	Rutting (HWTT@50°C)		Cracking (I-FIT
	No of passes	Rut Depth	FI
Mix#1a	10,000	>20	18
	15,000	>20	
	20,000	>20	
Mix#1b	10,000	8.5	11.7
	15,000	>20	
	20,000	>20	
Mix#1c	10,000	2.7	9.5
	15,000	2.8	
	20,000	3.0	

PSD of Mix#1a, Mix#1b, Mix#1c

To illustrate the overall performance of Mix #1a, Mix #1b, and Mix #1c, a Performance Space Diagram (PSD) was developed using the commonly adopted Balanced Mix Design criteria of a maximum rut depth of 12.5 mm in the Hamburg Wheel Tracking Test (HWTT) and a minimum Flexibility Index (FI) of 8.0 from the Illinois Flexibility Index Test (I-FIT). In this graphical representation, rutting resistance and cracking resistance are evaluated simultaneously, allowing each mixture to be classified as balanced or unbalanced based on its position relative to the selected performance thresholds.

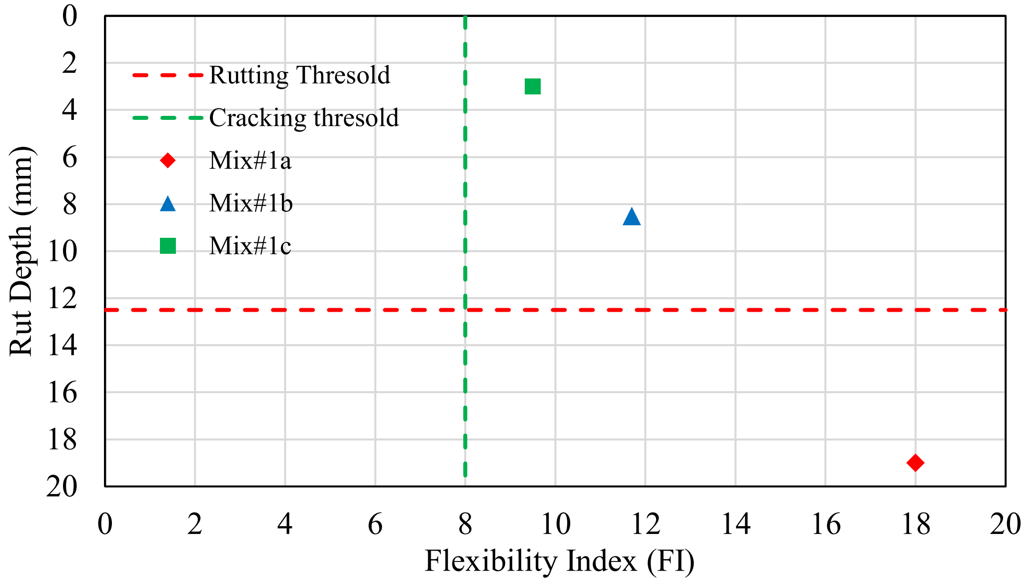


FIGURE 100 PSD of Mix#1a, Mix#1b, Mix#1c

As shown in the Performance Space Diagram in Figure 4.5, Mix #1b and Mix #1c satisfy both the rutting and cracking criteria and are therefore classified as balanced mixtures. In contrast, Mix #1a does not satisfy the rutting criterion and is classified as an unbalanced mixture.

4.3 EVALUATION OF MIX #2A AND MIX #2B

Mix #2a and Mix #2b were designed in the laboratory using five locally available aggregate stockpiles: PB #57, PB 1/2 in. Crusher Run, PB 3/8 in. Crusher Run, PB Crusher Fines, and PL Washed Concrete Sand, along with a PG 64-22 asphalt binder. Mix #2a was initially designed in accordance with the Superpave mix design procedure, and the optimum asphalt content was established based on volumetric requirements. The mixture was subsequently evaluated for rutting resistance using the Hamburg Wheel Tracking Test (HWTT) and for cracking resistance using the Semi-Circular Bend (SCB) test.

Although Mix #2a satisfied all Superpave volumetric criteria, it did not meet the selected performance requirements for rutting and cracking resistance. To improve performance, the mixture was redesigned by incorporating 15% reclaimed asphalt pavement (RAP) while maintaining the same aggregate structure and binder grade. The revised mixture, designated as Mix #2b, was then evaluated to identify an asphalt content that satisfied both the rutting and cracking performance criteria.

Table 4.5 presents the properties of aggregate used for Mix#2a, Mix#2b.

TABLE 4.5 Properties of aggregates for Mix#2a, Mix#2b

Aggregates	Bulk Sp. Gravity	% Absorption
PB #57	2.719	2.0
PB 1/2" CR	2.726	2.3
PB 3/8" CR	2.735	2.1
PB CF	2.776	2.0
PL WCS	2.569	0.8

The performance grade (PG) binder that has been used for this study was PG 64-22. The binder meets all the Superpave mix design criteria, i.e., the rutting, fatigue, and low-temperature cracking criteria. The mixing and compaction temperature range are 311°F and 291°F, respectively.

Design of Mix#2a

The final blended aggregate gradation is presented in Table 4.6 and Figure 4.6.

TABLE 4.6 Final blend and aggregate gradation for Mix#2a

Stockpile	PB #57		PB 1/2" CR		PB 3/8" CR		PB CF		PL WCS		Versabind
% Blend	17		10		10		46		16		1
Sieve Size	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Percent Passing	100	99	90	83	61	40	29	21	11	7	6

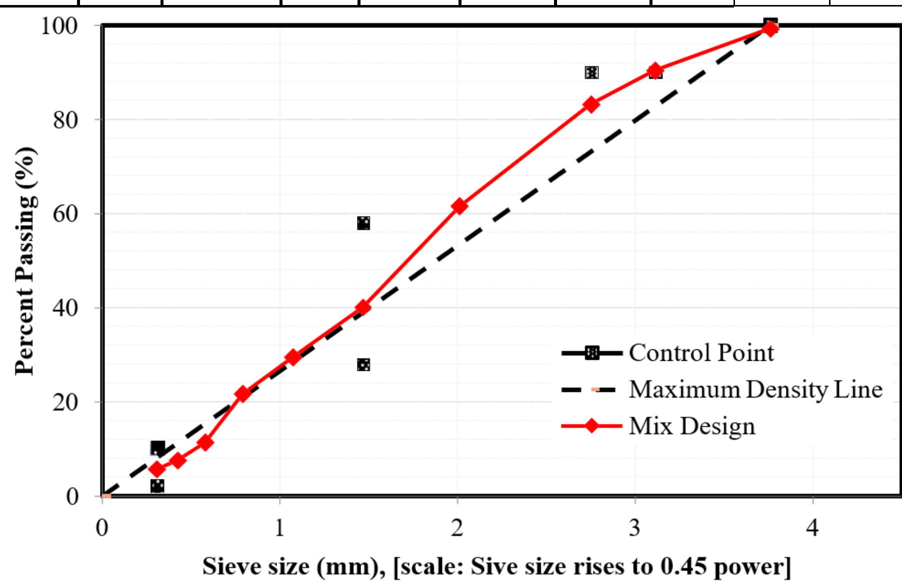


FIGURE 101 Aggregate gradation of the final blend for Mix#2a

Following the Superpave mix design procedure, specimens were prepared at four trial asphalt binder contents of 5.8%, 6.3%, 6.8%, and 7.3%. The volumetric properties of each specimen were determined, and the optimum asphalt content was selected as the binder content corresponding to 4.0% design air voids. Based on the relationship between air voids and asphalt content, the optimum asphalt content was determined to be 6.5% (Figure 4.7).

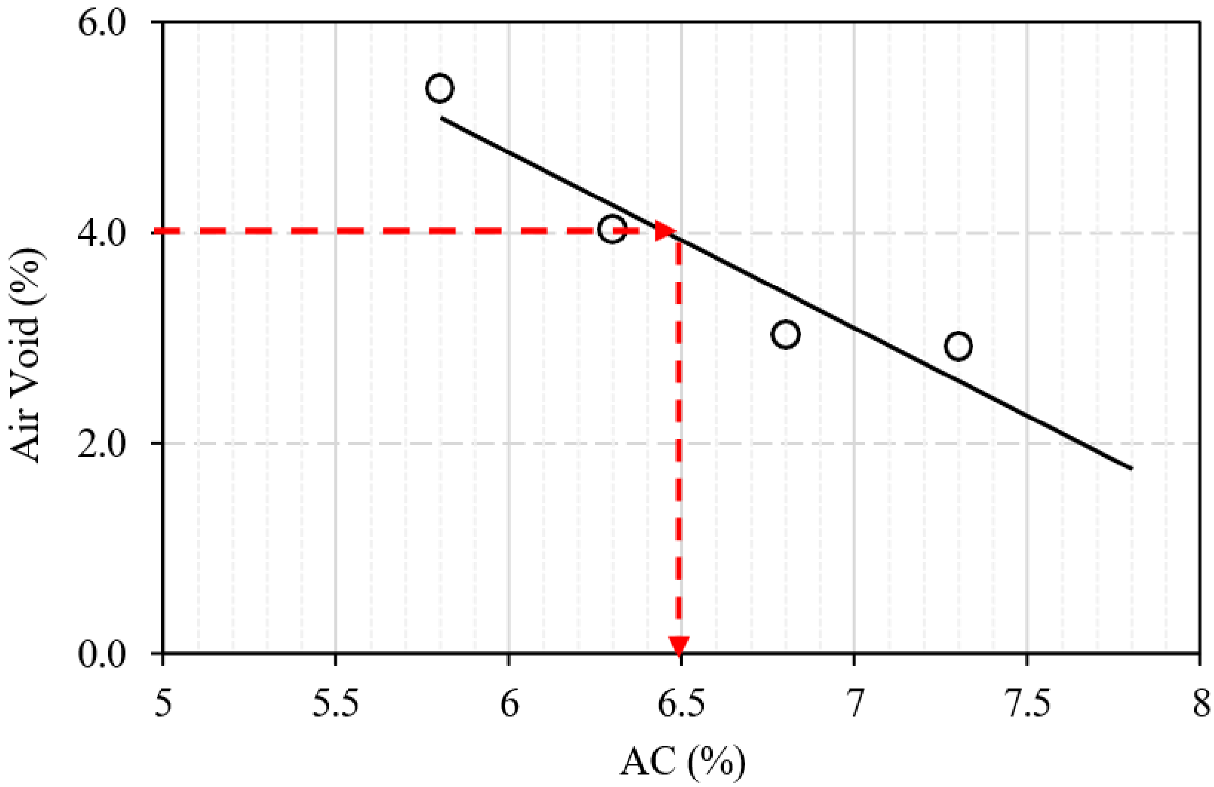


FIGURE 102 Optimum Asphalt Content of Mix#2a

4.3.2 Performance of Mix#2a

Rutting Performance

The HWTD rut test results for the designed mix are shown in Figure 4.8. The stripping potential was observed in the mix. As can be seen from Figure 4.8, the mix failed and could not run for 20,000 wheel passes. The maximum rut depth was observed 24 mm after at 12,000 wheel passes. The stripping inflection point (SIP) and stripping slope were measured 2,300 passes and 500 passes/mm, respectively.

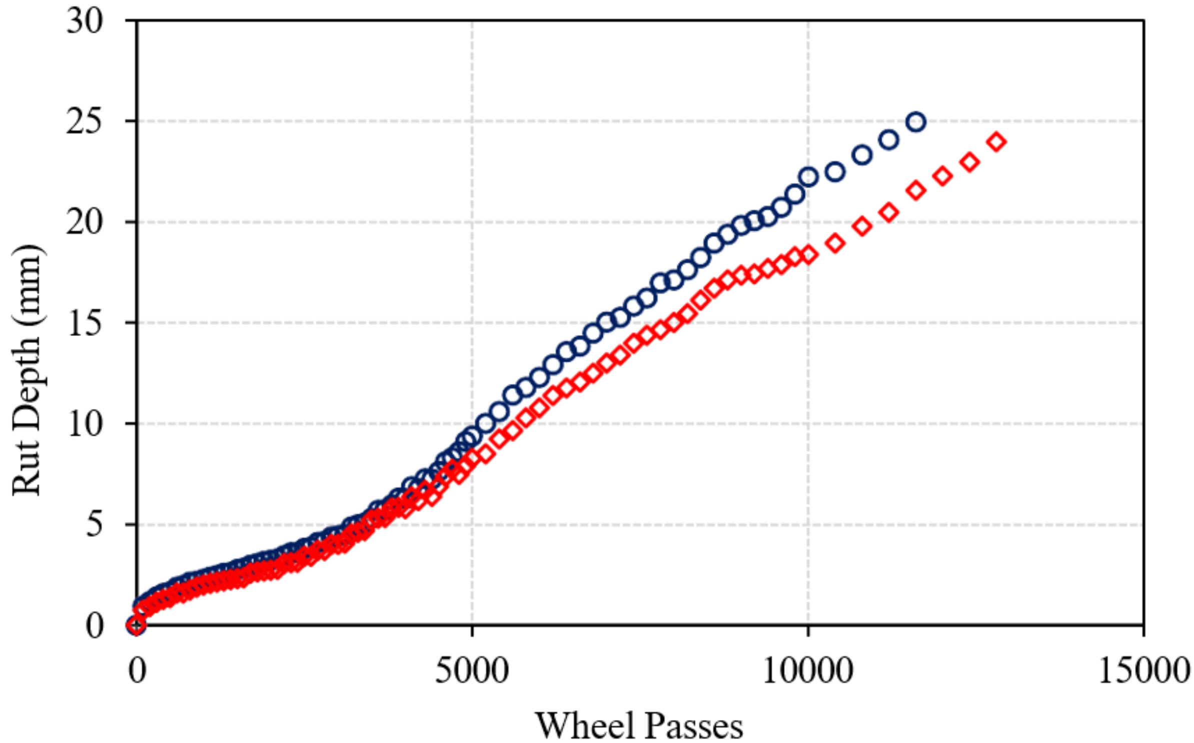


Figure 103 HWTD test results of Mix#2a

Cracking Performance

The critical strain energy release rate (kJ/m^2) that is the *Jc*-integral value (0.38 kJ/m2) obtained from SCB test results revealed that the Mix 2#a also did not satisfy the minimum requirement of *Jc* value of 0.40 kJ/m^2

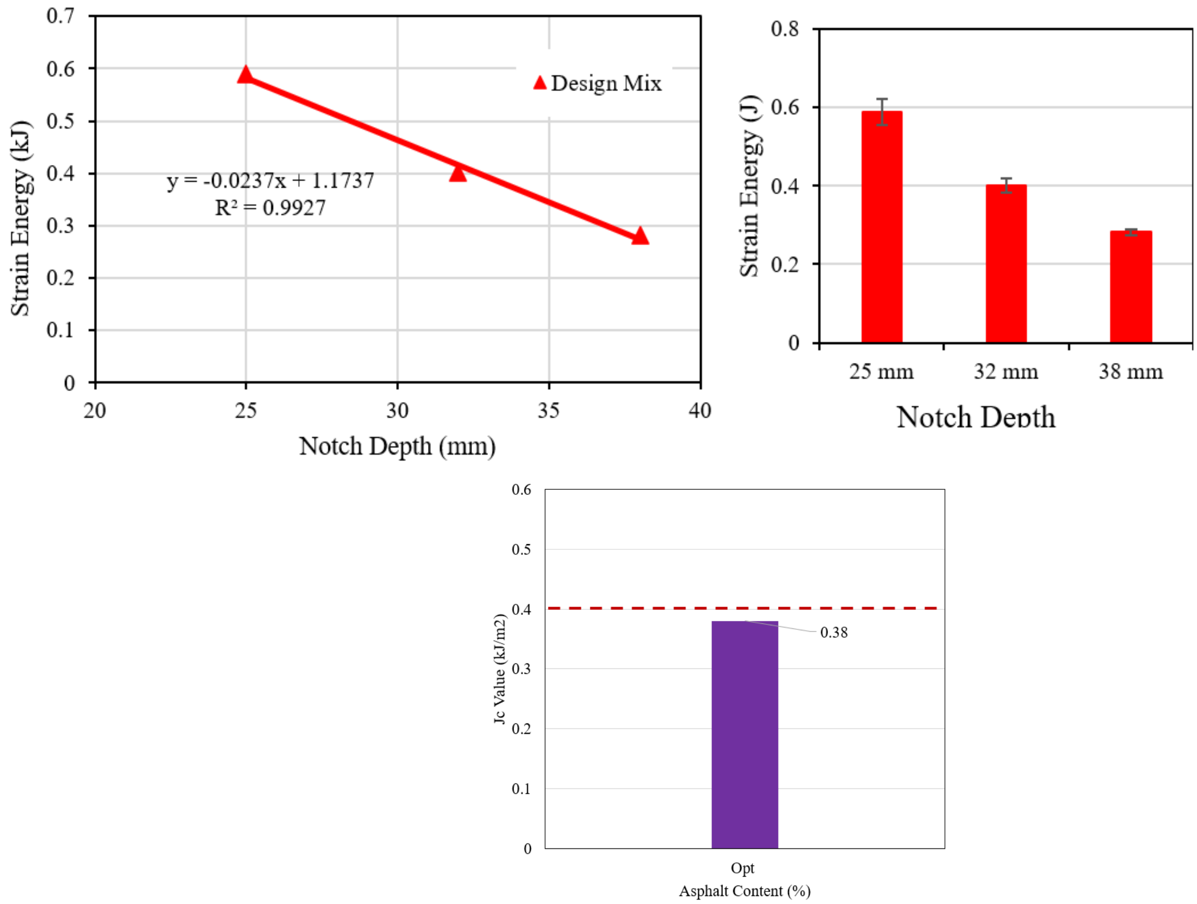
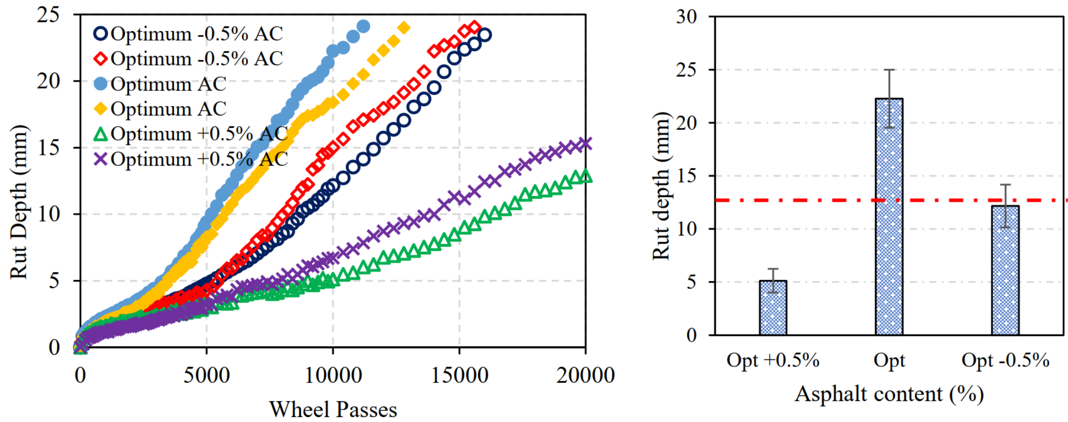


FIGURE 104 SCB test results for Mix#2a @optimum AC (%)

4.3.3 Performance of Mix#2b

Rutting Performance

The HWTT results for the Mix#2b at three asphalt binder contents (Opt, Opt+0.5%, Opt-0.5%) are presented in Figure 4.10. Stripping potential was observed in all mixtures. The original mixture at the design asphalt content exhibited severe rutting, with a rut depth of approximately 22 mm, indicating that it did not satisfy the adopted criterion of 12.5 mm at 10,000 wheel passes. Incorporation of 15% RAP significantly improved rutting resistance, reducing the rut depth to approximately 5.1 mm for the optimum asphalt content plus 0.5%. The mixture at the optimum asphalt content minus 0.5% produced a rut depth close to the threshold value. Based on these results, the mixture containing 15% RAP at the optimum asphalt content plus 0.5% satisfied the selected rutting criterion.

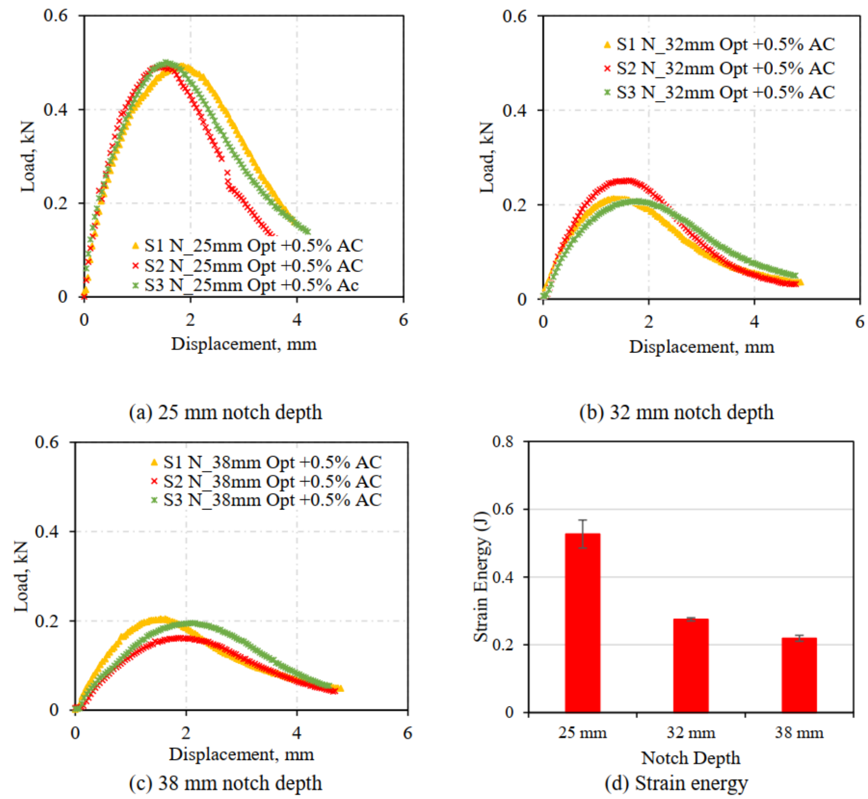


(a) (b)

FIGURE 4.10 HWTD test results of Mix#2b (a) rut depth vs. wheel pass (b) total rut depth at 10,000 passes

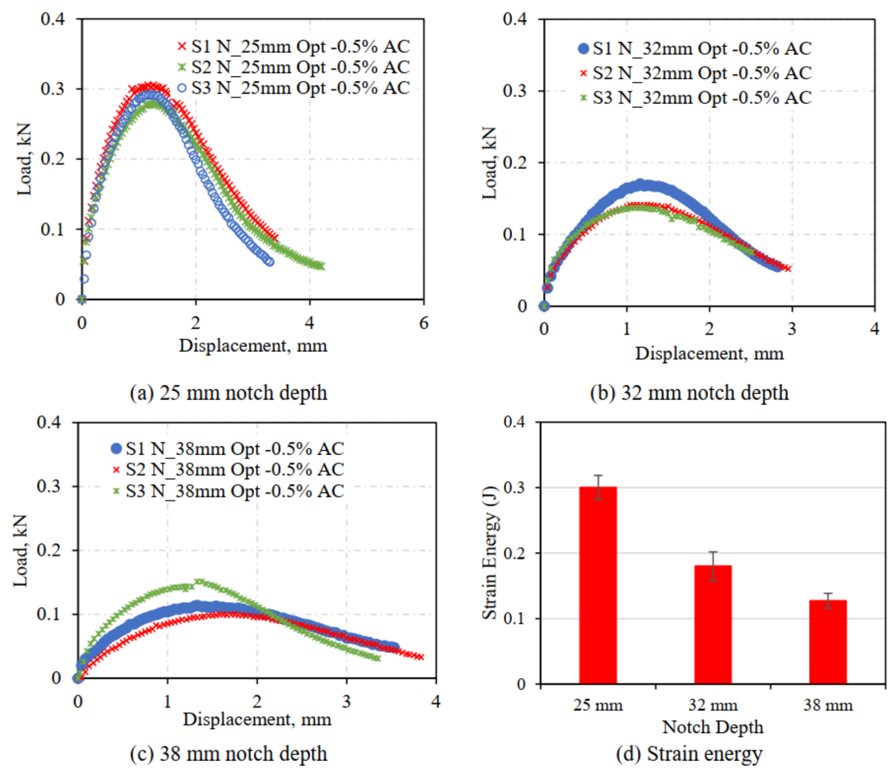
Cracking Performance

Figures 4.11(a) through 4(c) present the SCB load–displacement responses for the Mix2#b compacted at the optimum asphalt content plus 0.5% (6.5%) and tested at notch depths of 25, 32, and 38 mm. The area under each load–displacement curve up to peak load was used to determine the critical strain energy. As shown in Figure 4(d), the average strain energy decreased with increasing notch depth, with values of 0.527, 0.275, and 0.219 J for the 25, 32, and 38 mm notch depths, respectively.



(a) 25 mm notch depth
(b) 32 mm notch depth
(c) 38 mm notch depth
(d) Strain energy

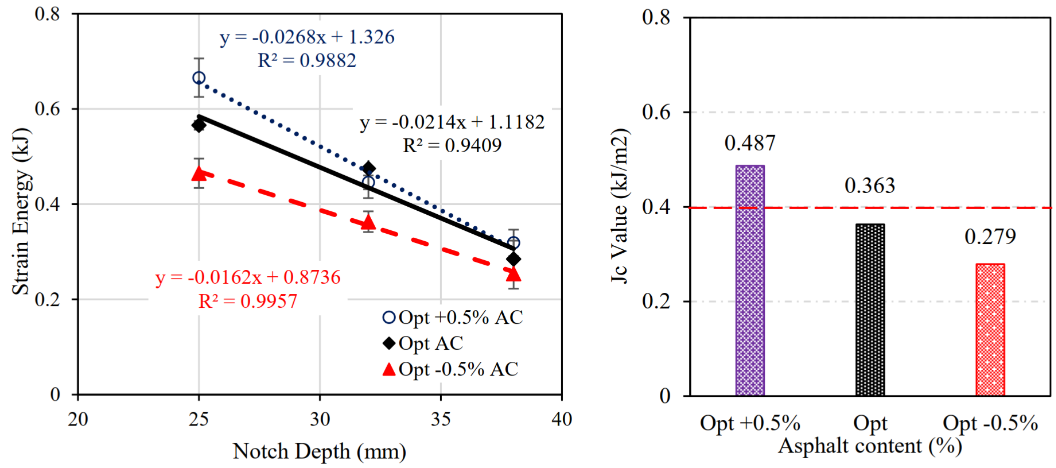
FIGURE 105 SCB test results forMix#2b@ optimum -0.5% AC



(a) 25 mm notch depth
(b) 32 mm notch depth
(c) 38 mm notch depth
(d) Strain energy

FIGURE 106 SCB test results forMix#2b@ optimum +0.5% AC

Figures 4.12(a), (b), and (c) show SCB test results for Mix#2b compacted at 0.5% lower asphalt content than the optimum (6.5%) at a notch depth of 25.0 mm, 32.0 mm, and 38.0 mm, respectively. The strain energy is calculated to be 0.300 J for 25 mm notch depth, whereas 0.180 J and 0.127 J for 32.0 and 38.0 mm notch depth, respectively.



(a) Strain energy vs. notch depth (a) J_c value at different asphalt content

FIGURE 107 Strain energy release rate determination for Mix#2b

The slope of the strain energy versus notch depth was used to determine the SCB critical strain energy release rate (J_c). As shown in Figure 4.13, the J_c values were 0.243 kJ/m² for the optimum asphalt content minus 0.5%, 0.38 kJ/m² for the design asphalt content (6.5%), and 0.48 kJ/m² for the optimum asphalt content plus 0.5%. Using the adopted cracking criterion of 0.40 kJ/m², only the mixture compacted at the optimum asphalt content plus 0.5% satisfied the selected cracking requirement (Figure 4.13).

Performance Space Diagram Mix#2a, Mix#2b

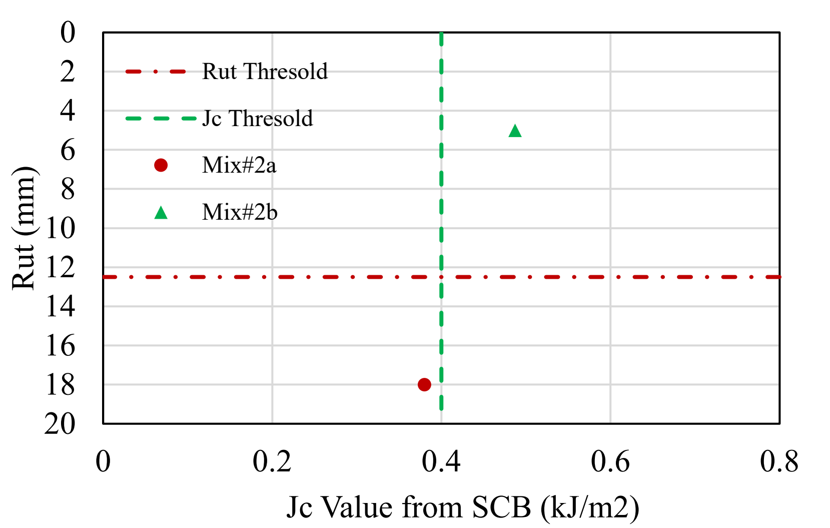


FIGURE 108 HWTT-SCB performance space diagram for Mix#2a, Mix#2b

As shown in the Performance Space Diagram (Figure 4.14), Mix #2a did not satisfy the selected BMD criteria. The mixture exhibited a rut depth of 18 mm, exceeding the 12.5 mm rutting threshold, and a J_c value of 0.38 kJ/m², slightly below the 0.40 kJ/m² cracking threshold. Therefore, Mix #2a is classified as unbalanced.

In contrast, Mix #2b, incorporating 15% RAP and compacted at optimum +0.5% asphalt content, satisfied both criteria, with a rut depth of 5 mm and a J_c value of 0.487 kJ/m². This indicates that the redesigned mixture substantially improved rutting resistance while also meeting the cracking requirement and is therefore classified as balanced.

4.4 EVALUATION OF MIX #3A AND MIX #3B

Mix #3a and Mix #3b were designed in the laboratory using locally available sand and gravel aggregates from the Aztec Pit in San Juan County, New Mexico, and PG 64-22 asphalt binder. Mix #3a was initially designed following the Superpave mix design procedure, and the optimum asphalt content was determined based on volumetric requirements. The mixture was evaluated for rutting resistance using the Hamburg Wheel Tracking Test (HWTT) and for cracking resistance using the Semi-Circular Bend (SCB) test.

Although Mix #3a satisfied the Superpave volumetric criteria, it did not meet the selected performance requirements for rutting and cracking resistance. To improve performance, the mixture was redesigned by incorporating 15% reclaimed asphalt pavement (RAP) while maintaining the same aggregate structure and binder grade. The revised mixture, designated as Mix #3b, was then evaluated to identify an asphalt content that satisfied both the rutting and cracking performance criteria. Table 4.7 presents the aggregate blend used in the design of Mix #3a and Mix #3b.

TABLE 4.7 Aggregate Properties Used for Mix#3a, Mix#3b

Aggregates	Bulk Sp. Gravity	% Absorption
5/8"	2.644	0.8
3/8"	2.616	1.1
CF	2.622	1.0
Versabind	1.0	

The performance grade (PG) binder that has been used for this study was PG 64-22. The binder meets all the Superpave mix design criteria, i.e., the rutting, fatigue, and low-temperature cracking criteria. The mixing and compaction temperature ranges are 311°F and 293°F, respectively.

Design of Mix#3a

The final blended aggregate gradation is presented in Table 4.8 and Figure 4.15.

TABLE 4.8 Final blend and aggregate gradation for Mix#3a

Stockpile		5/8"			3/8"				CF		Versabind
% Blend		28			27				44		1
Sieve Size	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Percent Passing		100	96	82	46	31	21	15.8	12	8.5	5.6

The gradation of the final blend is shown in Figure 4.15. This mix's primary control sieve number (NMAS of 12.5 mm) is #8, which has a sieve opening of 2.36 mm. The combined aggregate gradation is classified as coarse-graded when it passes below 40% through the primary sieve number. The percent passing through the sieve of 2.36 mm is 31%; therefore, it is a coarse-graded mix.

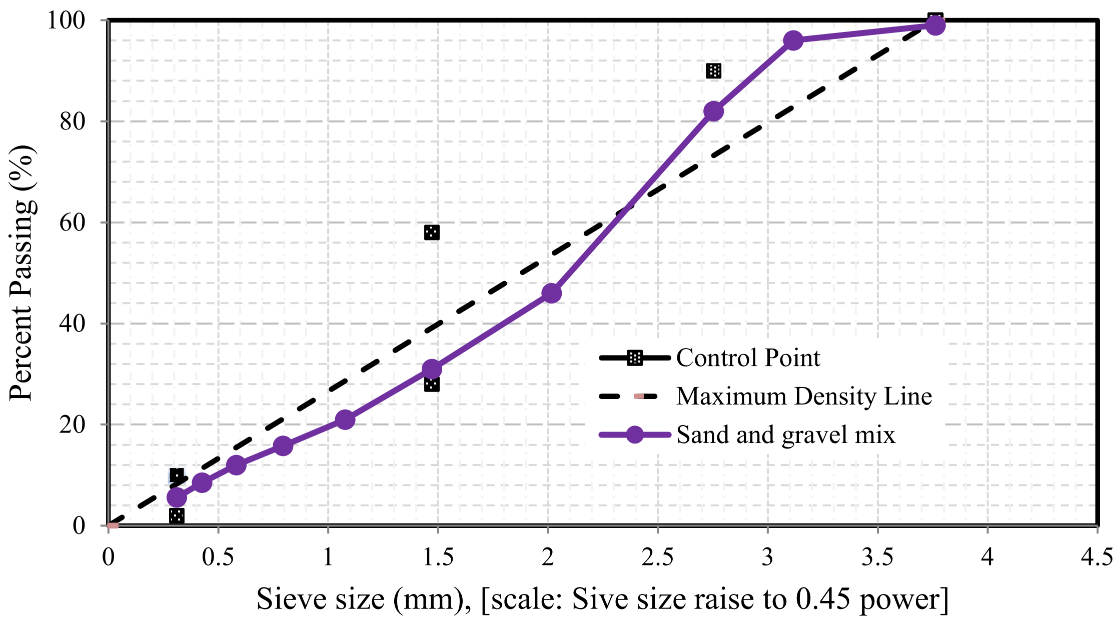


FIGURE 109 Aggregate gradation of the final blend for Mix#3a

The optimum asphalt content that maintains a specific amount of air void or different standard values can be selected using that data. To do that, four trial asphalt contents, i.e., 4.6%, 5.1%, 5.6%, and 6.1%, were selected. Figure 4.16 shows the air voids at each percent of asphalt content. This plot shows that for 4% of air voids, binder content is 5.2%.

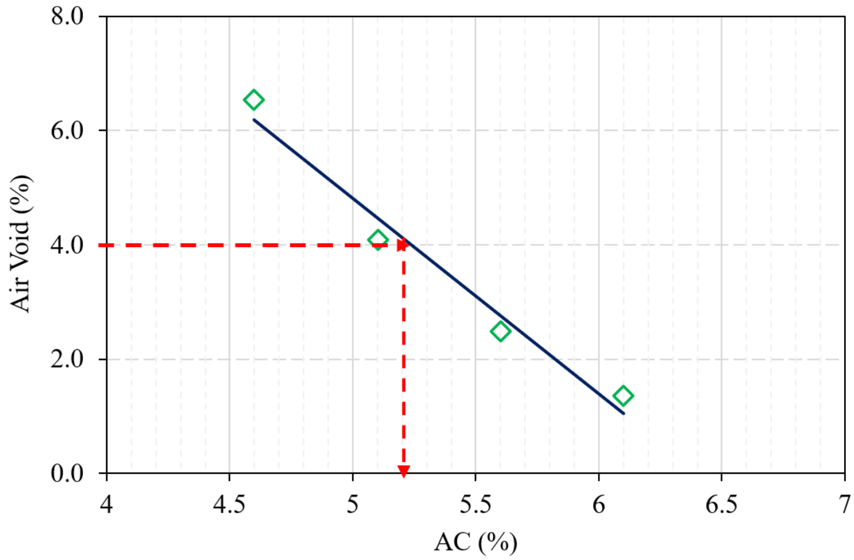


FIGURE 110 Optimum Asphalt Content of Mix#3a

4.4.1 Performance of Mix#3a

Rutting Performance

The HWTD rut test results for the designed Mix#3a are shown in Figure 4.17. The stripping potential was observed in the mix. As can be seen from Figure 4.17, the mix failed and could not run for 20,000 wheel passes. The maximum rut depth was observed 25 mm after at 14,300 wheel passes. The stripping inflection point (SIP) and stripping slope were measured 2,800 passes and 395 passes/mm, respectively.

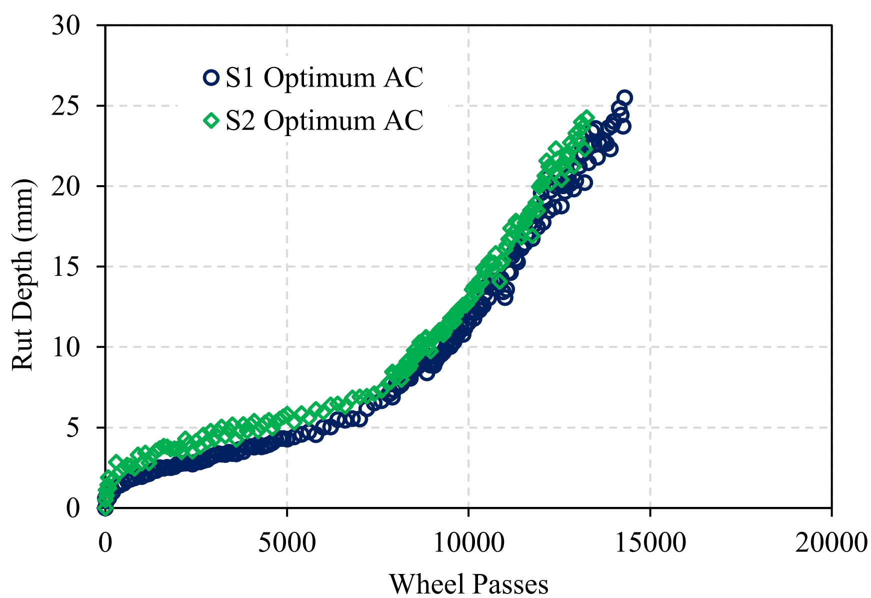
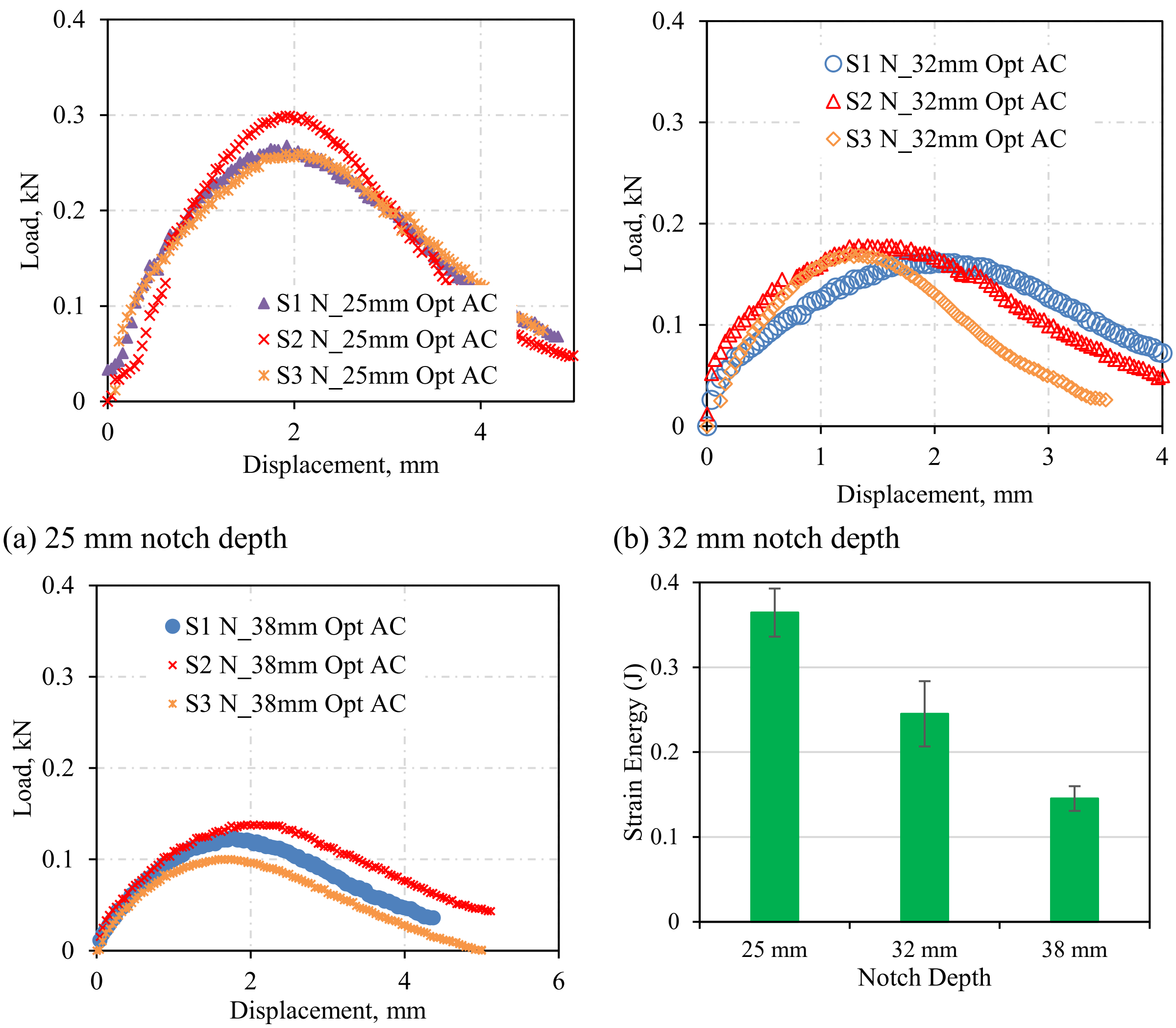


FIGURE 111: HWTD test results of Mix#3a

Cracking Performance

Figures 4.18(a), (b), and (c) show SCB test results for sand and gravel mix at the optimum (5.2%) binder content at a notch depth of 25.0 mm, 32.0 mm, and 38.0 mm, respectively. Initially, the load increases with an increase in displacement, and the load decreases as the sample fractures. To determine the peak load, peak displacement, and area under the load-displacement curve, a polynomial model is fitted through the measurements.

The area under the load-displacement plot up to peak load was determined for each specimen. This area represents critical strain energy and is plotted in Figure 4.18(d). As can be seen from Figure 59(d), the strain energy decreases with an increase in notch depth, which is obvious. Note that the average coefficient of variance (COV) of this mix's data points is less than 15%. The strain energy is calculated to be 0.364J for 25 mm notch depth, whereas 0.2451 J and 0.145 J for 32.0 and 38.0 mm notch depth, respectively.



(a) 25 mm notch depth

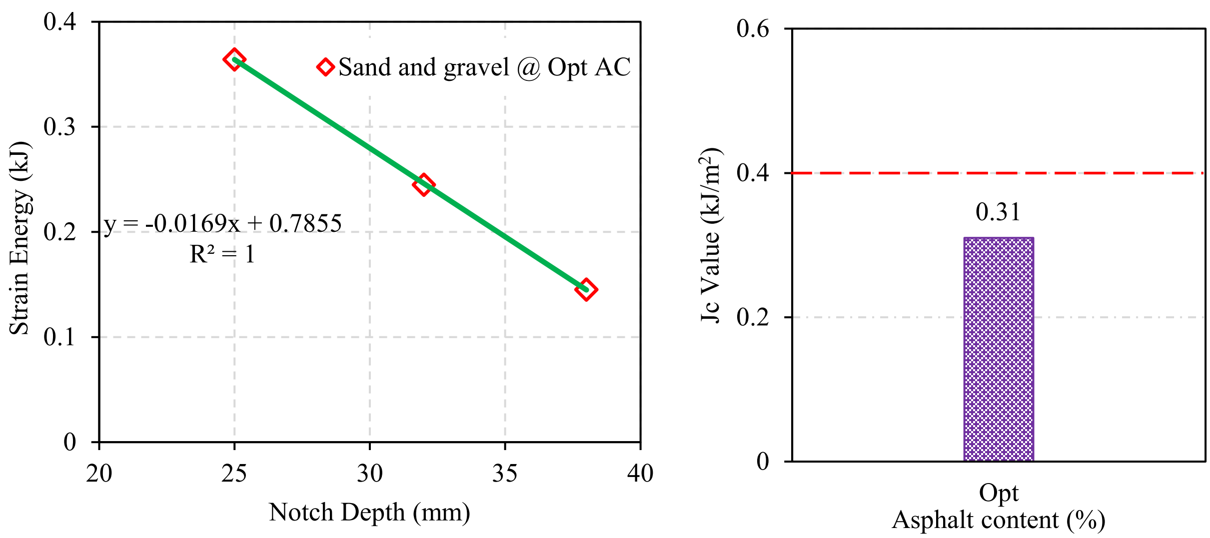
(b) 32 mm notch depth

(c) 38 mm notch depth

(d) Strain energy

FIGURE 112: SCB test results for optimum +0.5% AC

The slope of the strain energy vs. notch depth, which is known as J_C has also been determined. The J_C value obtained from the SCB test results is depicted in Figure 4.19. The J_C value is measured to be 0.31 kJ/m^2 for the optimum AC. A minimum J_c value of 0.4 kJ/m^2 is suggested in the specification set by Wisconsin DOT, which is used in this study for low to medium-volume traffic. Based on the specification, it can be said that the sand and gravel mix with optimum AC does not meet the minimum requirement for the J_c value, as shown in Figure 4.19(b).



(a) Strain energy vs. notch depth (b) J_c value at optimum AC

FIGURE 113: Strain energy release rate determination

Design of Mix#3b

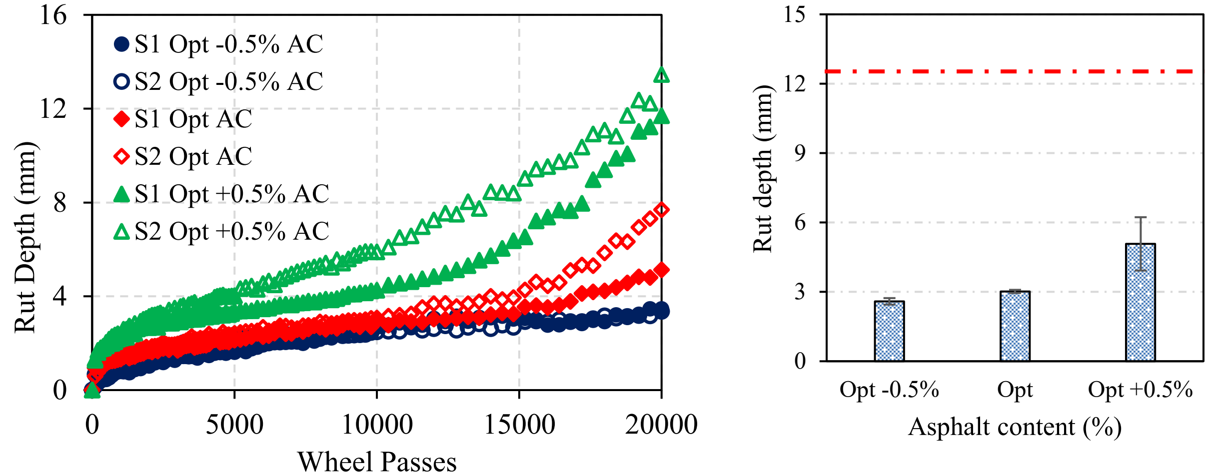
Mix #3a was designed using sand and gravel aggregates from the Aztec Pit in San Juan County, New Mexico, and PG 64-22 binder. The Superpave design yielded an optimum asphalt content of 5.2%. Performance testing using the Hamburg Wheel Tracking Test (HWTT) and the Semi-Circular Bend (SCB) test showed that the mixture did not meet the selected Balanced Mix Design criteria, with a rut depth of 12.6 mm at 10,000 wheel passes and an SCB Jc value of 0.31 kJ/m², compared with the adopted criteria of 12.5 mm and 0.40 kJ/m², respectively.

To improve both rutting and cracking performance, the mixture was redesigned by incorporating 15% reclaimed asphalt pavement (RAP) while maintaining the same aggregate structure and binder grade. The revised mixture, designated as Mix #3b, was evaluated at the design asphalt content as well as at ±0.5% of the optimum binder content to identify a binder content that satisfied both performance criteria.

4.4.2 Performance of Mix#3b

Rutting Performance

The HWTT results for Mix #2b at the optimum binder content and at ±0.5% asphalt content are presented in Figure 4.20. Incorporation of 15% RAP substantially improved rutting resistance compared with the original virgin mixture. At the design asphalt content, the rut depth at 10,000 wheel passes was approximately 3.0 mm, compared with 12.6 mm for Mix #2a. All three binder contents satisfied the adopted rutting criterion of 12.5 mm at 10,000 wheel passes, although stripping potential was observed in the optimum and optimum +0.5% mixtures. These results demonstrate the significant improvement in rutting resistance achieved through the addition of RAP.

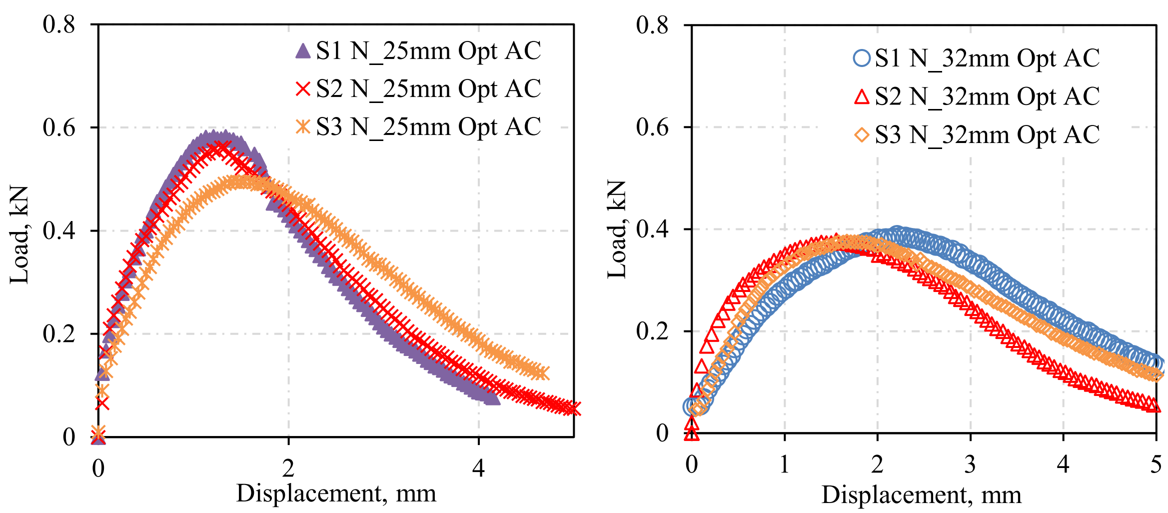


(a) (b)

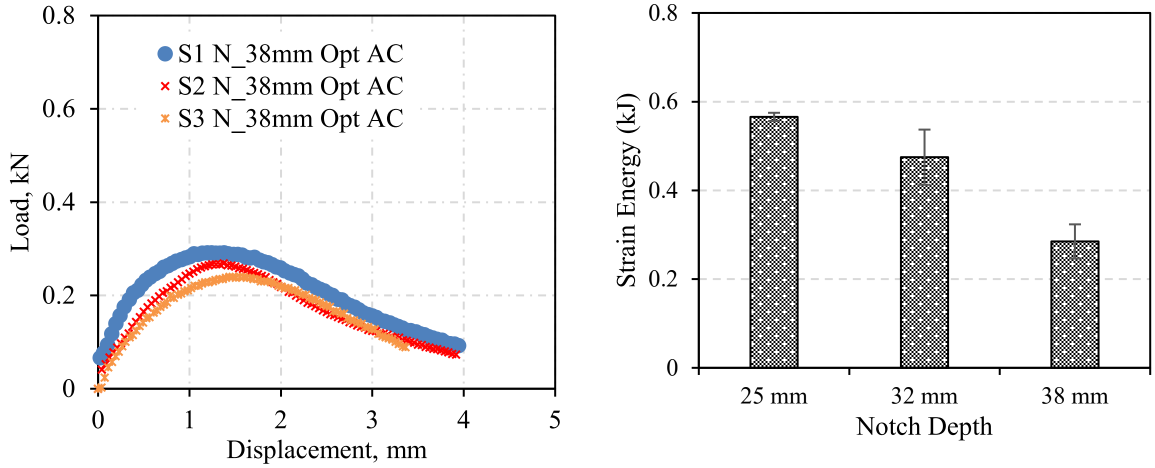
FIGURE 114: HWTD test results of Mix#3b (a) rut depth vs. wheel pass (b) total rut depth at 10,000 passes

Cracking Performance

Figures 4.21(a) through 62(c) present the SCB load–displacement responses for Mix #2b containing 15% RAP at the design asphalt content (5.2%) and notch depths of 25, 32, and 38 mm. The area under each load–displacement curve up to peak load was used to determine the critical strain energy. As shown in Figure 71(d), the average strain energy decreased with increasing notch depth, with values of 0.565, 0.475, and 0.285 kJ for the 25, 32, and 38 mm notch depths, respectively.



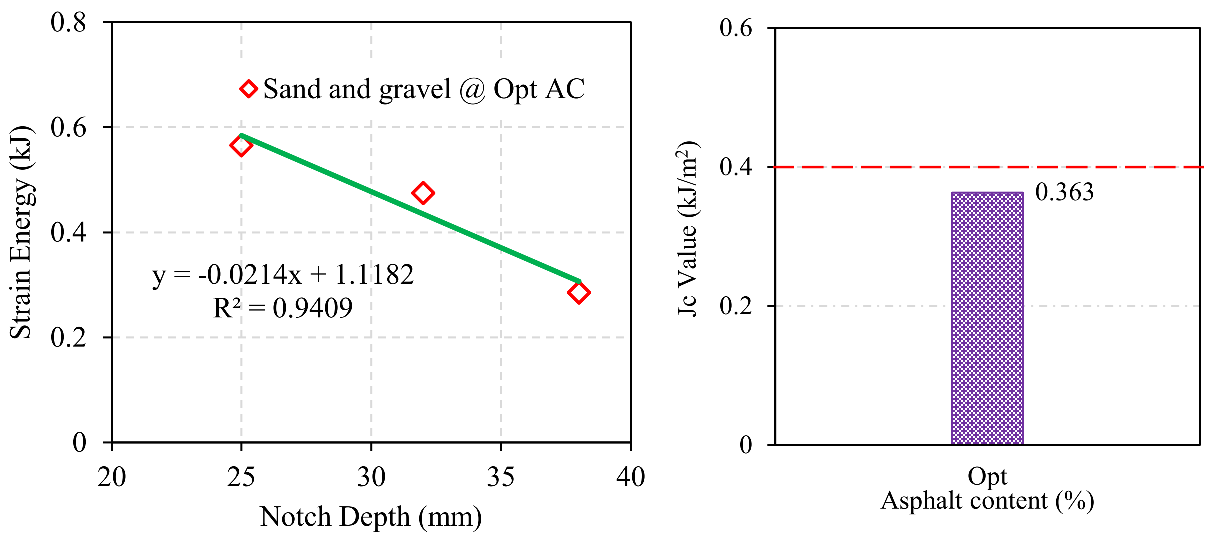
(a) 25 mm notch depth (b) 32 mm notch depth



(c) 38 mm notch depth (d) Strain energy

FIGURE 4.21: SCB test results for optimum AC

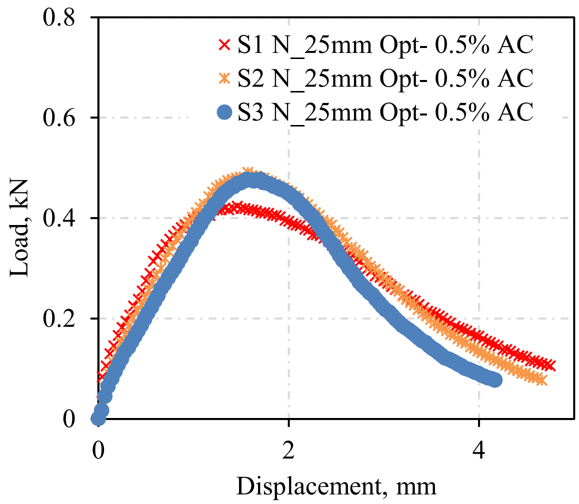
The slope of the strain energy vs. notch depth, which is known as J_C has also been determined. The J_C value obtained from the SCB test results is depicted in Figure 72. The J_C value is measured to be 0.363 kJ/m^2 for the optimum AC. A minimum J_c value of 0.4 kJ/m^2 is suggested in the specification set by Wisconsin DOT, which is used in this study for low to medium-volume traffic. Based on the specification, it can be said that the sand and gravel mix with optimum AC does not meet the minimum requirement for the J_c value, as shown in Figure 72(b).



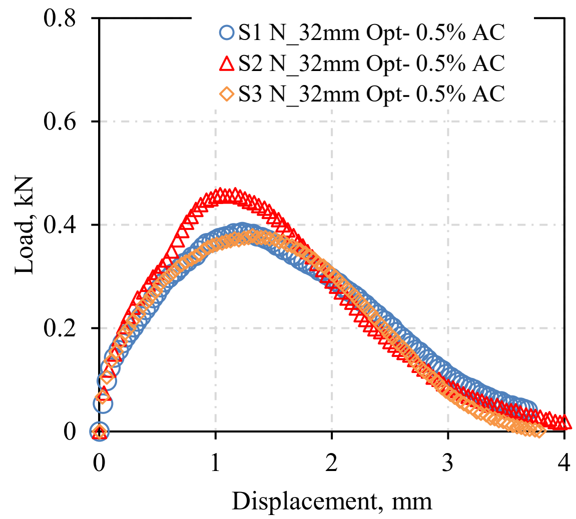
(a) Strain energy vs. notch depth (b) J_c value at optimum AC

FIGURE 4.22 Strain energy release rate determination

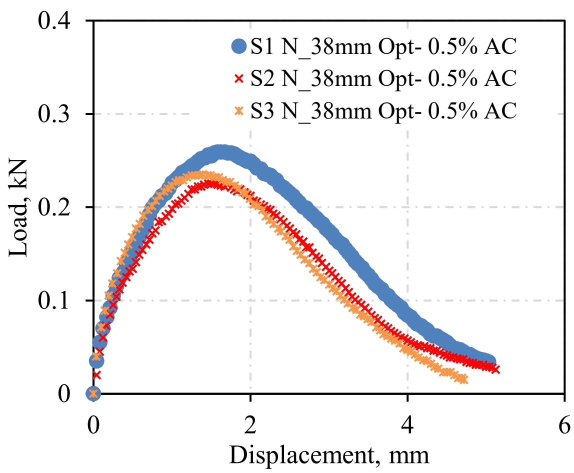
Figures 4.23(a), (b), and (c) show SCB test results for sand and gravel mix with 15% aged materials at the optimum -0.5% binder content at a notch depth of 25.0 mm, 32.0 mm, and 38.0 mm, respectively. The area under the load-displacement plot up to peak load was determined for each specimen. This area represents critical strain energy and is plotted in Figure 73(d). As can be seen from Figure 73(d), the strain energy decreases with an increase in notch depth, which is obvious. The average strain energy is calculated to be 0.465 kJ for 25 mm notch depth, whereas 0.363 kJ and 0.254 kJ for 32.0 and 38.0 mm notch depth, respectively.



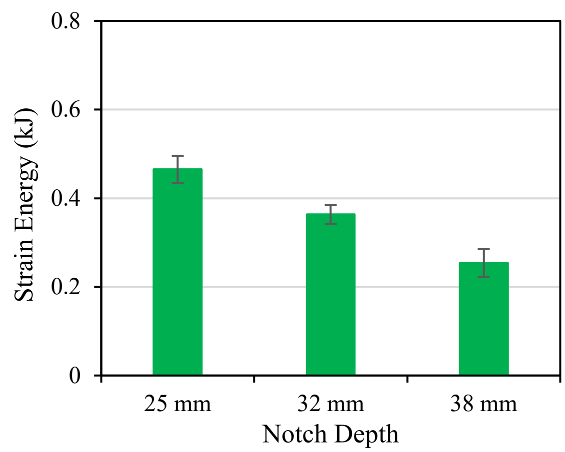
(a) 25 mm notch depth



(b) 32 mm notch depth



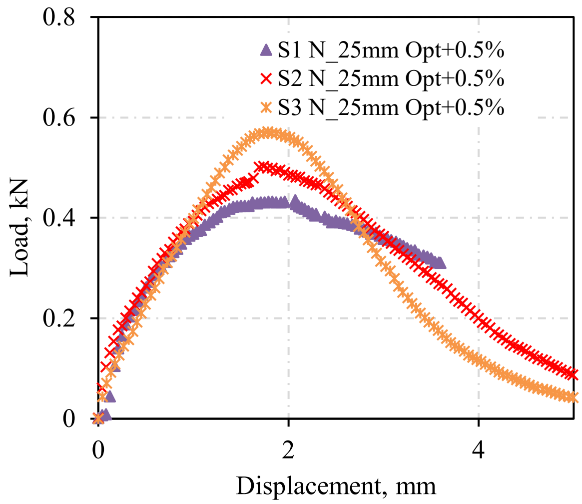
(c) 38 mm notch depth



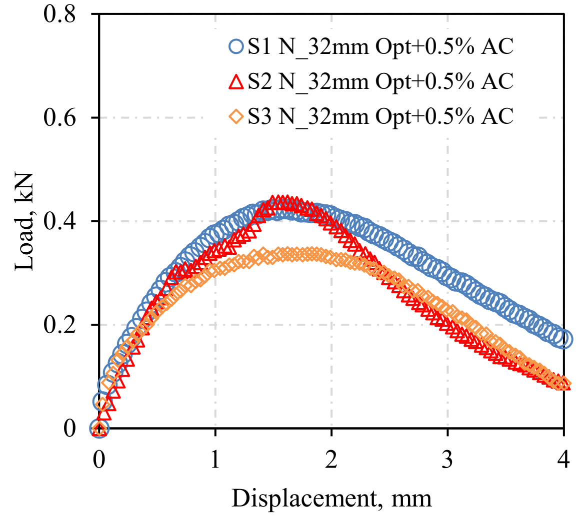
(d) Strain energy

FIGURE 4.23 SCB test results for optimum -0.5% AC

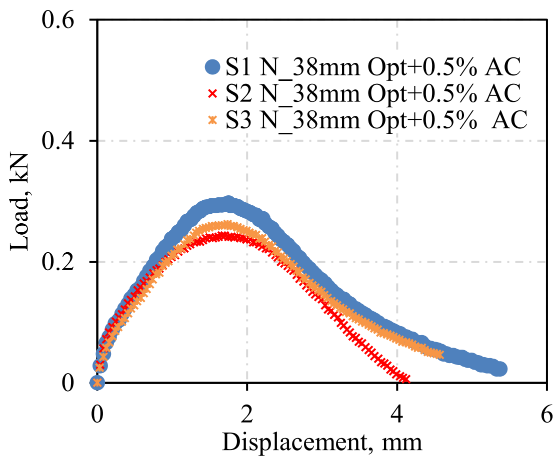
Figures 4.24 (a), (b), and (c) show SCB test results for sand and gravel mix with 15% aged materials at the optimum +0.5% binder content at a notch depth of 25.0 mm, 32.0 mm, and 38.0 mm, respectively. The area under the load-displacement plot up to peak load was determined for each specimen. This area represents critical strain energy and is plotted in Figure 74(d). As can be seen from Figure 74(d), the strain energy decreases with an increase in notch depth, which is obvious. The average strain energy is calculated to be 0.666 kJ for 25 mm notch depth, whereas 0.446 kJ and 0.319 kJ for 32.0 and 38.0 mm notch depth, respectively.



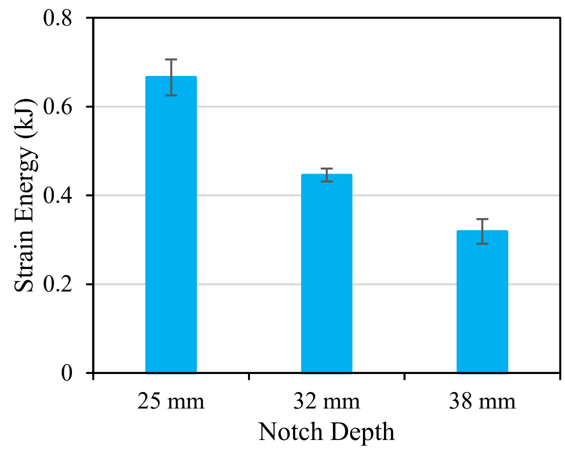
(a) 25 mm notch depth



(b) 32 mm notch depth



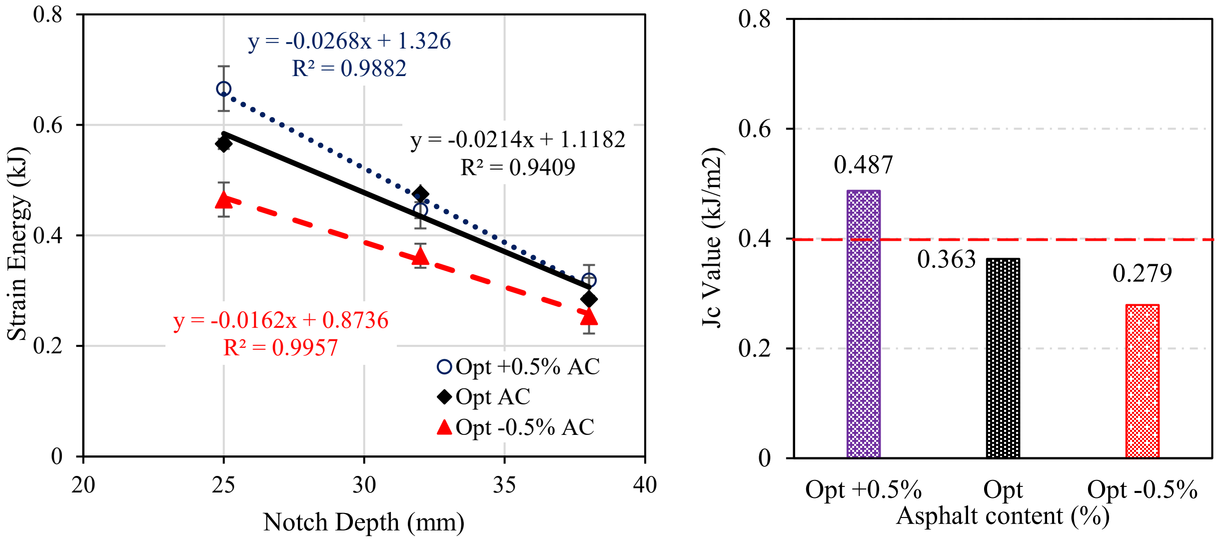
(c) 38 mm notch depth



(d) Strain energy

FIGURE 4.24 SCB test results for optimum +0.5% AC

The slope of the strain energy vs. notch depth, which is known as J_C was determined for optimum +0.5% and -0.5%. A comparison of J_C values of the mixes obtained from the SCB test is illustrated in Figure 75. The J_C value is measured to be 0.48 kJ/m^2 for the optimum +0.5% AC, whereas it is 0.363 kJ/m^2 for the optimum asphalt content (5.2%) and 0.279 kJ/m^2 for the optimum -0.5% AC. A minimum J_c value of 0.4 kJ/m^2 is suggested in the specification set by Wisconsin DOT (6), which is used in this study for low to medium-volume traffic. Based on the specification, it can be said that mix with optimum +0.5% AC meets the minimum requirement for the J_c value, as shown in Figure 4.25(b).



(a) Strain energy vs. notch depth (a) J_c value at different asphalt content

FIGURE 4.25 Comparison of J_c value at different asphalt content

Performance Space Diagram Mix#3a, Mix#3b

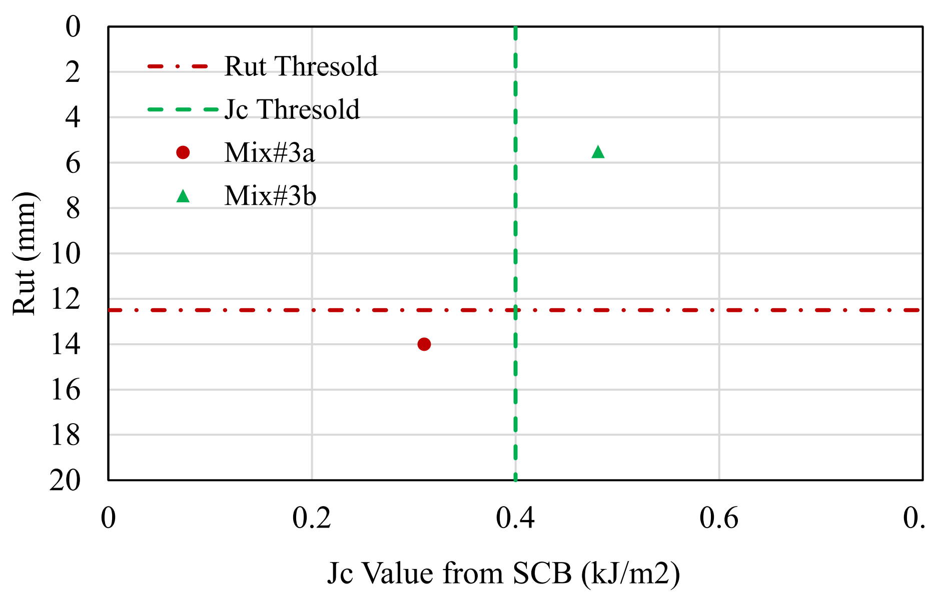


FIGURE 4.26 HWTT-SCB performance space diagram for Mix#3a, Mix#3b

As shown in the Performance Space Diagram in Figure 4.26, Mix#3a did not satisfy either the rutting or cracking performance criteria. The mixture exhibited a rut depth of 14.0 mm, which exceeded the selected threshold of 12.5 mm, and an SCB Jc value of 0.31 kJ/m², which was below the minimum criterion of 0.40 kJ/m². Consequently, Mix#3a was classified as an unbalanced mixture.

In contrast, Mix#3b, which incorporated 15% RAP and was evaluated at the optimum asphalt content plus 0.5%, satisfied both performance requirements. The mixture exhibited a rut depth of 5.5 mm and an SCB Jc value of 0.481 kJ/m², placing it within the acceptable performance region. These results demonstrate that the addition of RAP combined with a modest increase in asphalt content significantly improved both rutting and cracking performance, resulting in a balanced mixture.

4.5 EVALUATION OF MIX #4

Mix #4 was designed in the laboratory using locally available aggregates with the addition of 15% reclaimed asphalt pavement (RAP) and PG 70-28 asphalt binder. Mix #4 was initially designed following the Superpave mix design procedure, evaluated for rutting resistance using the Hamburg Wheel Tracking Test (HWTT) and for cracking resistance using the Semi-Circular Bend (SCB) test and Illinois Flexibility Index Test (IFIT). The properties of aggregates used to prepare Mix#4 is presented in Table 4.9.

TABLE 4.9 Properties of Aggregates used for Preparation of Mix#4

Materials	Percentage (%)	Bulk Specific Gravity (Gsb)	Absorption (%)
1 in. Aggregate	40.0	2.618	0.9
1/2 in. Aggregate	18.0	2.606	1.1
ASCF	17.0	2.557	1.5
DCF	10.0	2.533	2.3
RAP	15.0	2.702	—
Liquid Antistrip	0.55	1.000	—

Design of Mix#4

The blended gradation of blended aggregates for Mix#4 is shown in Figure 4.27

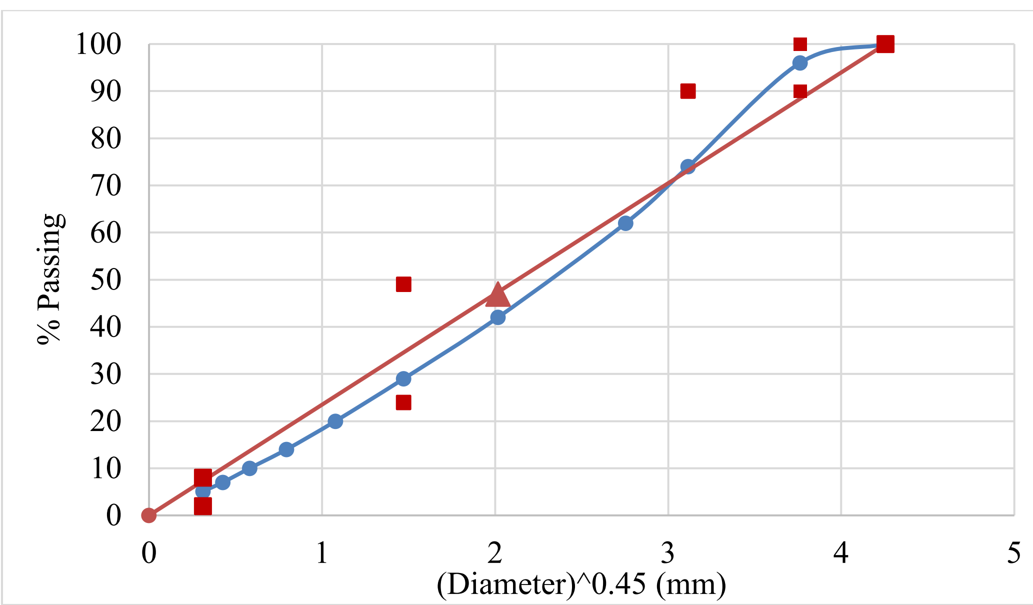


FIGURE 4.27 Aggregate gradation of the final blend for Mix#4

Following the Superpave mix design procedure, specimens were prepared at four trial asphalt binder contents of 4.2%, 4.7%, 5.2%, and 5.7%. The volumetric properties of each specimen were determined, and the optimum asphalt content was selected as the binder content corresponding to 4.0% design air voids. Based on the relationship between air voids and asphalt content, the optimum asphalt content was determined to be 4.8%, as shown in Figure 4.28.

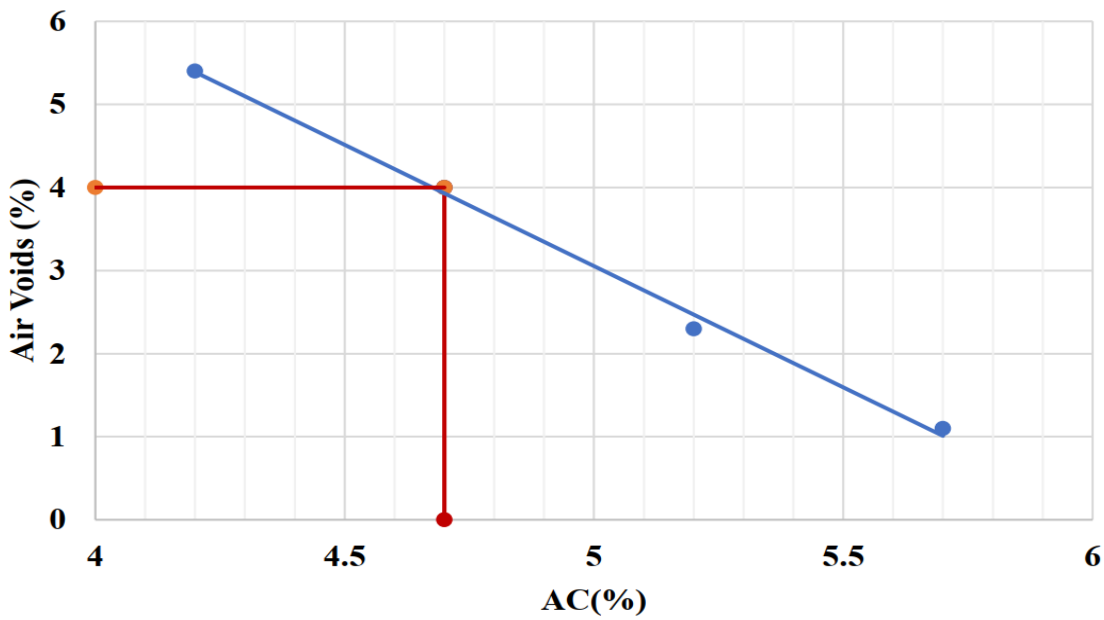


FIGURE 4.28 Optimum Asphalt Content of Mix#4

The volumetric properties of Mix#4 are presented in Table 4.10.

TABLE 4.10 The volumetric properties of Mix#4

Design Parameters	Design Values	Design Criteria Lower	Design Criteria Upper	Acceptance Limits Lower	Acceptance Limits Upper
Design A.C.	4.80			4.3	5.3
RAP A.C.	1.67			-	-
Virgin A.C.	3.13			-	-
Air Voids	4.0	4.0	4.0	2.6	5.4
VMA	13.5	13.5	15.0	11.9	15.1

VFA	70.4	68.0	75.0	-	-
Binder Absorption	0.74				
Eff. % AC	4.10	-	-	-	-

4.5.1 Performance of Mix#4

Rutting Performance

The Hamburg Wheel Tracking Device (HWTD) test results for Mix #4 are presented in Figure 4.19. No evidence of moisture-induced damage or stripping inflection was observed throughout the test, indicating good resistance to stripping under the test conditions. As shown in Figure 4.29, the mixture exhibited a maximum rut depth of approximately 7 mm after 20,000 wheel passes.

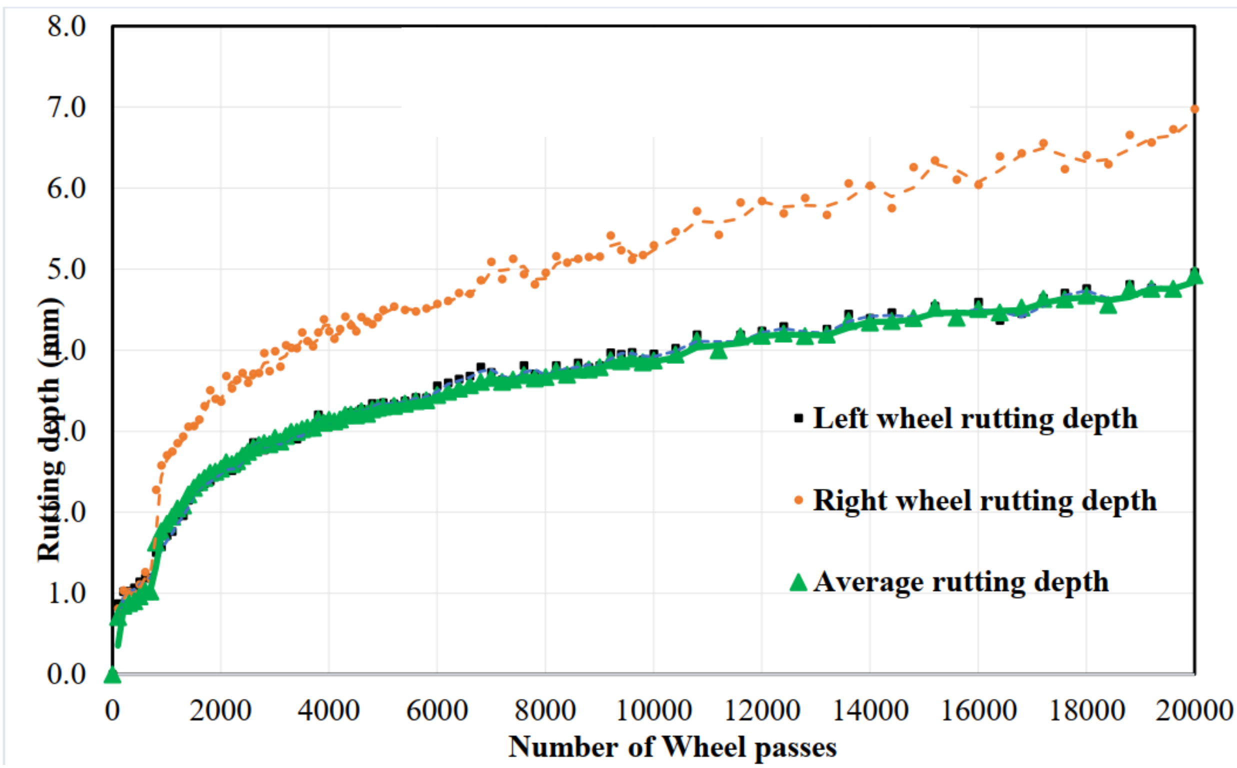


FIGURE 115 HWTT result for Mix#4

Cracking Performance

SCB Test

SCB spe SCB test resultscimens were prepared at the optimum asphalt content of 4.8% with notch depths of 25, 32, and 37 mm. The critical strain energy (Wc), which was calculated as 0.52 J, 0.26 J, and 0.25 J for notch depths of 25, 32, and 37 mm, respectively. The slope of the strain energy versus notch depth relationship was used to determine the critical strain energy release rate, Jc. The resulting Jc value at the optimum asphalt content was 0.414 kJ/m², greater than the minimum requirement of 0.40 kJ/m² specified by the Wisconsin Department of Transportation and adopted in this study. Therefore, the mixture satisfies the cracking performance criterion, as shown in Figure 4.30.

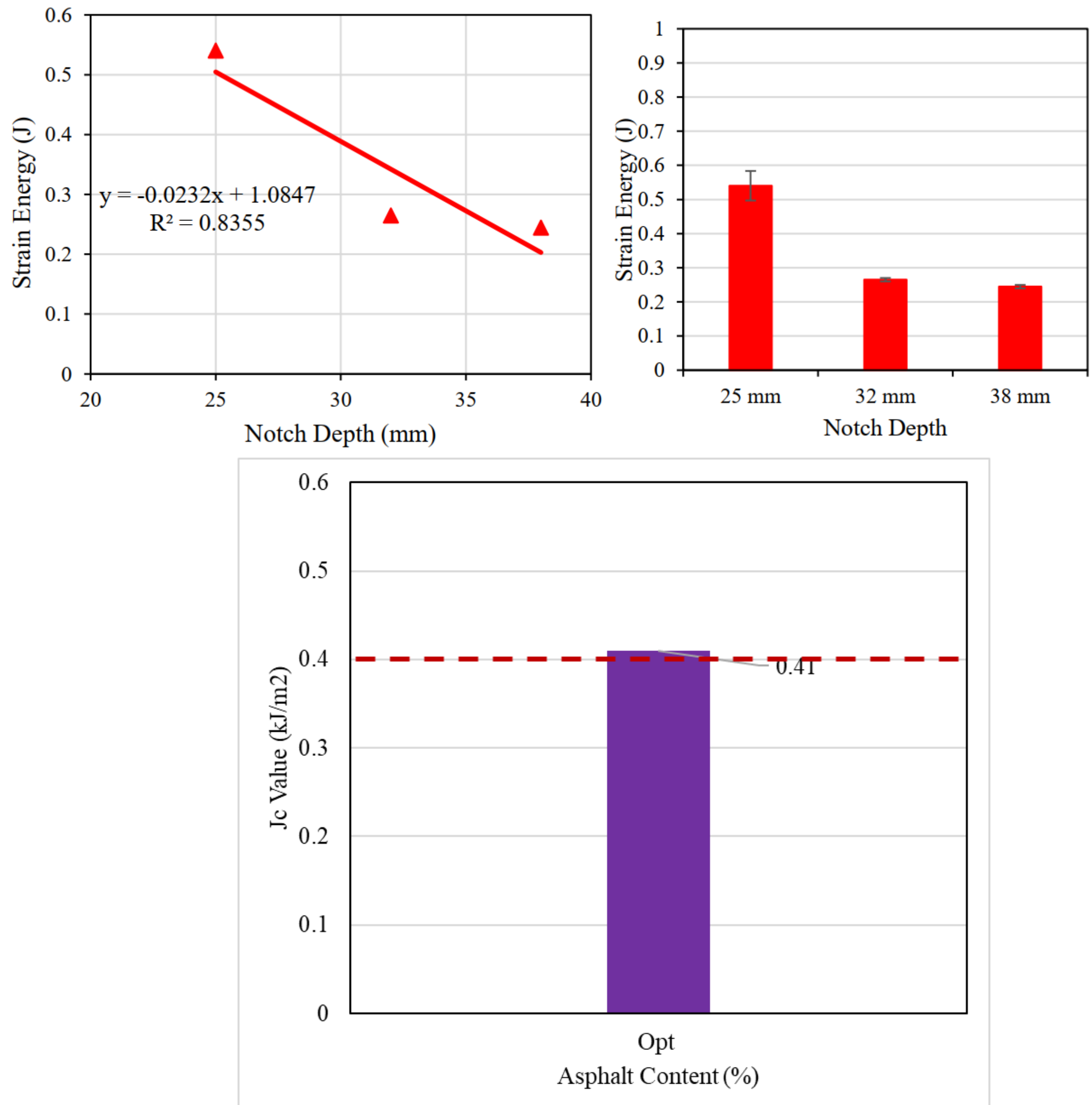


FIGURE 4.30 SCB test results of Mix#4

IFIT Test

The load-displacement response from the Illinois Flexibility Index Test (I-FIT) for Mix#4 is presented in Figure 4.31. The applied load increased with displacement until reaching the peak load, after which it decreased as the specimen fractured. As shown in Figure 4.32, the mixture at the optimum asphalt content exhibited a Flexibility Index (FI) of 9.2. This value exceeds the commonly accepted FI criterion of 8.0 (4). Therefore, the mixture satisfies the cracking performance requirement based on the I-FIT criteria.

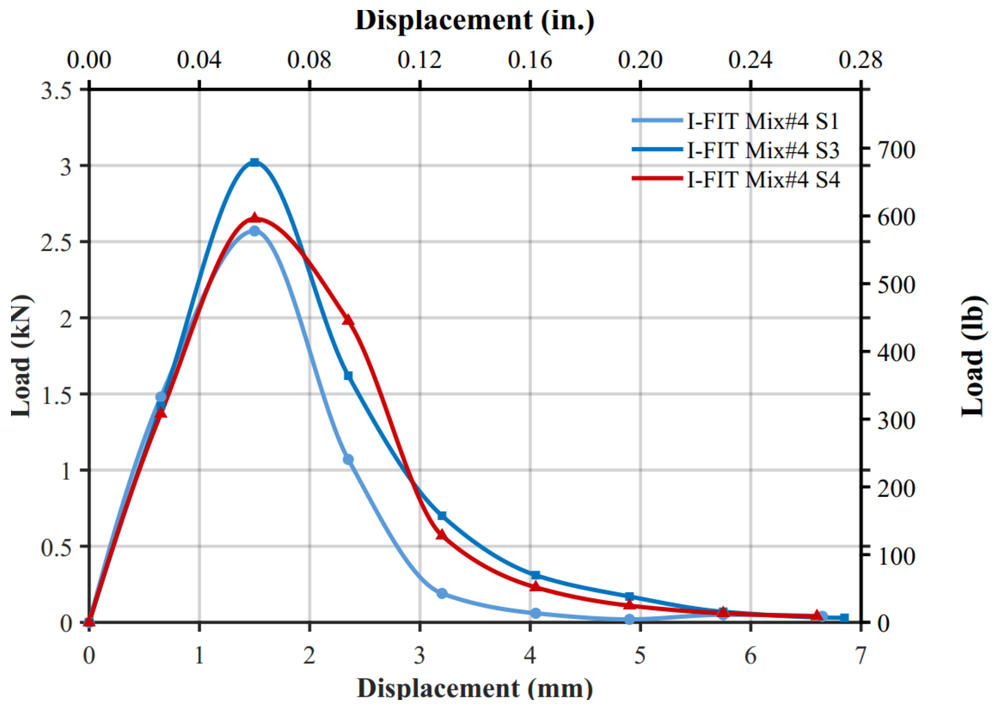


FIGURE 116 IFIT test results of Mix#4

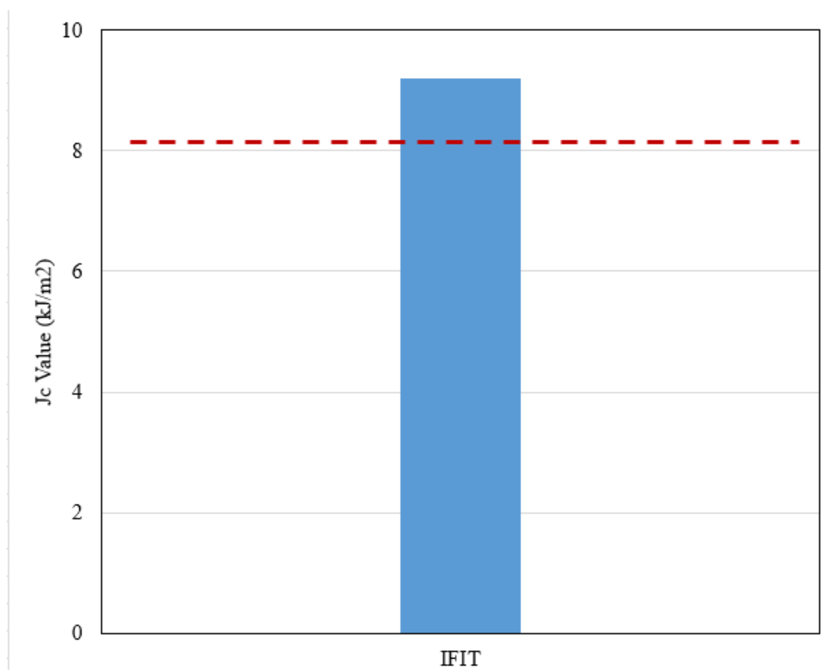


FIGURE 117 IFIT of Mix#4

Performance Space Diagram of Mix#4

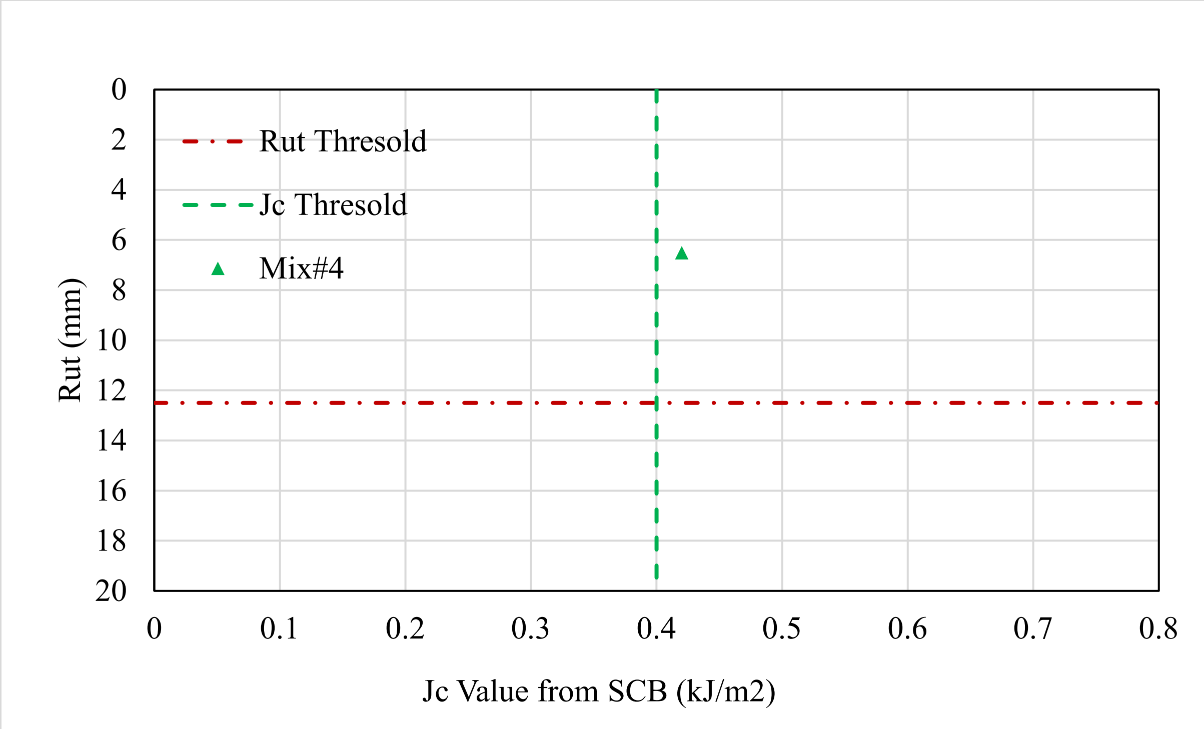


FIGURE 118 Performance Space Diagram of Mix#4

As shown in the Performance Space Diagram in Figure 4.33, Mix#4 satisfied both the rutting or cracking performance criteria. The mixture exhibited a rut depth of 6.5 mm, which is below the selected threshold of 12.5 mm, and an SCB Jc value of 0.41 kJ/m², above the minimum criterion of 0.40 kJ/m². Consequently, Mix#4 was classified as an balanced mixture.

4.6 EVALUATION OF MIX #5

Mix #5 was collected from field. The mix consisted of 35% RAP material, and the binder of the mix was PG 70-28 asphalt binder. The mix was reheated to compaction temperature following the compaction using Superpave gyratory compactor. The performance for rutting resistance was evaluated using the Hamburg Wheel Tracking Test (HWTT) and for cracking resistance using the Semi-Circular Bend (SCB). The properties of aggregates used to prepare Mix#5 is presented in Table 4.11.

TABLE 4.11 Properties of Aggregates used for Mix#5

Combination Used		Bulk Sp. Gravities	Abs. %
1" Minus	26%	2.637	1
1/2" Minus	17%	2.606	1.4
ASCF	22%	2.556	1.7
C-RAP	10%	2.698	NA
F-RAP	25%	2.728	NA
Liquid Antistrip	0.88%	0.998	NA

Properties of Mix#5

The blended gradation of field mix Mix#5 is shown in Figure 4.34.

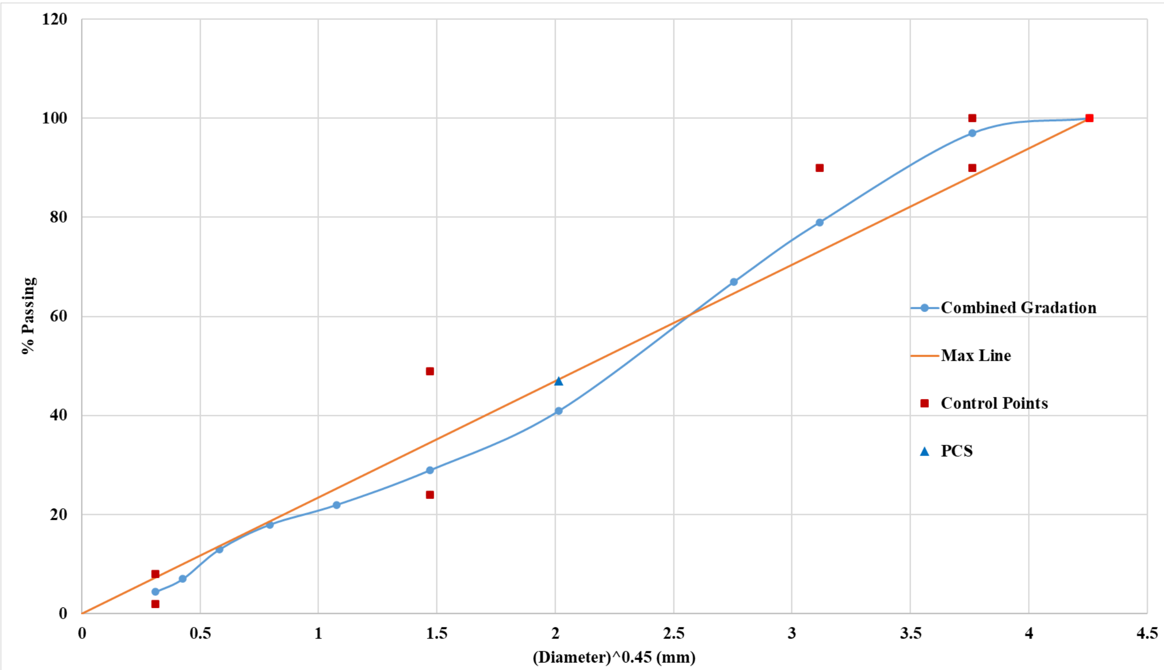


FIGURE119 Aggregate gradation of the final blend for Mix#4

Following the Superpave mix design procedure, for trial asphalt binder contents of 4.2%, 4.7%, 5.2%, and 5.7%, the optimum asphalt content was selected as the binder content corresponding to 4.0% design air voids. Based on the relationship between air voids and asphalt content, the optimum asphalt content was determined to be 4.7%, as shown in Figure 4.35, and the properties of mixes are presented in Table 4.12.

TABLE 4.12 Properties of trial mixes of Mix#5

AC (%)	Gmm	Gmb	Unit Wt. (lb/ft³)	Air Voids (%)	VMA (%)	VFA (%)	Dust to Binder Ratio
4.2	2.51	2.389	149.1	4.8	13.4	64	1.2
4.7	2.491	2.392	149.2	4	13.7	71	1.05
5.2	2.472	2.402	149.9	2.8	13.8	79.4	0.94
5.7	2.454	2.408	150.2	1.9	14	86.7	0.85

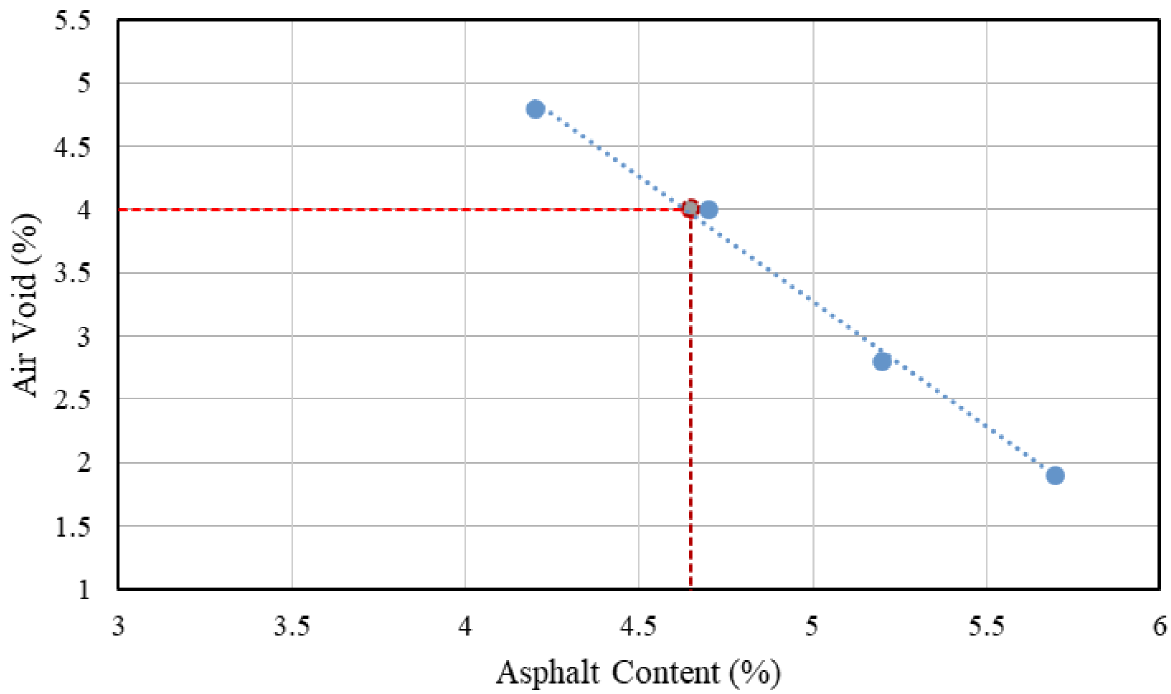


FIGURE 120 Optimum Asphalt Content of Mix#5

The volumetric properties of Mix#5 are presented in Table 4.13.

TABLE 4.13 The volumetric properties of Mix#5

Design Parameters	Design Values	Design Criteria		Acceptance Limits	
		Lower	**Upper**	**Lower**	**Upper**
Design A.C.	4.7	-	-	4.2	5.2
RAP A.C.	1.75	-	-	-	-
Virgin A.C.	2.95	-	-	-	-
Air Voids	4	-	4	2.6	5.4
VMA	13.7	13.5	15	12.1	15.3
VFA	70.8	68	75	-	-
Binder Absorption	0.57	-	-	-	-
Effective AC (%)	4.16	-	-	-	-
Liquid Antistrip	0.88	-	-	0.68	1.08
Average AC of the RAP Material	4.71%		--	-	-
Unit Weight	155.4	-	-	-	-
Gmb (T-166) @ Ndes	2.392	-	-	-	-
Gmm (T-209) @ Design A.C.	2.491	-	-	-	-
Gse	2.681	-	-	-	-

Density @ Ninitial (8 Gyrations)	87.7	89 Max		-	-
Density @ Nmaximum (160 Gyrations)	97.2	98 Max		-	-
Dust Proportion	1.1	0.6	1.4	0.8	1.4
Water @ Mixing of Liquid Antistrip + Aggregates	N/A	-	-	-	-

4.6.1 Performance of Mix#5

Rutting Performance

HWTT was used to evaluate the rutting performance of Mix#5. From the rutting test results, Figure 4.36, it was found that after 20,000 wheels passing the rutting value ranged from 2.3mm to 3.8mm which is way below the standard value of 12.5mm. The mix did not show any stripping potential.

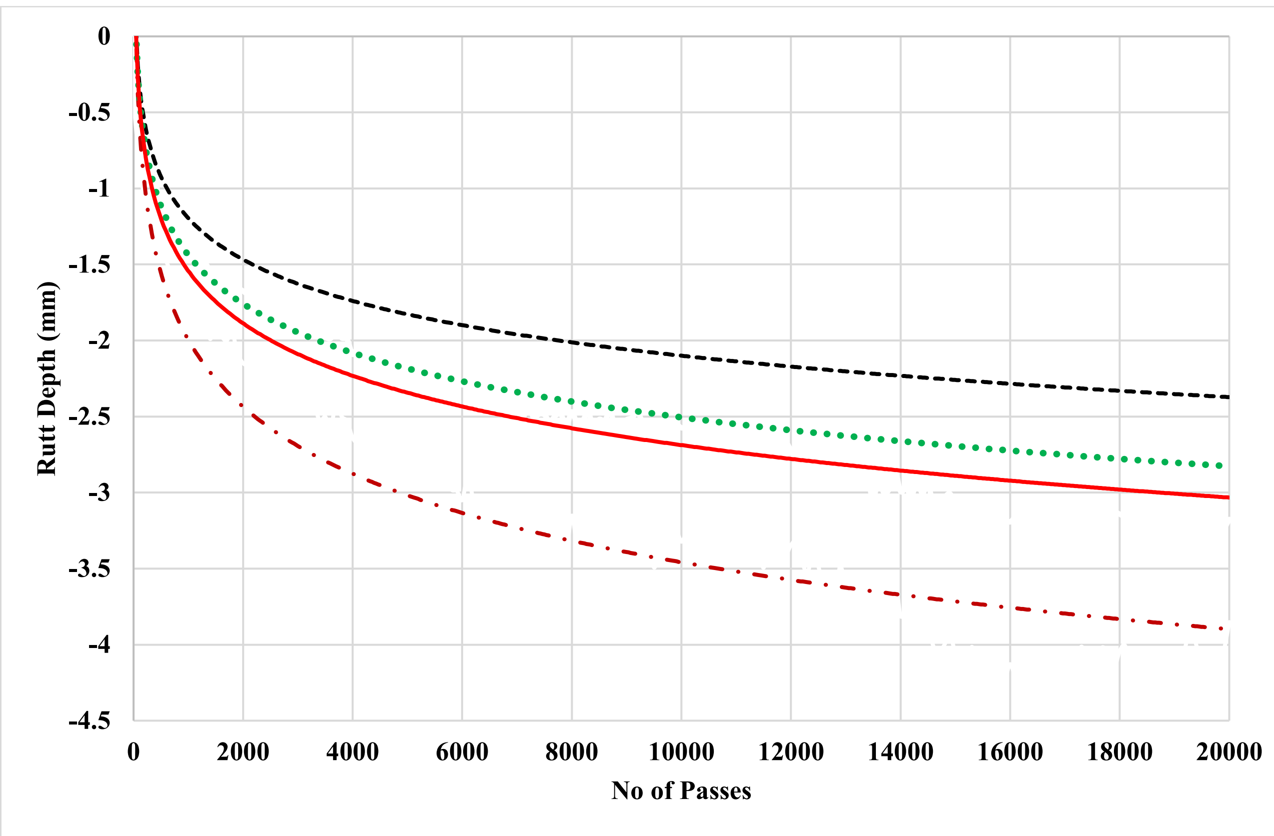
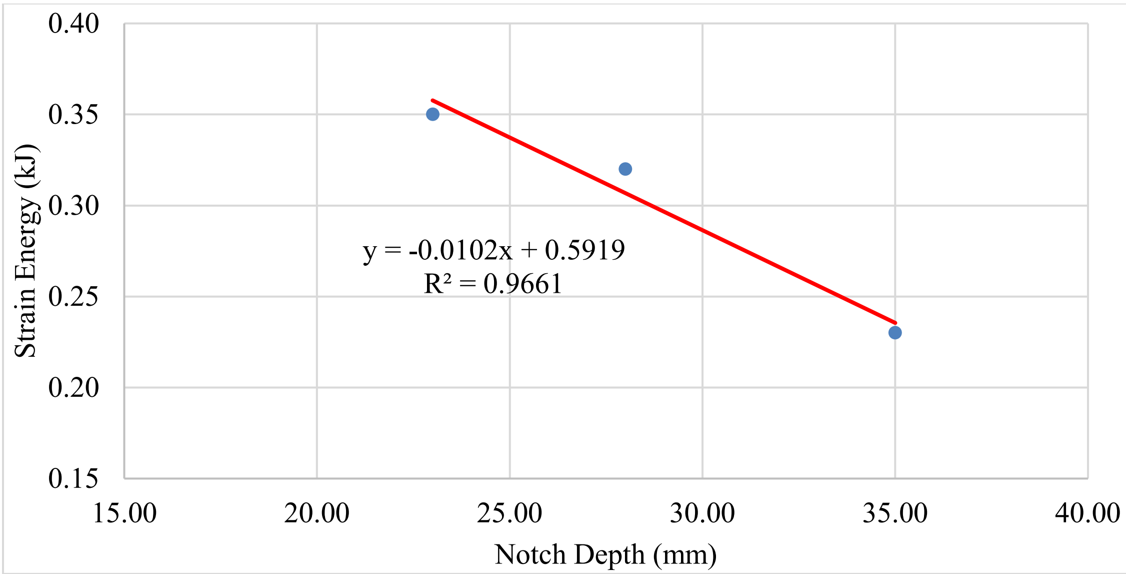


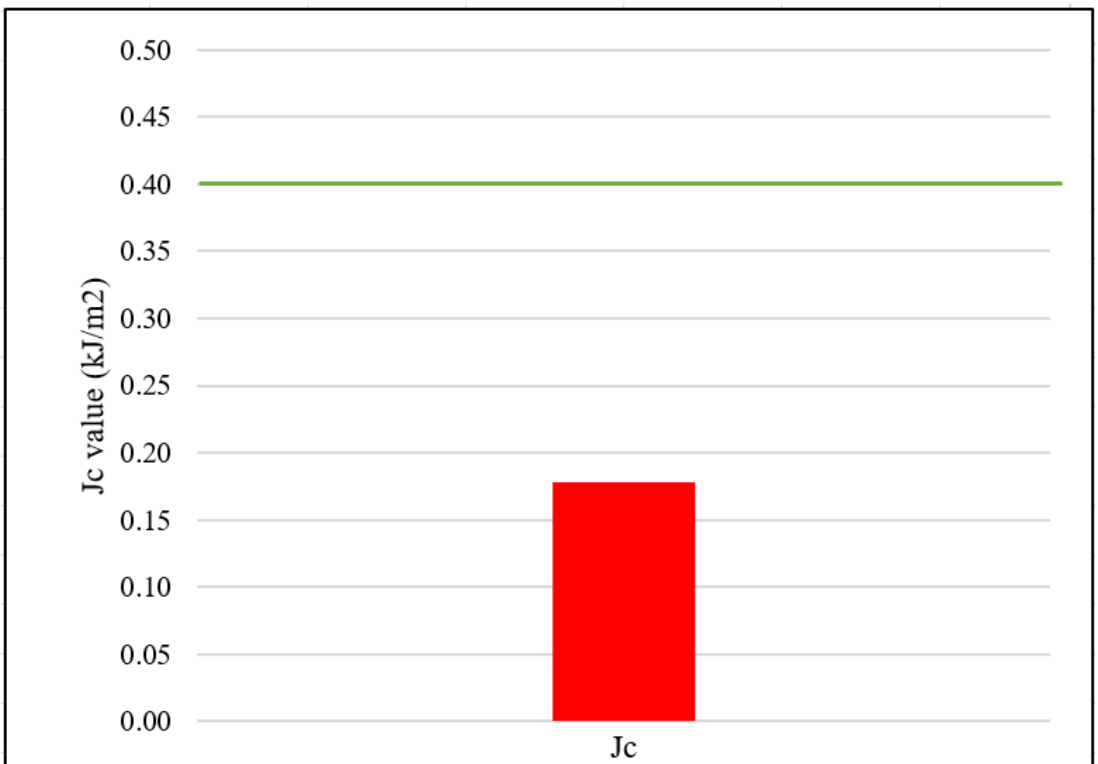
FIGURE 121 HWTT test results of Mix#5

Cracking Performance

SCB Test



(a) Strain energy vs notch depth for BMD#5 mix



(b) Jc value of BMD#5

FIGURE 122 SCB of BMD#5

SCB test specimens were prepared at the optimum asphalt content of 4.7% with notch depths of 25, 32, and 37 mm. The critical strain energy (Wc), which was calculated as 0.35 kJ, 0.32 kJ, and 0.23 kJ for notch depths of 25, 32, and 37 mm, respectively. The slope of the strain energy versus notch depth relationship was used to determine the critical strain energy release rate, Jc. The resulting Jc value at the optimum asphalt content was 0.18 kJ/m², way below the minimum requirement of 0.40 kJ/m². Therefore, the mixture did not meet the cracking performance criterion, as shown in Figure 4.27.

Performance Space Diagram of Mix#5

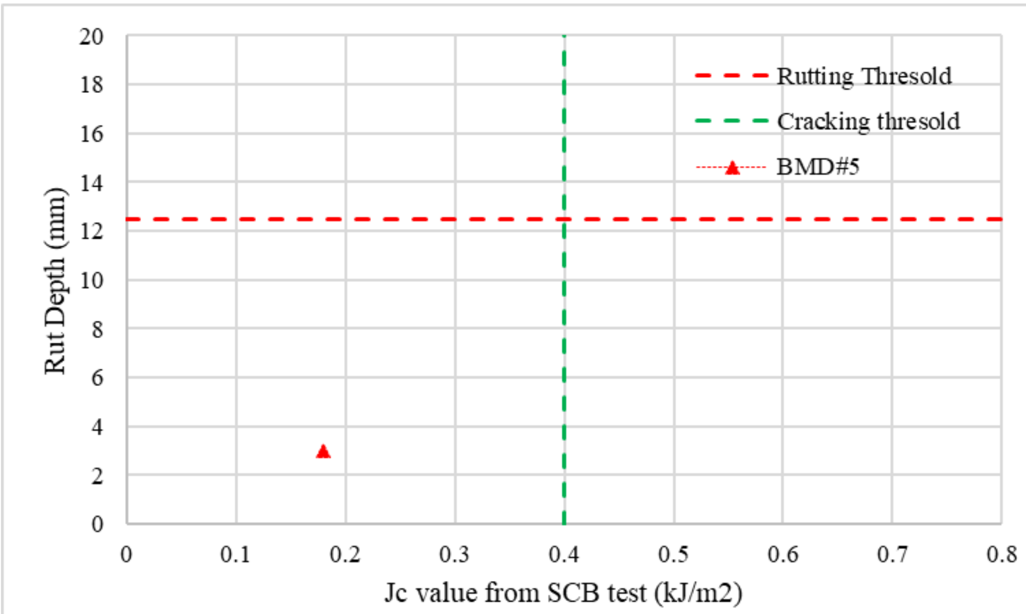


FIGURE 123 HWTT-SCB performance space diagram for Mix#5

As shown in the Performance Space Diagram in Figure 4.38, Mix#5 did not satisfy the cracking performance criteria. The mixture exhibited a rut depth of 3.5 mm, which is below the selected threshold of 12.5 mm, and an SCB Jc value of 0.18 kJ/m², way below the minimum criterion of 0.40 kJ/m². Consequently, Mix#5 was classified as an unbalanced mixture.

4.7 EVALUATION OF MIX #7

Mix #7 was collected from field. The mix consisted of 15% RAP material, and the binder of the mix was PG 76-22 asphalt binder. The mix was reheated to compaction temperature following the compaction using Superpave gyratory compactor. The performance for rutting resistance was evaluated using the Hamburg Wheel Tracking Test (HWTT) and for cracking resistance using the Semi-Circular Bend (SCB). The properties of aggregates used to prepare Mix#5 is presented in Table 4.14.

TABLE 4.14 Properties of Aggregates used for Mix#7

Combination Used		Bulk Sp. Gravities	Abs. %
CA 3/4"	28%	2.722	1.7
IA 3/8"	26%	2.773	2.3
CF	31%	2.859	1.3
RAP	15%	2.755	NA
Liquid Antistrip	0.3%	1	NA

Properties of Mix#7

The blended gradation of field mix Mix#7 is shown in Figure 4.39.

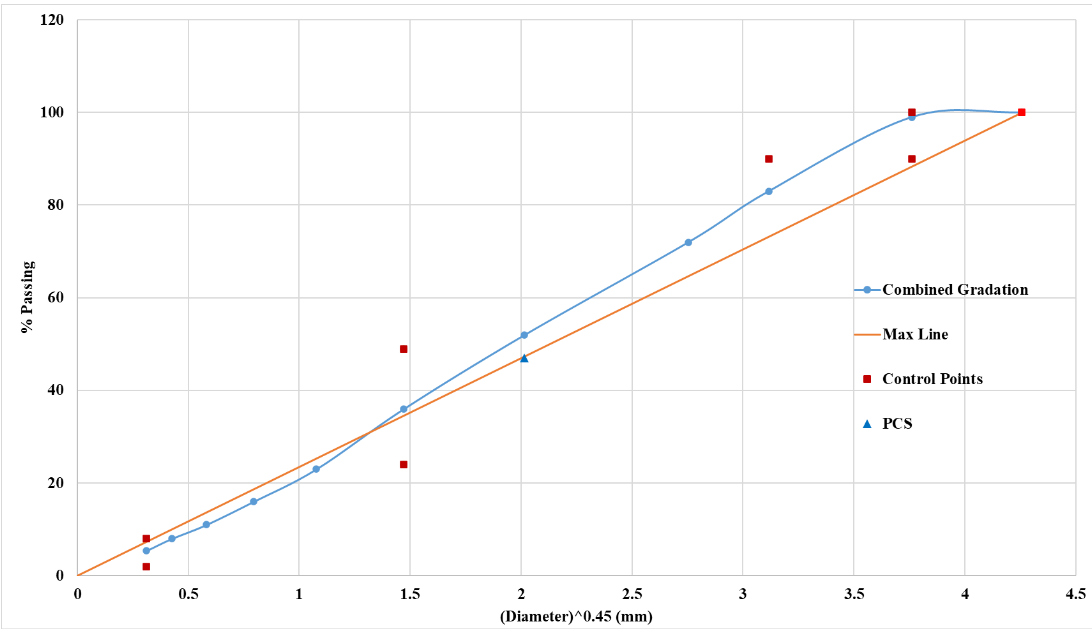


FIGURE 124 Aggregate gradation of the final blend for Mix#7

Following the Superpave mix design procedure, for trial asphalt binder contents of 4.5%, 5%, 5.5%, and 6%, the optimum asphalt content was selected as the binder content corresponding to 4.0% design air voids. Based on the relationship between air voids and asphalt content, the optimum asphalt content was determined to be 5%, as shown in Figure 4.30, and the properties of mixes are presented in Table 4.15.

TABLE 4.15 Properties of trial mixes of Mix#5

AC (%)	Gmm	Gmb	Unit Wt. (lb/ft^3)	Air Voids (%)	VMA (%)	VFA (%)	Dust to Binder Ratio
4.5	2.658	2.505	156.3	5.7	14	59	1.59
5	2.636	2.529	157.8	4.1	13.6	70.2	1.39
5.5	2.614	2.557	159.6	2.2	13.1	83.3	1.23
6	2.593	2.582	161.1	0.4	12.7	96.7	1.1

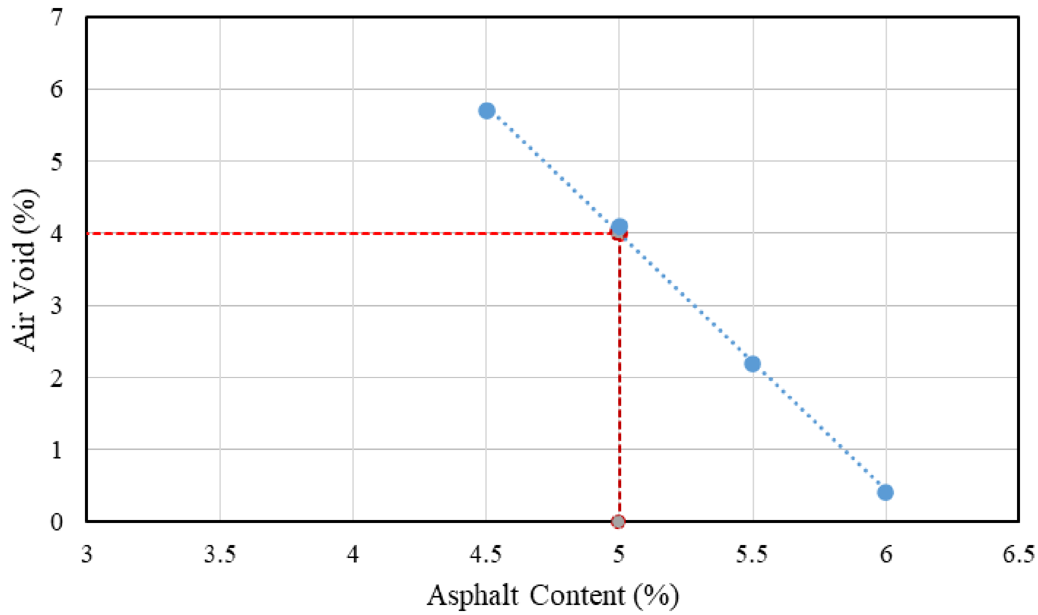


FIGURE 125 Optimum Asphalt Content of Mix#7

The volumetric properties of Mix#5 are presented in Table 4.16.

TABLE 4.16 The volumetric properties of Mix#7

Design Parameters	Design Values	Design Criteria		Acceptance Limits	
		Lower	Upper	Lower	Upper
Design A.C.	5	-	-	4.5	5.5
RAP A.C.	0.88	-	-	-	-
Virgin A.C.	4.12	-	-	-	-
Air Voids	4	-	4	2.6	5.4
VMA	13.6	13.5	15	12	15.2
VFA	70.7	68	75	-	-
Binder Absorption	1.17	-	-	-	-
Effective AC (%)	3.89	-	-	-	-
Liquid Antistrip	0.3%	-	-	0.1	0.5

Average AC of the RAP Material	5.89%		--	-	-
Unit Weight	164.5	-	-	-	-
Gmb (T-166) @ Ndes	2.529	-	-	-	-
Gmm (T-209) @ Design A.C.	2.636	-	-	-	-
Gse	2.872	-	-	-	-
Density @ Ninitial (8 Gyrations)	86.1	89 Max		-	-
Density @ Nmaximum (160 Gyrations)	97.2	98 Max		-	-
Dust Proportion	1.4	0.6	1.4	1.1	1.7
Water @ Mixing of Liquid Antistrip + Aggregates	N/A	-	-	-	-

4.7.1 Performance of Mix#7

Rutting Performance

HWTT was used to evaluate the rutting performance of Mix#5. From the rutting test results, Figure 4.41, it was found that after 20,000 wheels passing the rutting value ranged from 2.5mm to 3.5mm which is way below the standard value of 12.5mm. The mix did not show any stripping potential.

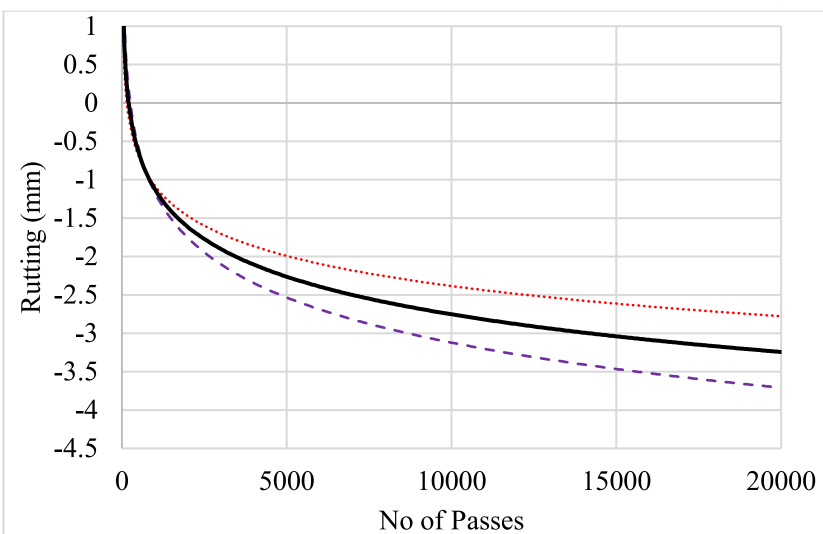
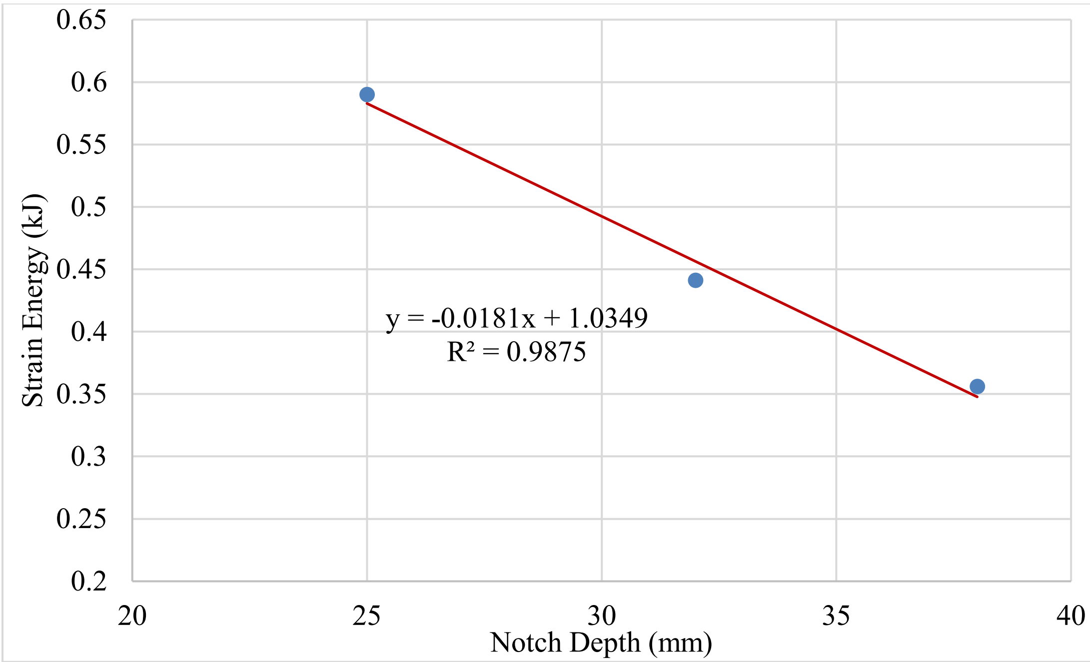


FIGURE 126 HWTT test results of Mix#7

Cracking Performance

SCB Test



(a) Strain energy vs notch depth of BMD#7 mix

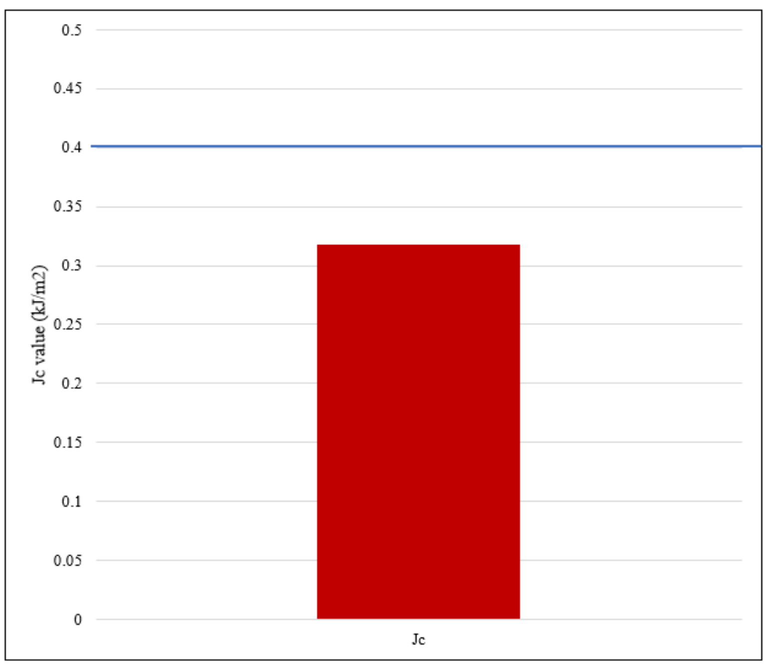


FIGURE 127 SCB of BMD#7

SCB test specimens were prepared at the optimum asphalt content of 5% with notch depths of 25, 32, and 37 mm. The resulting Jc value at the optimum asphalt content was 0.31 kJ/m², below the minimum requirement of 0.40 kJ/m². Therefore, the mixture did not meet the cracking performance criterion, as shown in Figure 4.42.

Performance Space Diagram of Mix#7

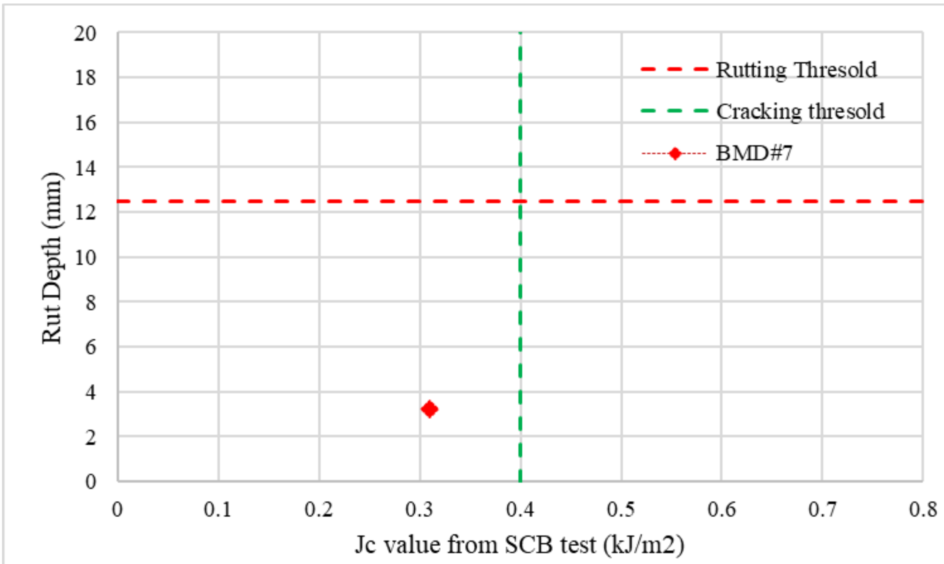


FIGURE 128 HWTT-SCB performance space diagram for Mix#7

As shown in the Performance Space Diagram in Figure 4.43, Mix#7 did not satisfy the cracking performance criteria. The mixture exhibited a rut depth of 3.5 mm, which is below the selected threshold of 12.5 mm, and an SCB Jc value of 0.18 kJ/m², way below the minimum criterion of 0.40 kJ/m². Consequently, Mix#5 was classified as an unbalanced mixture.

4.8 EVALUATION OF MIX#8

Mix #8 was collected from field. The mix did not include any RAP material, and the binder of the mix was PG 64-22 asphalt binder. The mix was reheated to compaction temperature following the compaction using Superpave gyratory compactor. The performance for rutting resistance was evaluated using the Hamburg Wheel Tracking Test (HWTT) and for cracking resistance using the Indirect Tensile Asphalt Cracking Test (IDEAL-CT). The properties of aggregates used to prepare Mix#8 is presented in Table 4.17.

TABLE 4.17 Properties of aggregates for Mix#8

Combination Used		Bulk Sp. Gravities	Abs. %
5/8"	25%	2.637	0.9
3/8"	25%	2.625	1.1
CF	50%	2.663	0.2
Liquid Antistrip	0.8%	1	NA

The combined gradation for the BMD#8 aggregates is shown in Figure 4.44. The NMAS for gradation is 12.5 mm and the gradation lies below the primary control sieve (PCS) is 2.36 mm. The percentage passing the PCS control point is < 39%, so the combined gradation for BMD#8 was classified as coarse graded.

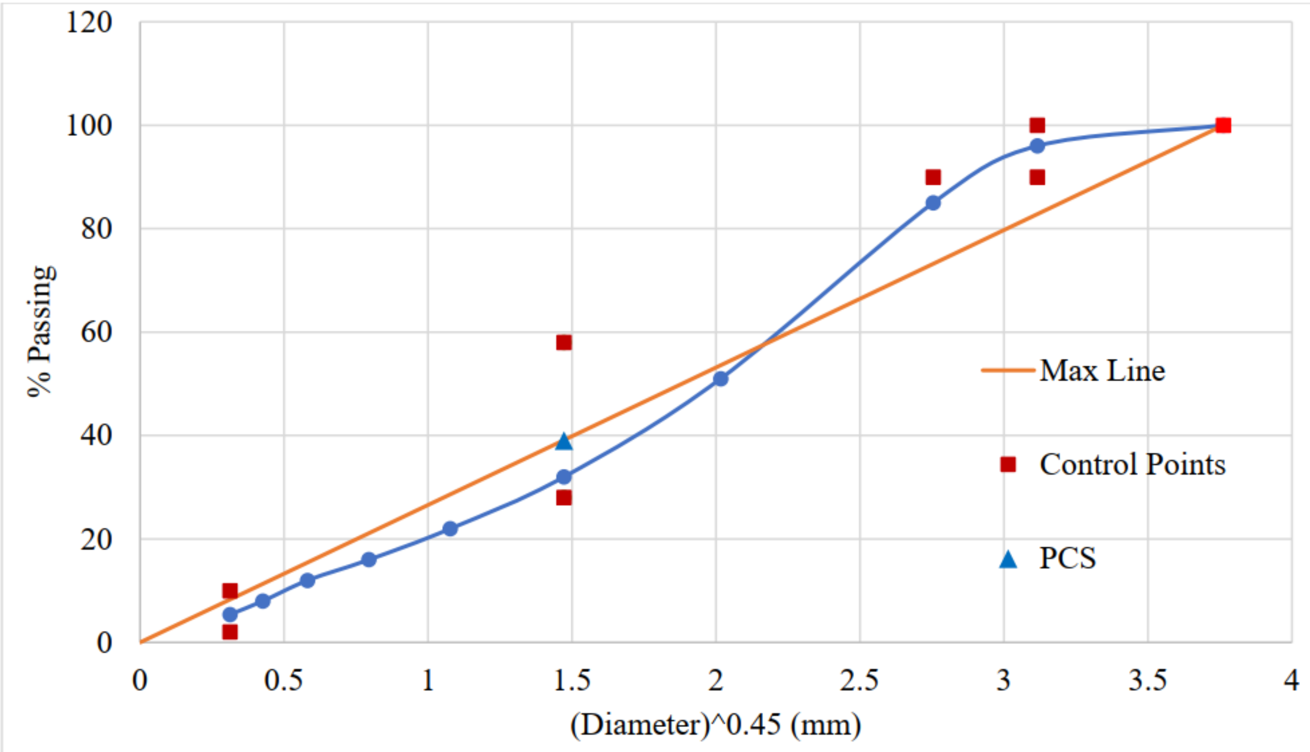


FIGURE 129 Combined gradation of Aggregates for Mix#8

According to Superpave method different AC (%) was tried and the AC (%) that gave 4% air void for design gyration was selected as design asphalt content. The design AC for BMD#8 found as 5.1% (Figure 4.45). Table 4.18 presents the properties of BMD#8 trial mixes at different AC.

TABLE 4.18 Properties of compacted BMD#8 mixes

AC (%)	Gmm	Gmb	Unit Wt. (lb/ft³)	Air Voids (%)	VMA (%)	VFA (%)	Dust to Binder Ratio
4.6	2.474	2.33	145.4	5.8	16.0	63.7	1.22
5.1	2.456	2.357	147.1	4.0	15.5	74.1	1.1
5.6	2.438	2.377	148.3	2.5	15.2	83.7	1.0
6.1	2.42	2.397	149.6	0.9	15.0	93.7	0.91

From the asphalt content (%) vs air voids (%) plot (Figure 4.35) it was found that 4.7% AC matches the 4% air void at design gyration and other volumetric properties (VMA, VFA, dust proportion) presented in Table 4.19.

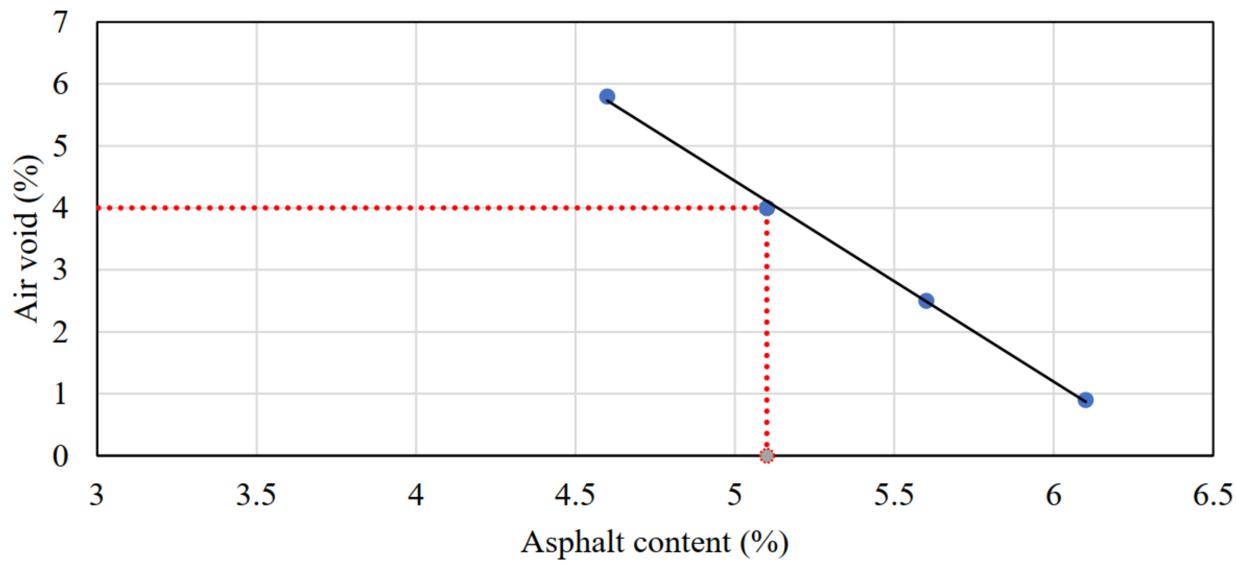


FIGURE 4.45 Optimum AC (%) of Mix#8

TABLE 4.19 Volumetric Properties of Mix#8

Design Parameters	Design Values	Design Criteria		Acceptance Limits	
		Lower	Upper	Lower	Upper
Design A.C.	5.1	-	-	4.6	5.6
RAP A.C.	0	-	-	-	-
Virgin A.C.	5.1	-	-	-	-
Air Voids	4	-	4	2.6	5.4
VMA	15.5	14.5	16	13.9	17.1
VFA	74.2	68	78	-	-
Binder Absorption	0.16	-	-	-	-
Effective AC (%)	4.95	-	-	-	-
Liquid Antistrip	0.3	-	-	0.1	0.5
Average AC of the RAP Material	4.71%		--	-	-
Unit Weight	147.1	-	-	-	-
Gmb (T-166) @ Ndes	2.357	-	-	-	-
Gmm (T-209) @ Design A.C.	2.456	-	-	-	-
Gse	2.658	-	-	-	-
Density @ Ninitial (8 Gyrations)	86.3	90.5 Max		-	-
Density @ Nmaximum (160 Gyrations)	96.5	98 Max		-	-
Dust Proportion	1.1	0.6	1.4	0.8	1.4

4.8.1 Performance of Mix#8

Rutting Performance

The Hamburg Wheel-Track Test is a laboratory procedure used to evaluate the rutting performance of asphalt mixtures under simulated traffic loading and moisture conditions. From the rutting test results it was found that after 20,000 wheels passing the rutting value was 5.2mm which is way below the standard value of 12.5mm. The mix did not show any stripping potential (Figure 4.46).

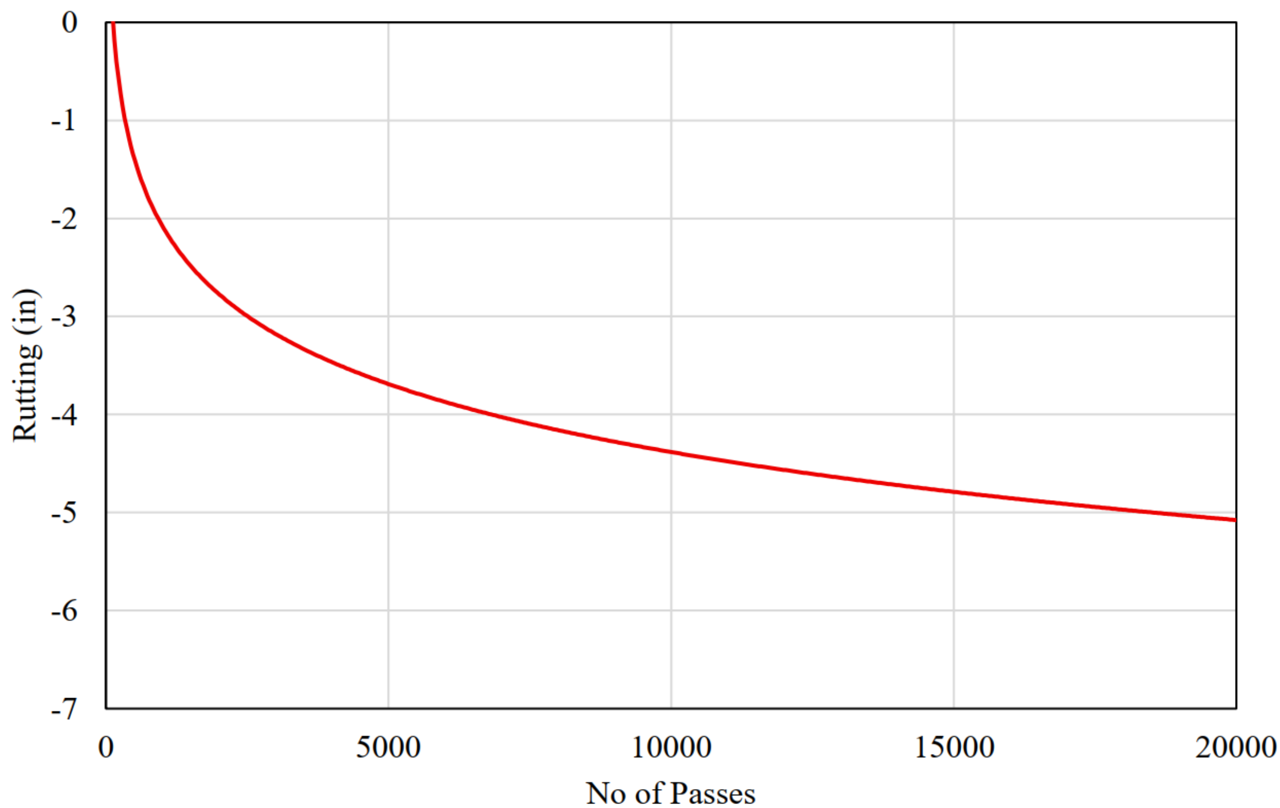


FIGURE 130 HWTT Test result of Mix#8

Cracking Performance

The IDEAL Cracking Test (IDEAL-CT) was conducted to evaluate the cracking resistance of the asphalt mixture. Test specimens were prepared from 150-mm-diameter gyratory-compacted samples with a height of 62 mm at a target air void content of 7.0%. The specimens were tested at 25°C using a displacement rate of 50 mm/min. The cracking resistance was quantified using the CT_{Index}, which was calculated from the load–displacement response. The IDEAL-CT test results for Mix #8 are presented in Figure 4.47.

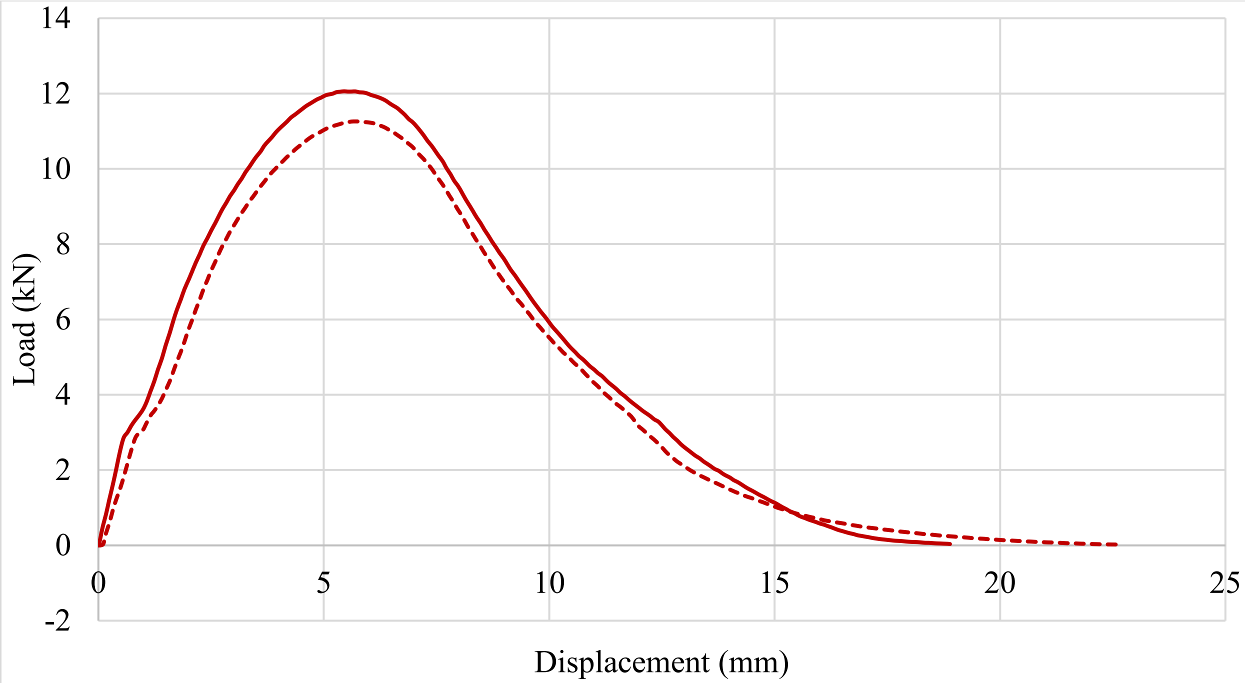


FIGURE 131 Load-displacement for Ideal-CT tests for BMD#8 mix

From the Ideal-CT test results of Mix#8 mix it was found that the average CT_{Index} values were 170 (CT_{Index} >80) which means the Mix#8 mix is good for cracking resistance.

Performance Space Diagram of Mix#8

The performance space diagram (PSD), based on HWTT rutting and Ideal-CT cracking, of the Mix#8 mix is shown in figure 4.48.

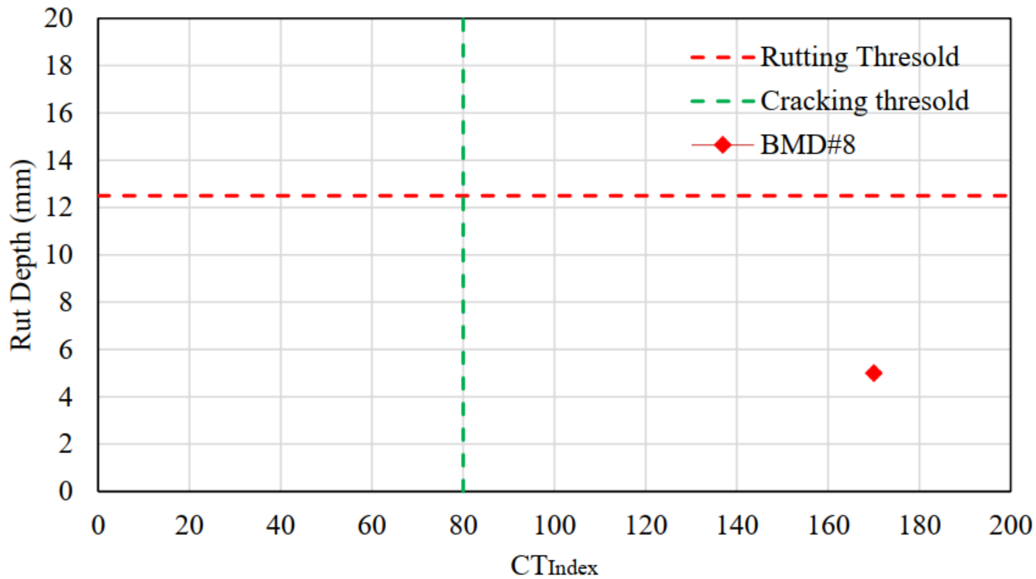


FIGURE 132 HWTT-IDEAL-CT performance space diagram for Mix#8

The Mix#8 mix showed both rutting and cracking resistance; thus Mix#8 could be classified as balanced mix.

4.9 EVALUATION OF MIX#9

Mix #9 was collected from field. The mix included 35% RAP material, and the binder of the mix was PG 58-28 asphalt binder. The mix was reheated to compaction temperature following the compaction using Superpave gyratory compactor. The performance for rutting resistance was evaluated using the Hamburg Wheel Tracking Test (HWTT) and for cracking resistance using the Indirect Tensile Asphalt Cracking Test (IDEAL-CT). The properties of aggregates used to prepare Mix#9 is presented in Table 4.20.

TABLE 4.20 Properties of aggregates for Mix#9

Combination Used		Bulk Sp. Gravities	Abs. %
CA 3/4"	10%	2.483	1.9
3/8"	30%	2.457	3.4
CF	25%	2.427	3.8
RAP	35%	2.632	NA
Liquid Antistrip	0.3%	0.999	NA

The combined gradation for the Mix#9 aggregates is shown in Figure 4.49. The NMAS for gradation is 12.5 mm and the gradation lies below the primary control sieve (PCS) is 2.36 mm. The percentage passing the PCS control point is > 39%, so the combined gradation for Mix#9 is classified as fine graded.

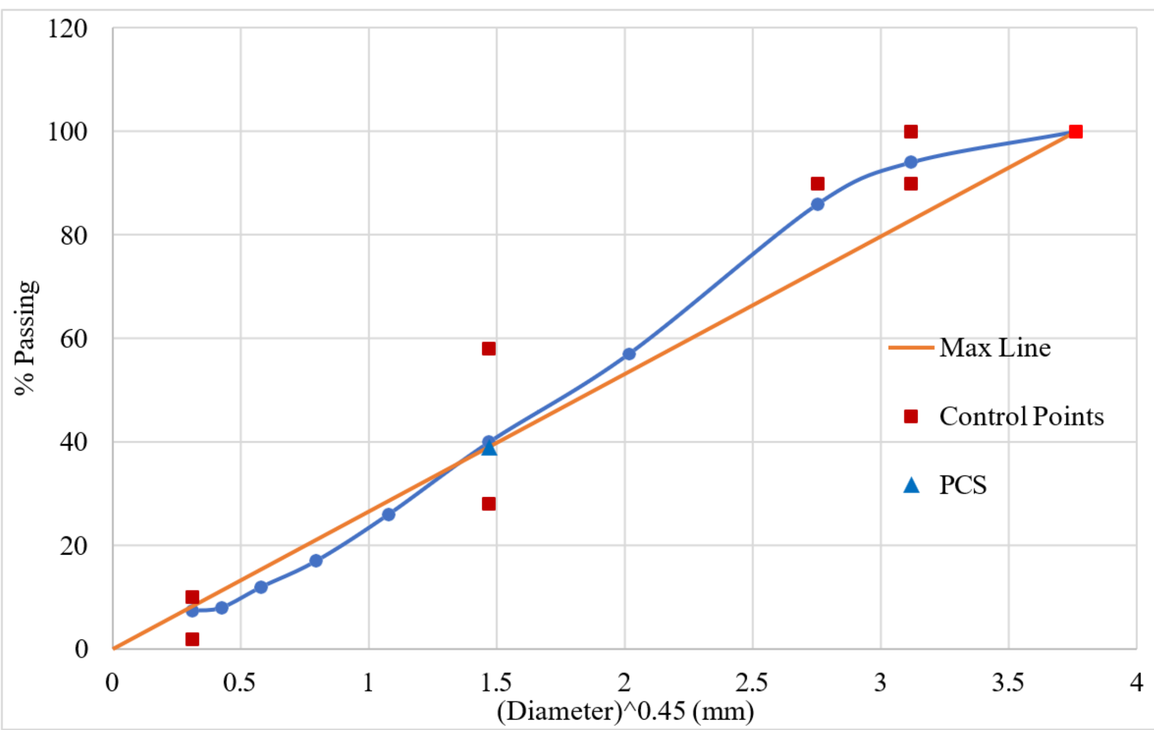


FIGURE 133 Combined gradation of Aggregates for Mix#9

According to Superpave method different AC (%) was tried and the AC (%) that gave 4% air void for design gyration was selected as design asphalt content. The design AC for Mix#9 found as 4.7% (Figure 4.50). Table 4.21 presents the properties of Mix#9 trial mixes at different AC.

TABLE 4.21 Properties of compacted BMD#9 mixes

AC (%)	Gmm	Gmb	Unit Wt. (lb/ft³)	Air Voids (%)	VMA (%)	VFA (%)	Dust to Binder Ratio
4.5	2.36	2.251	140.5	4.6	14.4	67.9	1.36
5	2.349	2.276	142	3.1	13.9	77.7	1.24
5.5	2.335	2.289	142.9	2	13.8	85.9	1.14
6	2.323	2.294	143.1	1.3	14.1	91	1.05

From the asphalt content (%) vs air voids (%) plot (Figure 95) it was found that 4.7% AC matches the 4% air void.

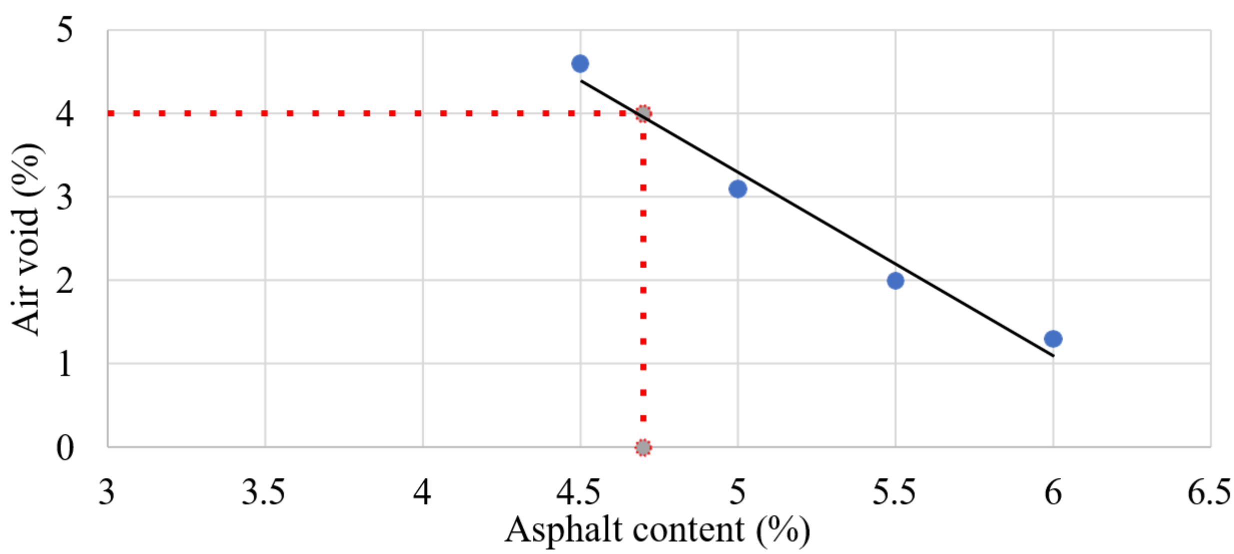


FIGURE 4.50 Optimum AC (%) of Mix#9

4.9.1 Performance of Mix#9

Rutting Performance

The Hamburg Wheel-Track Test is a laboratory procedure used to evaluate the rutting performance of asphalt mixtures under simulated traffic loading and moisture conditions. From the rutting test results, it was found that after 20,000 wheels passing the rutting value found to be 3.3 mm which is way below the standard value of 12.5mm. The mix showed stripping potential after 15000 passes (Figure 4.51).

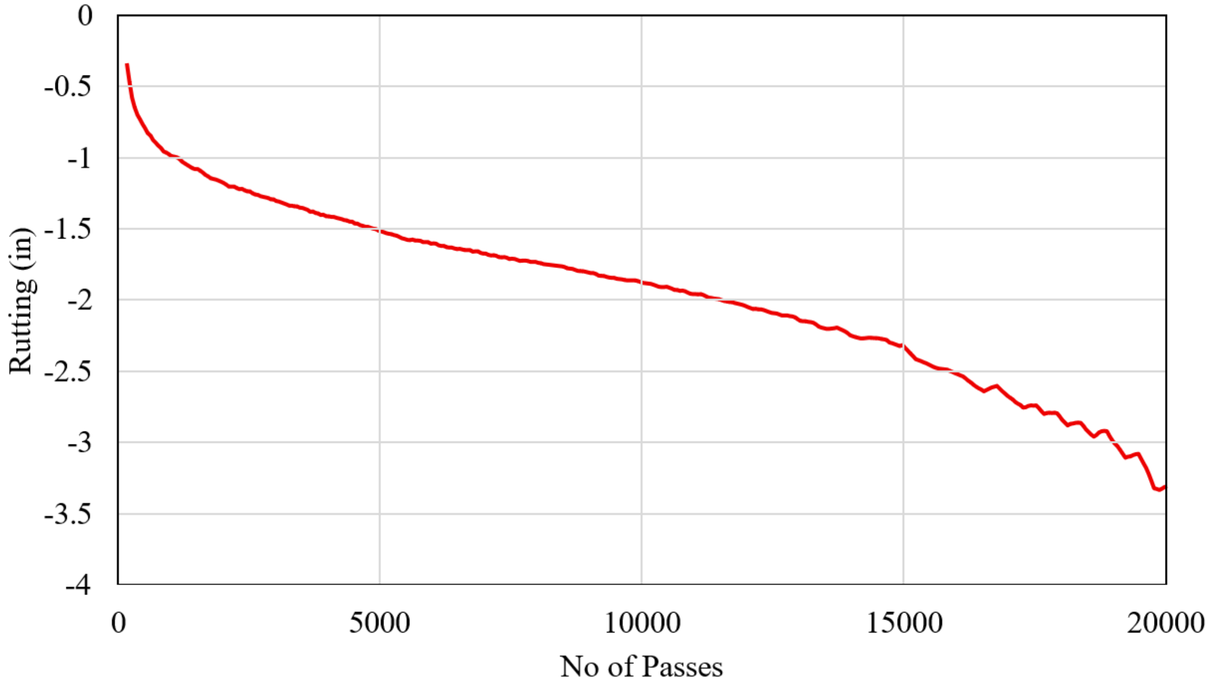


FIGURE 134 HWTT Test result of Mix#9

Cracking Performance

The IDEAL Cracking Test (IDEAL-CT) was conducted to evaluate the cracking resistance of the asphalt mixture. Test specimens were prepared from 150-mm-diameter gyratory-compacted samples with a height of 62 mm at a target air void content of 7.0%. The specimens were tested at 25°C using a displacement rate of 50 mm/min. The cracking resistance was quantified using the CT_{Index}, which was calculated from the load–displacement response. The IDEAL-CT test results for Mix #9 are presented in Figure 4.52.

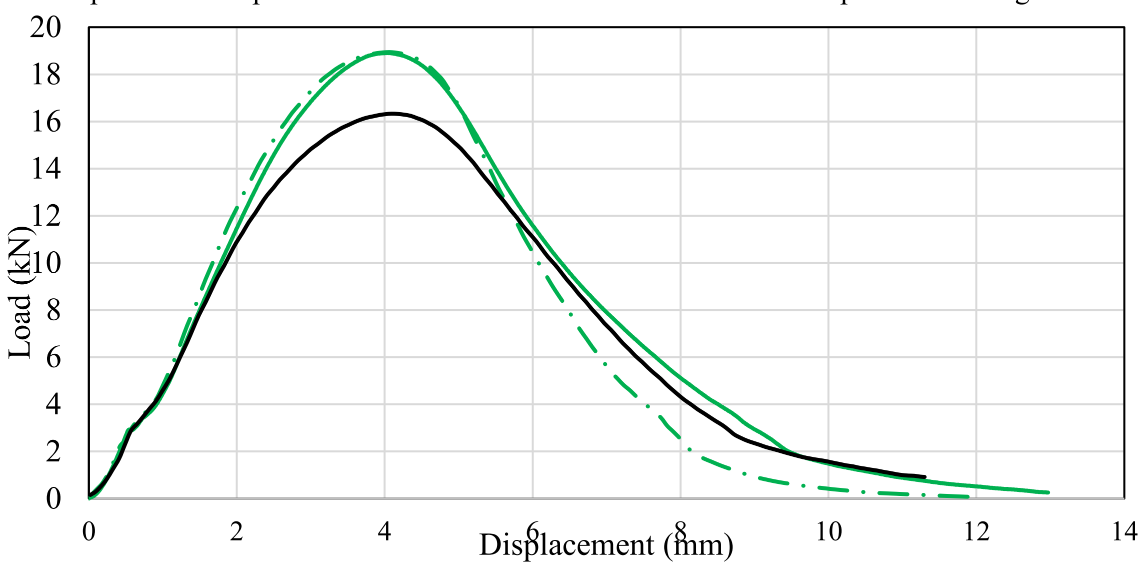


FIGURE 135 Load-displacement for Ideal-CT tests for BMD#9 mix

From the Ideal-CT test results of Mix#9 mix it was found that the average CT_{Index} values were 100 (CT_{Index} >80) which means the Mix#9mix is good for cracking resistance.

Performance Space Diagram of Mix#9

The performance space diagram (PSD), based on HWTT rutting and Ideal-CT cracking, of the Mix#8 mix is shown in Figure 4.53.

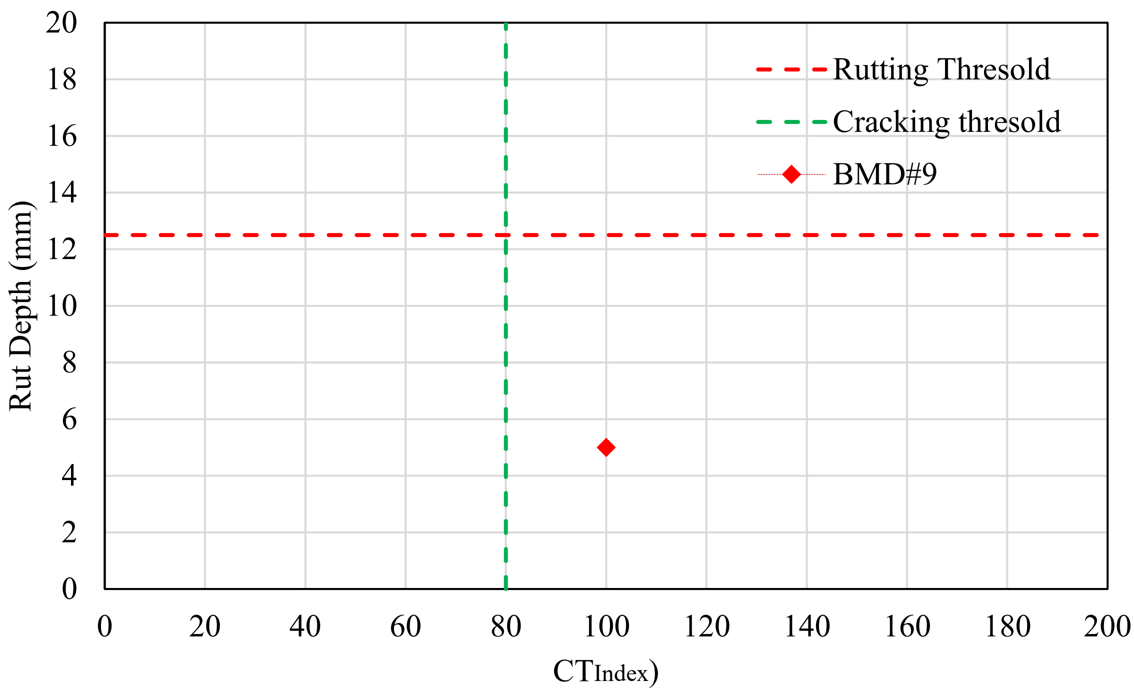


FIGURE 136 HWTT-IDEAL-CT performance space diagram for Mix#9

The Mix#9 demonstrated both rutting and cracking resistance; thus Mix#9 could be classified as balanced mix.

4.10 EVALUATION OF MIX#10

Design of Mix#10

The aggregates were collected from local contractor. The aggregate properties and gradations are discussed below. The type of BMD#5 aggregates is Sand &Gravel, and the source is Cox Pit. Table 4.22 lists the properties of Mix#10 aggregates.

TABLE 4.22 Aggregates properties for Mix#10

Combination Used		Bulk Sp. Gravities	Abs. %
1" Minus	26%	2.637	1
1/2" Minus	17%	2.606	1.4
ASCF	22%	2.556	1.7
Liquid Antistrip	0.35%	0.998	NA

The combined gradation for the Mix#10 aggregates is shown in Figure 4.54. The NMAS for gradation is 19mm and the gradation lies below the primary control sieve (PCS) is 4.75 mm. The percentage passing the PCS control point is 35% < 47%, so the combined gradation for Mix#10 is classified as coarse graded.

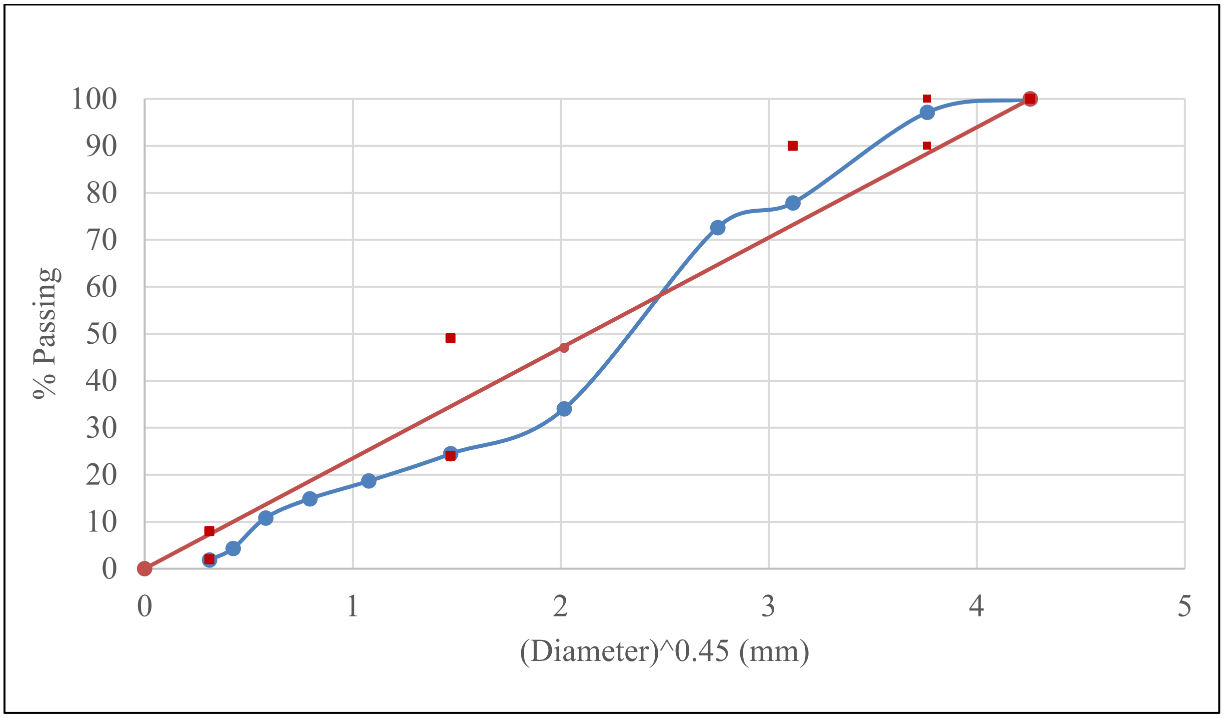


FIGURE 137 Combined gradation for the Mix#10 aggregates

The performance grade (PG) binder that has been used for this study was PG 70-22. The binder meets all the Superpave mix design criteria, i.e., the rutting, fatigue, and low-temperature cracking criteria. The mixing and compaction temperature range are 270°F and 241°F, respectively.

According to Superpave method different AC (%) was tried and the AC (%) that gave 4% air void for design gyration was selected as design asphalt content. The procedure for determining Optimum AC (%) is shown in Figure 4.55. The Optimum AC was found to be 5.2%.

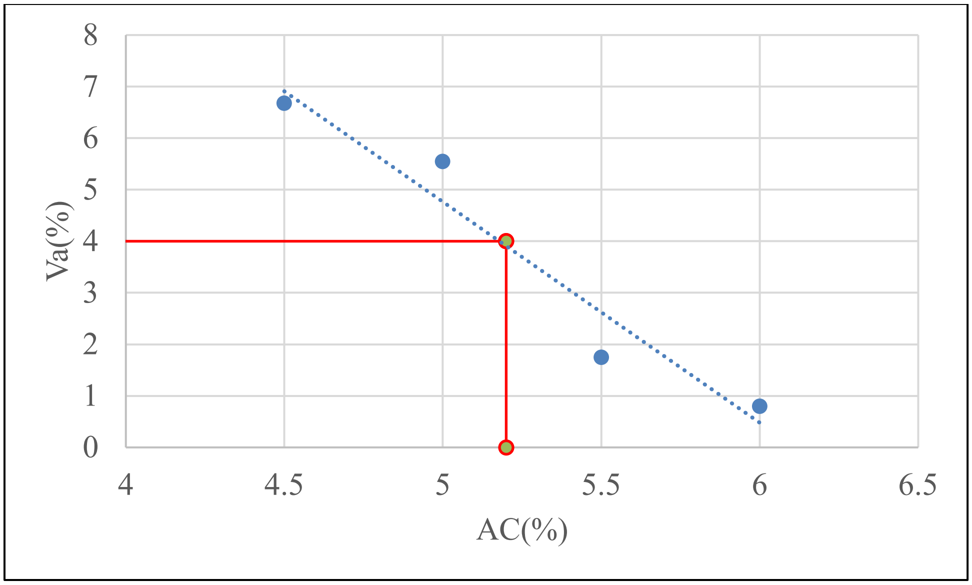


FIGURE 138 Determination of Optimum AC (%) Mix#10

4.10.1 Performance of Mix#10

Rutting Performance

The Hamburg Wheel-Track Test is a laboratory procedure used to evaluate the rutting performance of asphalt mixtures under simulated traffic loading and moisture conditions. HWTT specimens were prepared at three binder contents 5%; 5.5% and 6% to evaluate the rutting potential of the mix at different AC (%). The test results are shown in Figure 4.56, Figure 4.57 and summarized in Table 4.23.

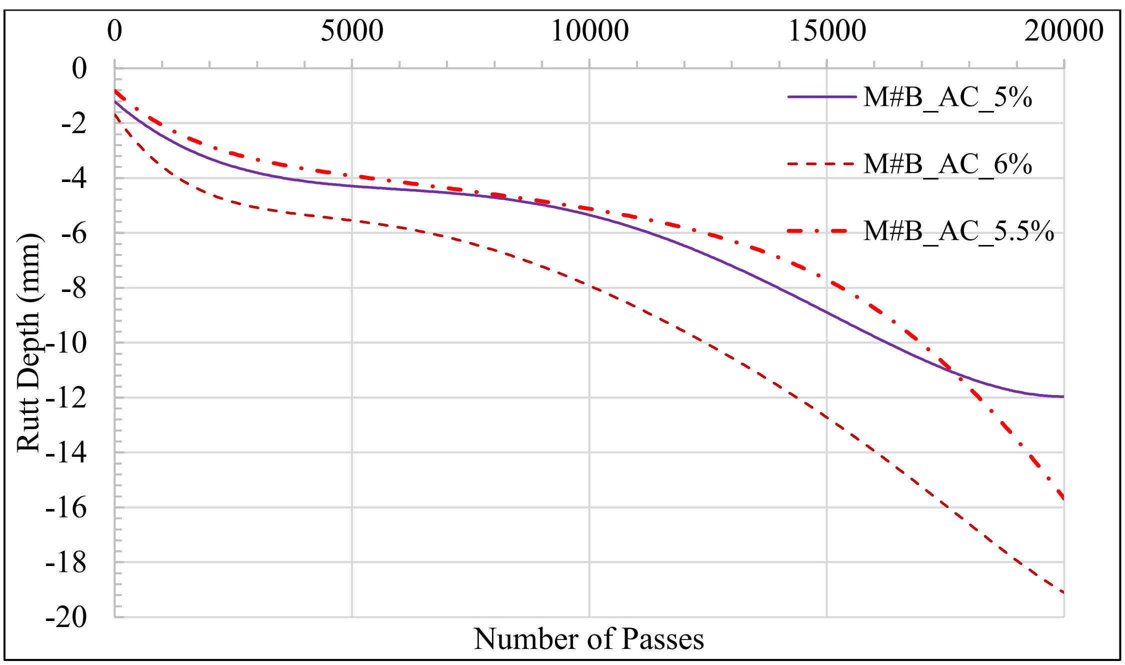


FIGURE 139 HWTT test results for Mix#10

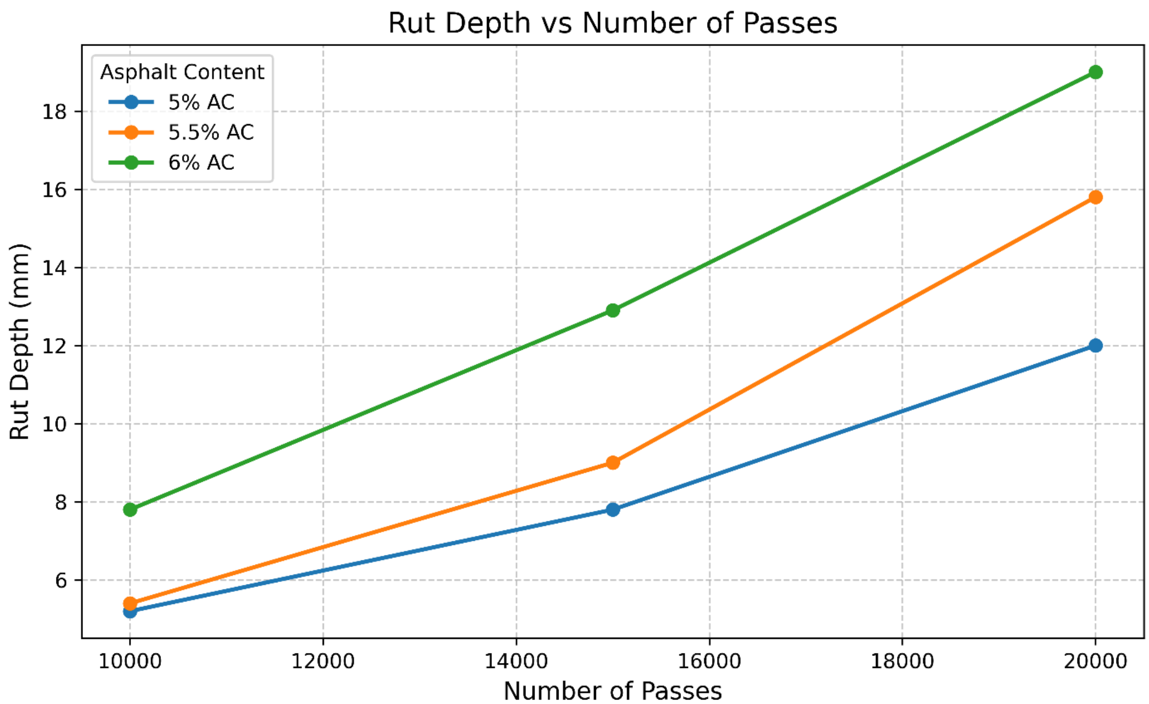


FIGURE 140. Rut depth vs AC (%) Mix#10

TABLE 4.23 Aggregates properties for Mix#10

No. of Passes	5% AC	5.5% AC	6% AC
10000	5.2 mm	5.4 mm	7.8 mm
15000	7.8 mm	9 mm	12.9 mm
20000	12 mm	15.8 mm	19mm

From the HWTT test results it was observed that for 5% and 5.5% AC minimum number of passes (>15000) for 12.5mm was meet; however, for 6% AC the threshold was not meet.

Cracking Performance

Illinois Flexibility Index Test (I-FIT) test results

I-FIT specimens of 15mm notch depth SCB geometry were loaded at 50mm/min displacement rate. The flexibility index value was determined from the load-displacement plot. The test results are summarized in Table 4.24 and Figure 4.58.

TABLE 4.24 IFIT test result summary Mix#10

AC(%)	IFIT value			
	Specimens			Average
5%	7.7	9.3	9.7	8.9
5.5%	11.28	11.32	9.1	10.6
6%	17.59	18.6	18.56	18.3

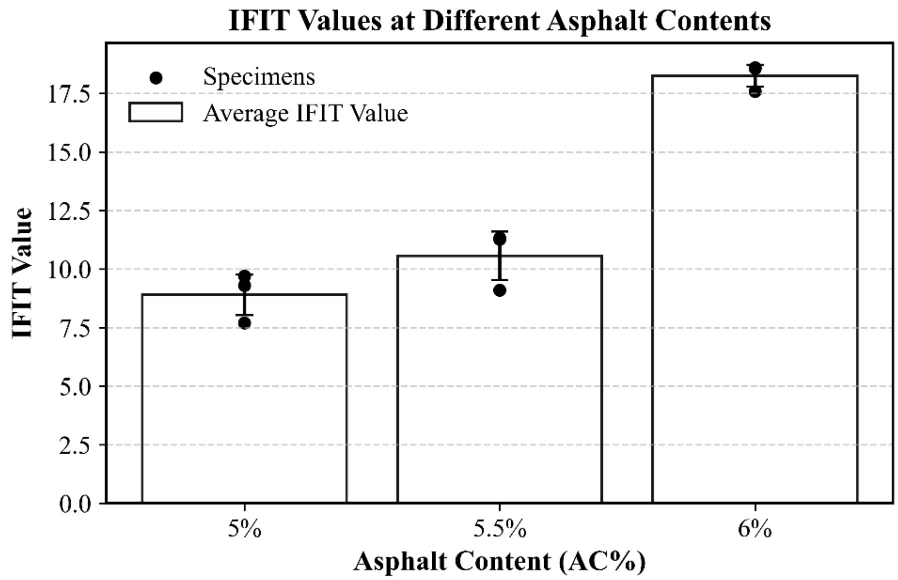


FIGURE 141. I-FIT test results for Mix#10

The Flexibility Index (FI) values ranges from 8.9 to 18.5 value which are within the acceptable value of 8 (26).

IDEAL-CT test

The CT_{index} values of Mix#10 for different AC is shown in Figure 4.59.

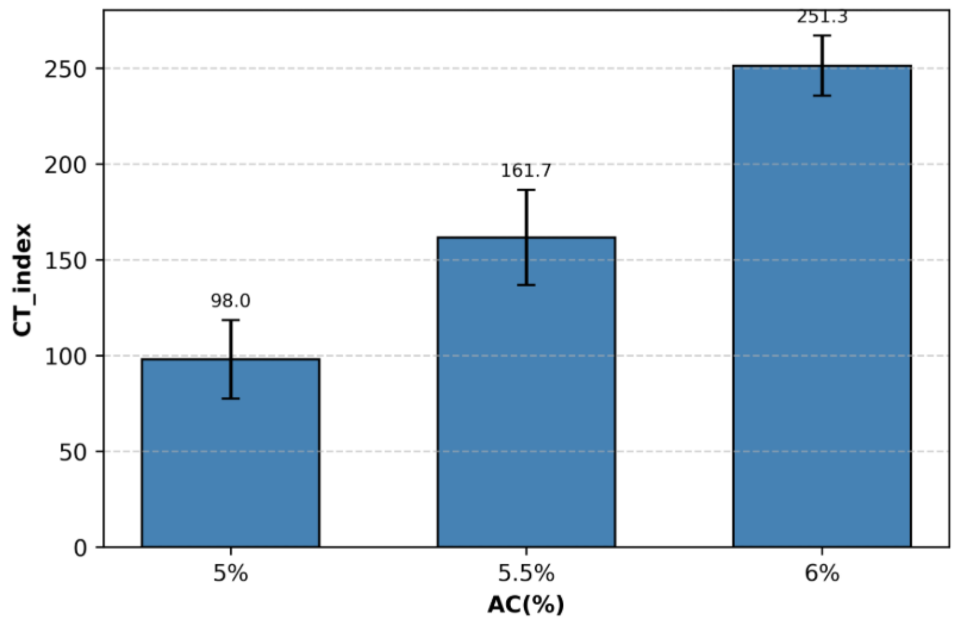


FIGURE 142. CT_index value for ACs

The results indicate that the CT_{index} value for Mix#10 was slightly lower than the threshold value (>100) for 5% AC. For 5.5%, and 6% ACs the values are greater than the threshold value 100.

Performance Space Diagram (PSD) of Mix#10

The performance space diagram (PSD), based on HWTT rutting and SCB cracking, of the Mix#B is shown in Figure 4.60.

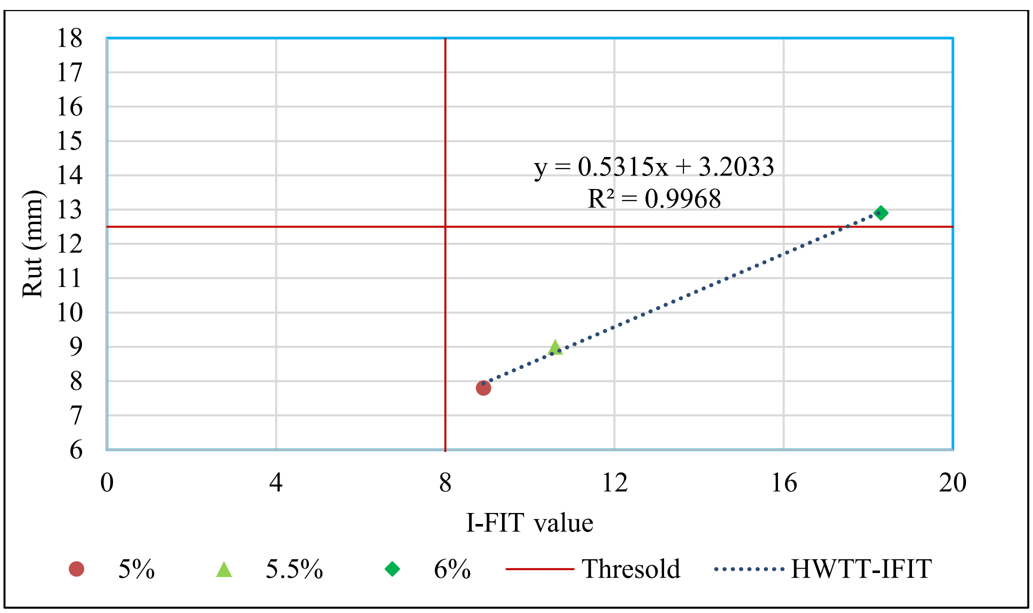


FIGURE 143 Performance space diagram (HWTT-IDEAL-CT) for Mix#10

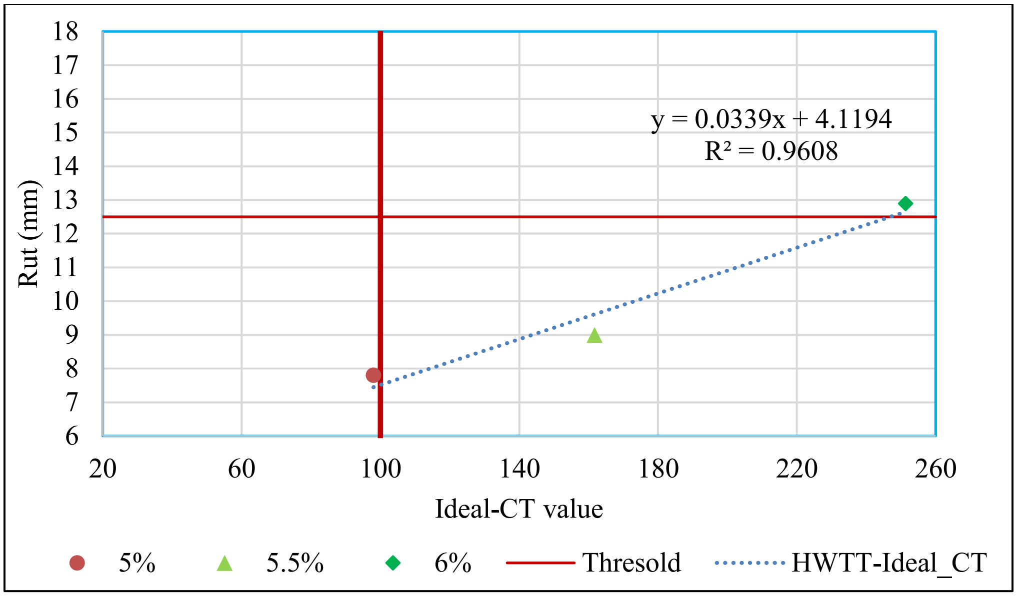


FIGURE 144 PSD of Mix#10 (HWTT-IDEAL_CT)

From the performance space diagram, it is observed that both Ideal-CT and I-FIT cracking index (Figure 4.61) shows good correlation with rutting result from HWTT. Considering both PSD 5.5% AC meet the cracking and rutting threshold for the Mix#10.

4.11 SUMMARY OF RUTTING AND CRACKING PERFORMANCE RESULTS FOR NEW MEXICO ASPHALT MIXTURES

In this study, a total of nineteen asphalt mixtures representative of materials and production practices used in New Mexico were evaluated to assess their rutting and cracking performance. The dataset included eleven laboratory-compacted short-term aged (LCSTA) mixtures and eight field mix reheated (FMRH) mixtures. Rutting performance was evaluated using the Hamburg Wheel Tracking Test (HWTT) and, where available, the IDEAL Rutting Test (IDEAL-RT), while cracking performance was assessed using the Illinois Flexibility Index Test (I-FIT), Semi-Circular Bend (SCB) test, and Texas Overlay Test (OT). Table 4.25 summarizes the key performance results for all mixtures and identifies whether each mixture satisfied the selected Balanced Mix Design criteria. This comprehensive dataset forms the basis for evaluating the applicability of commonly adopted performance thresholds and developing preliminary New Mexico-specific Balanced Mix Design criteria.

TABLE 4.25 Summary of Performance Results of New Mexico Mixes

Mix#ID	Mix type	RAP (%)	Lab/Field	PG grade	Mix Design Properties					Rutting			Cracking	Meets BMD?
					OAC (%)	Eff. AC (%)	Gmm	VMA (%)	VFA (%)	HWTT@50°C			I-FIT @25°C	
										No of passes	Rut Depth (mm)	SIP		
M#1a	SP-IV (12.5mm)	0	LC STA	58-28	4.7	4.35	2.356	14.2	71.8	10,000	>20	4,500	FI=18	No
										15,000	>20			
										20,000	>20			
M#1b	SP-IV (12.5mm)	0	LC STA	64-22	5.1	4.56	2.465	14.5	72.2	10,000	8.5	8,500	FI=11.7	Yes
										15,000	>20			
										20,000	>20			
M#1c	SP-IV (12.5mm)	0	LC STA	76-28	5	4.95	2.636	13.6	70.2	10,000	2.7	NS	FI=9.5	Yes
										15,000	2.8			
										20,000	3.0			

						HWTT@50°C			**SCB @25°C**	
Mix#2a	SP-IV (12.5mm)	0	LC STA	64-22	6.5	No of passes	Rut Depth (mm)	SIP		
						10,000	18		Jc=0.4 kJ/m^2	
						15,000	>20	2,300		No
						20,000	>20			
						HWTT@50°C			**IFIT @25°C**	
									FI=6.2	
Mix#2a	SP-IV (12.5mm)	15%	LC STA	64-22	7% (Opt+0.5%)	No of passes	Rut Depth (mm)	SIP		Yes
						10,000	5		**OT**	
						15,000	8	NS	CPR: 0.327	
						20,000	12		CFE =3.2 in.lb/in.^{2}	
						HWTT@50°C			**SCB @25°C**	
Mix#3a	SP-IV (12.5mm)		LC STA	64-22	5.2%	No of passes	Rut Depth (mm)	SIP		No
						10,000	12.6		Jc=0.31 kJ/m^2	
						15,000	>20	2,800		
						20,000	>20			

										HWTT@50°C			**SCB @25°C**	
										No of passes	Rut Depth (mm)	SIP	Jc=0.48 kJ/m^2	
Mix#3b	SP-IV (12.5mm)	15%	LC STA	64-22	5.7% (Opt+0.5%)					10,000	4		**OT**	Yes
										15,000	7	12,000	CPR: 0.256	
										10,000	12		CFE =2.11 in.lb/in.^{2}	
										HWTT@50°C			**SCB @25°C**	
Mix#4	SP-IIII (19mm)	35%	FM RH	70-28	4.7	4.11	2.469	13.5	70.4	No of passes	Rut Depth (mm)	SIP	Jc=0.41 kJ/m^2 **IFIT @25°C**	Yes
										10,000	5.3	NS	FI=9	
										15,000	6.5			
										20,000	7			
										HWTT@50°C			**IFIT @25°C**	
										No of passes	Rut Depth (mm)	SIP	FI=3.7	
Mix#5	SP-IIII (19mm)	35%	FM RH	70-28	4.7	4.16	2.491	13.7	71	10,000	3.4		**OT**	No
										15,000	3.7	NS	CPR: 0.6;	
										20,000	3.9		CFE =1.8 in.lb/in.^{2}	

Mix#6	SP-IV (12.5mm)	25%	FM RH	76-22	5.2	4.33	2.592	14.6	72.5	**HWTT@50°C** No of passes 10,000 15,000 20,000	Rut Depth (mm) 1.7 2.2 2.4	SIP NS	**IDEAL-CT** **CT_{Index} = 16**	No
Mix#7	SP-IIII (19mm)	15%	FM RH	76-22	5	3.89	2.636	13.6	70.7	10,000 15,000 20,000	2.8 3.2 3.8	NS	**SCB @25°C** 0.31 kJ/m^2 CPR: 0.35 CFE =0.25in.lb/in.^{2}	No
Mix#8	SP-IV (12.5mm)		FM RH	64-22	5.1	4.95	2.456	15.5	74.2	**HWTT@50°C** No of passes 10,000 15,000 20,000	Rut Depth (mm) 4.4 4.8 5.2	SIP NS	**IDEAL-CT** **CT_{Index} = 75** **OT** CPR: 1.21; CFE =0.55in.lb/in.^{2}	Yes
Mix#9	SP-IV (12.5mm)	35%	FM RH	70-22	5.9	5.06	2.323	14.1	91	**HWTT@50°C** No of passes 10,000	Rut Depth (mm) 1.8	SIP NS	**IDEAL-CT** **CT_{Index} = 32** **OT**	Yes

										15,000 — 2.4 20,000 — 3.4	CPR: 0.6; CFE=1.95in.lb/in.^{2}	
Mix#10	SP-IIII (19mm)	0%	LC STA	70- 22	5.5					**HWTT@50°C** No of passes / Rut Depth (mm) / SIP 10,000 / 5.2 / 15,000 / 7.8 / NS 20,000 / 12 /	**IFIT @25°C** 8.9 **IDEAL-CT** CT_{Index} = 98 **OT** CPR: 0.31 CFE =1.23in.lb/in^2	Yes
Mix#11	SP-IV (12.5mm)	15%	FM RH	64- 22	4.8	4.51	2.518	14.7	72.8	**HWTT@50°C** No of passes / Rut Depth (mm) / SIP 10,000 / 5.2 15,000 / 7.8 20,000 / 12 **IDEAL-RT** **RT_{Index} = 77**	**IFIT @25°C** FI=11.2 **IDEAL-CT** **CT_{Index} = 150**	Yes
Mix#12a	SP-IV (12.5mm)	0	LC STA	64-22	5.9					**HWTT@50°C** No of passes / Rut Depth (mm) / SIP 10,000 / 7.9 15,000 / 9.8	**IFIT @25°C** **10.7** **IDEAL-CT**	Yes

									20,000 >20 **IDEAL-RT** **RT_{Index} = 81**	**CT_{Index} = 176**	
Mix#12b	SP-IV (12.5mm)	0	LC STA	70-22	5.7				HWTT@50°C No of passes / Rut Depth (mm) / SIP 10,000 / 5.9 15,000 / 8.4 20,000 / 11.8 **IDEAL-RT** **RT_{Index} = 95**	**IFIT @25°C** **4.8** **IDEAL-CT** **CT_{Index} = 153**	Yes
Mix#12c	SP-IV (12.5mm)	0	LC STA	76-22	6.3				HWTT@50°C No of passes / Rut Depth (mm) / SIP 10,000 / 3.9 15,000 / 4.6 20,000 / 5.3 **IDEAL-RT** **RT_{Index} = 134**	**IFIT @25°C** **18.3** **IDEAL-CT** **CT_{Index} = 85**	Yes
Mix#13	SP-III (19mm)	25%	FM RH		5.1	4.03	2.597	14	**IDEAL-RT** **RT_{Index} = 242**	**IDEAL-CT** **CT_{Index} = 52**	

Note: LCSTA-Laboratory Compacted Short-term aged; FMRH= Field mix reheated; SIP = Stripping Inflection Point; NS = No stripping observed;

CHAPTER 5
DEVELOPMENT OF NEW MEXICO PERFORMANCE THRESHOLDS

5.1 INTRODUCTION

The development of performance thresholds of local materials and conditions is a fundamental requirement for successful Balanced Mix Design (BMD) implementation. Performance thresholds established by other state Departments of Transportation (DOTs) provide useful benchmarks; however, threshold values developed elsewhere may not be directly applicable to New Mexico given the variability in aggregate sources, climate, traffic patterns, and binder grades used throughout the state. Adopting thresholds calibrated to local materials is therefore essential to ensure that the proposed BMD framework is both practical and discriminatory in its ability to identify well-performing asphalt mixtures.

This chapter presents the development of preliminary performance-based design criteria for Balanced Mix Design implementation in New Mexico. The approach consisted of two sequential phases. In the first phase, a total of nineteen asphalt mixtures representative of materials, binder grades, RAP contents, and production practices commonly used across New Mexico were evaluated using established rutting and cracking performance tests. Each mixture was assessed against commonly adopted national BMD threshold criteria to classify it as either balanced or unbalanced. In the second phase, the performance results from the subset of balanced mixtures were subjected to statistical distribution analysis to establish New Mexico-specific preliminary performance thresholds for each of the test methods employed.

The resulting threshold recommendations are intended to define minimum acceptable performance levels that align with the distribution of well-performing New Mexico mixtures, thereby supporting the statewide implementation of a practical and locally calibrated BMD framework.

5.2 EVALUATION OF NEW MEXICO ASPHALT MIXTURES AGAINST ESTABLISHED BMD CRITERIA

Overview of the Evaluated Mixture Dataset

A total of nineteen asphalt mixtures were evaluated in this study, comprising eleven laboratory-compacted short-term aged (LC-STA) mixtures and eight field mix reheated (FM-RH) mixtures. The dataset was assembled to represent the range of aggregate sources, nominal maximum aggregate sizes (NMAS), binder performance grades, and RAP contents typically encountered in New Mexico highway construction. The mixtures included SP-IV (12.5 mm NMAS) and SP-III (19 mm NMAS) gradations, with binder grades ranging from PG 58-28 to PG 76-28, and RAP contents from 0% to 35%.

Rutting performance was evaluated using the Hamburg Wheel Tracking Test (HWTT, AASHTO T 324) and, where applicable, the IDEAL Rutting Test (IDEAL-RT). Cracking performance was assessed using the Illinois Flexibility Index Test (I-FIT), the IDEAL Cracking Test (IDEAL-CT), the Semi-Circular Bend (SCB) test, and the Texas Overlay Test (OT). Not all tests were performed on every mixture; the specific combination of tests applied to each mixture reflects the research program design and the availability of specimens.

5.3 COMMONLY ADOPTED BMD THRESHOLD CRITERIA USED FOR CLASSIFICATION

To classify each mixture as balanced or unbalanced, the performance results were evaluated against commonly adopted BMD criteria reported in the literature and employed by state DOTs. For rutting, the primary criterion was an HWTT rut depth not exceeding 12.5 mm at the number of wheel passes corresponding to the applicable binder grade (10,000 passes for PG 64 or lower; 15,000 for PG 70; 20,000 for PG 76 or higher). For cracking, the primary criterion was an I-FIT Flexibility Index (FI) of not less than 8.0. Where the I-FIT was not performed, SCB Jc values were evaluated against a minimum of 0.40 kJ/m², and IDEAL-CT results were assessed against a minimum CT Index of 100. A mixture was classified as balanced if it simultaneously satisfied the applicable rutting and cracking criteria; if it failed either criterion, it was classified as unbalanced.

This classification step was critical to ensuring that the statistical analysis used to establish New Mexico-specific thresholds was based exclusively on mixtures that represent satisfactory combined performance, consistent with the fundamental objective of Balanced Mix Design.

5.4 SUMMARY OF PERFORMANCE RESULTS AND BMD CLASSIFICATION

Table 5.1 presents a comprehensive summary of the key performance test results and BMD classification for all nineteen evaluated mixtures. The table includes the mixture designation, type, RAP content, binder grade, conditioning method, HWTT rut depth, I-FIT Flexibility Index, IDEAL-CT Index, IDEAL-RT Index, and the resulting BMD classification (green = Balanced; red = Unbalanced).

TABLE 5.1 Summary of Performance Test Results and BMD Classification for NM Mixtures

Mix ID	Mix Type	RAP (%)	PG Grade	Lab/Field	HWTT Rut @ 20k passes (mm)	I-FIT FI	IDEAL-CT Index	IDEAL-RT Index	BMD Class
M#1a	SP-IV	0%	PG 58-28	LC-STA	>20	18.0	—	—	**Unbalanced**
M#1b	SP-IV	0%	PG 64-22	LC-STA	>20	11.7	—	—	**Balanced**
M#1c	SP-IV	0%	PG 76-28	LC-STA	3.0	9.5	—	—	**Balanced**

Mix ID	Mix Type	RAP (%)	PG Grade	Lab/Field	HWTT Rut @ 20k passes (mm)	I-FIT FI	IDEAL-CT Index	IDEAL-RT Index	BMD Class
M#2a	SP-IV	0%	PG 64-22	LC-STA	>20	—	—	—	**Unbalanced**
M#2b	SP-IV	15%	PG 64-22	LC-STA	12.0	6.2	—	—	**Balanced**
M#3a	SP-IV	0%	PG 64-22	LC-STA	>20	—	—	—	**Unbalanced**
M#3b	SP-IV	15%	PG 64-22	LC-STA	12.0	—	—	—	**Balanced**
M#4	SP-III	35%	PG 70-28	FM-RH	7.0	9.0	—	—	**Balanced**
M#5	SP-III	35%	PG 70-28	FM-RH	3.9	3.7	—	—	**Unbalanced**
M#6	SP-IV	25%	PG 76-22	FM-RH	2.4	—	16	—	**Unbalanced**
M#7	SP-III	15%	PG 76-22	FM-RH	3.8	—	—	—	**Unbalanced**
M#8	SP-IV	0%	PG 64-22	FM-RH	5.2	—	75	—	**Balanced**
M#9	SP-IV	35%	PG 70-22	FM-RH	3.4	—	32§	—	**Balanced**
M#10	SP-III	0%	PG 70-22	LC-STA	12.0	8.9	98	—	**Balanced**
M#11	SP-IV	15%	PG 64-22	FM-RH	12.0	11.2	150	77	**Balanced**
M#12a	SP-IV	0%	PG 64-22	LC-STA	>20	10.7	176	81	**Balanced**
M#12b	SP-IV	0%	PG 70-22	LC-STA	11.8	4.8	153	95	**Balanced**
M#12c	SP-IV	0%	PG 76-22	LC-STA	5.3	18.3	85	134	**Balanced**
M#13	SP-III	25%	—	FM-RH	—	—	52	242	—

Of the nineteen mixtures evaluated, twelve were classified as balanced and seven as unbalanced. The unbalanced mixtures generally failed either the rutting criterion (excessive rut depth or early stripping in the HWTT) or the cracking criterion (low FI or Jc below threshold), or both. Notably, several mixtures that satisfied all Superpave volumetric requirements were found to be unbalanced under BMD criteria, demonstrating the added discriminatory value of performance-based testing. The balanced mixtures spanned a range of binder grades, RAP contents, aggregate types, and production methods, providing a sufficiently diverse dataset for subsequent threshold development.

5.5 STATISTICAL DISTRIBUTION ANALYSIS OF BALANCED MIXTURE PERFORMANCE

Methodology

The objective of the statistical analysis was to characterize the distribution of performance test results among the balanced New Mexico mixtures and to use this distribution to identify preliminary performance thresholds consistent with local material behavior. The rationale for this approach is that mixtures already confirmed to exhibit satisfactory combined rutting and cracking performance under established national BMD criteria represent the range of acceptable performance achievable with New Mexico materials. Setting thresholds based on the lower tail of this distribution — rather than adopting thresholds calibrated to different material systems — ensures that the proposed criteria are simultaneously rigorous and practically achievable.

For each performance test, the measured values from the balanced mixture subset were fitted to a normal distribution, and the mean, median, and standard deviation were computed. The –1 standard deviation (–1 SD) value was used as the primary reference point for establishing minimum threshold recommendations, as it captures the lower bound of typical performance within the balanced population while still being more conservative than the mean. Where the –1 SD value aligned with thresholds commonly reported in the literature, this provided additional validation for the proposed criteria. The balanced mixture performance data used in this analysis are summarized in Table 5.2.

TABLE 5.2 Performance Test Results for Balanced NM Mixtures Used in Statistical Analysis

Mix ID	HWTT Rut @ 20k passes (mm)	I-FIT FI	IDEAL-CT Index	IDEAL-RT Index
M#1b	>20 (PG 64)	11.7	—	—
M#1c	3.0 (PG 76)	9.5	—	—
M#2b	12.0 (PG 64)	6.2	—	—
M#3b	12.0 (PG 64)	—	—	—

Mix ID	HWTT Rut @ 20k passes (mm)	I-FIT FI	IDEAL-CT Index	IDEAL-RT Index
M#4	7.0 (PG 70)	9.0	—	—
M#8	5.2 (PG 64)	—	75	—
M#9	3.4 (PG 70)	—	32	—
M#10	12.0 (PG 70)	8.9	98	—
M#11	12.0 (PG 64)	11.2	150	77
M#12a	>20 (PG 64)	10.7	176	81
M#12b	11.8 (PG 70)	4.8	153	95
M#12c	5.3 (PG 76)	18.3	85	134

** I-FIT FI for M#2b = 6.2 (below the 8.0 criterion); included in the FI distribution as a lower-end data point.*

5.5.1 HWTT Rut Depth Distribution

The distribution of HWTT rut depths at 20,000 wheel passes for the balanced New Mexico mixtures was fitted to a normal distribution with a mean of 5.0 mm and a median of 5.2 mm. The –1 SD boundary fell at approximately 3.9 mm, and the +1 SD boundary at 6.1 mm. Individual mixture rut depths ranged from approximately 2.7 mm (M#1c, PG 76-28 virgin mix) to approximately 12.0 mm for mixtures evaluated with softer binders at their applicable pass count. Figure 5.1 presents the fitted normal distribution with individual mixture data points and ±1 SD boundaries.

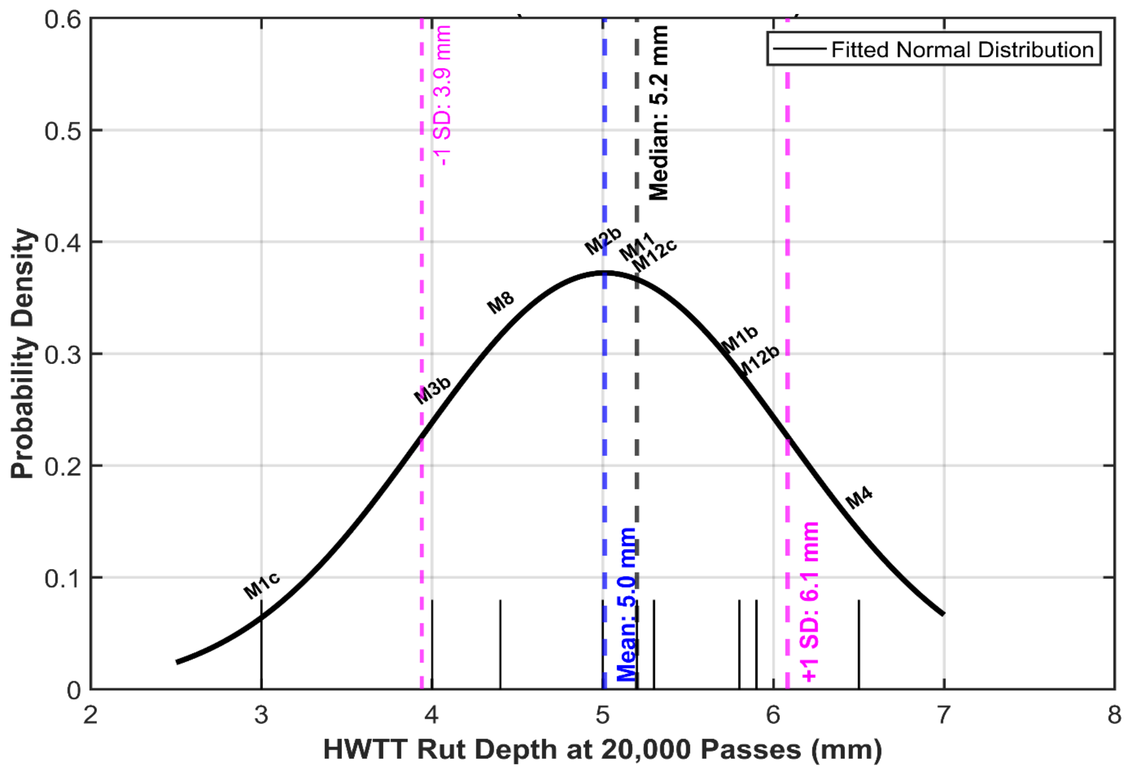


FIGURE 145 Distribution of HWTT Rut Depth for New Mexico Balanced Mixes (Mean = 5.0 mm, Median = 5.2 mm)

The distribution is centered well below the commonly adopted maximum rut depth criterion of 12.5 mm, confirming that the evaluated balanced New Mexico mixtures exhibit strong inherent rutting resistance. This is consistent with the generally arid and high-temperature climate of New Mexico, which tends to favor stiffer binders and well-graded aggregate structures that resist permanent deformation. The +1 SD boundary of 6.1 mm provides a useful practical reference: mixtures with HWTT rut depths approaching or exceeding this value should be evaluated with additional scrutiny within the BMD framework.

For threshold development purposes, the existing pass-count-based HWTT criteria (10,000 passes for PG 64, 15,000 for PG 70, 20,000 for PG 76) are recommended to be retained. Additionally, a supplementary rut depth criterion at 6 mm at the applicable number of passes is proposed as a more stringent, NM-specific preferred threshold that better reflects the distribution of balanced mixture performance in the state.

5.5.2 Flexibility Index (I-FIT) Distribution

The I-FIT Flexibility Index (FI) values for the balanced New Mexico mixtures followed a normal distribution with a mean of 10.4 and a median of 11.2. The distribution ranged from approximately FI = 4.8 (M#12b, PG 70-22 with no RAP) to FI = 18.3 (M#12c, PG 76-22 with no RAP), illustrating the significant influence of binder grade and aging on cracking resistance. Figure 5.2 presents the fitted normal distribution with the FI = 8 minimum boundary and mean indicated.

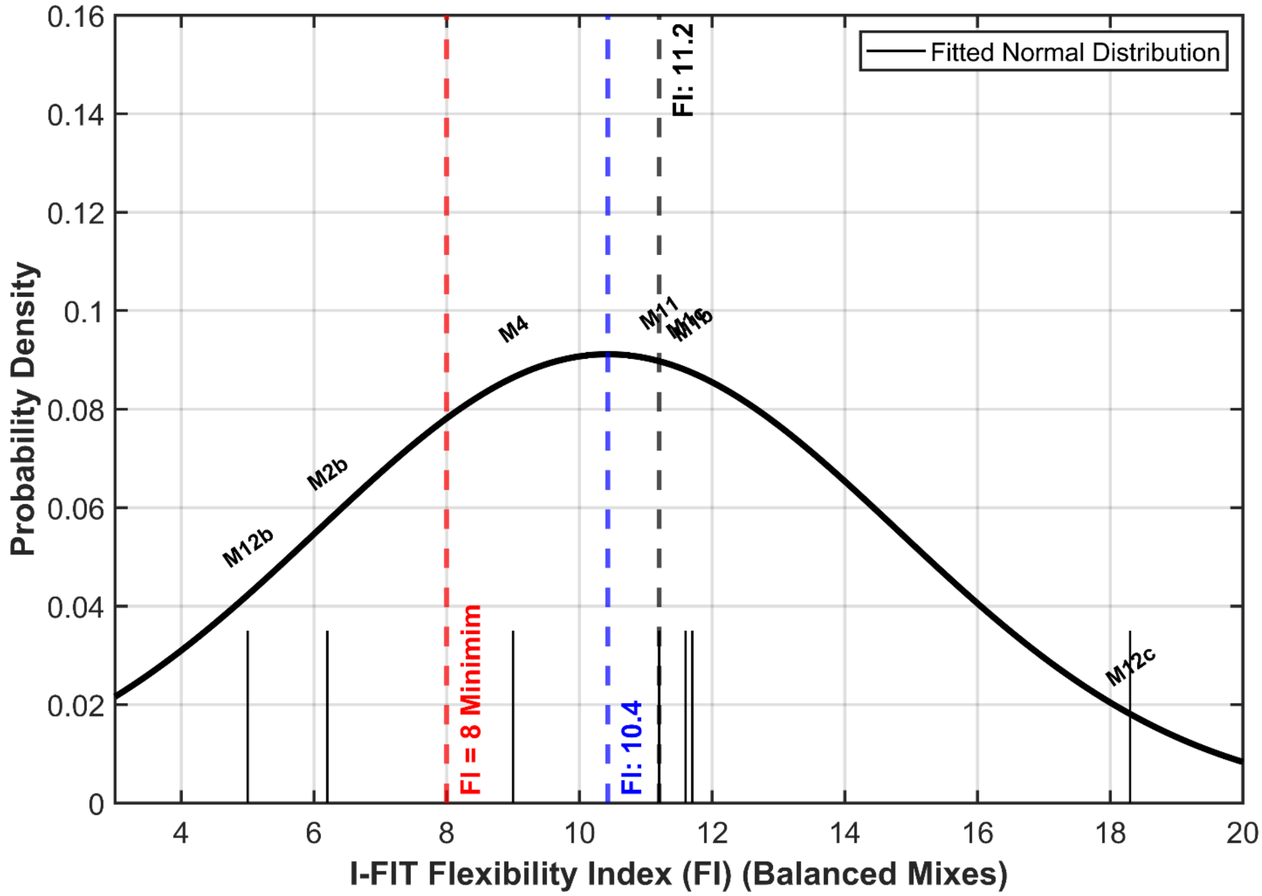


FIGURE 5.2 Distribution of I-FIT Flexibility Index for New Mexico Balanced Mixes

The minimum FI 8.0 was recommended based on the most widely adopted minimum FI threshold in the national BMD literature. This alignment between the statistically derived lower bound and the established national minimum threshold provides strong statistical validation for the applicability of FI ≥ 8.0 as a minimum criterion for New Mexico. The distribution also supports establishing a preferred threshold at FI ≥ 10, which corresponds approximately to the mean of the balanced mixture distribution. Mixtures meeting the preferred threshold would be expected to exhibit cracking resistance consistent with the central tendency of well-performing NM mixes, while the minimum threshold of FI ≥ 8.0 establishes the lower acceptable bound.

5.5.3 IDEAL-CT Index Distribution

The IDEAL-CT Index values for the balanced New Mexico mixtures (excluding the outlier M#9 value of 32, which is discussed separately) were fitted to a normal distribution with a mean of 112 and a median of 98. The distribution ranged from a CT Index of approximately 75 (M#8) to 176 (M#12a), reflecting considerable variability associated with differences in aggregate angularity, binder grade, and RAP content. Figure 5.3 presents the fitted distribution with the CT = 75 threshold boundary and the mean and median lines.

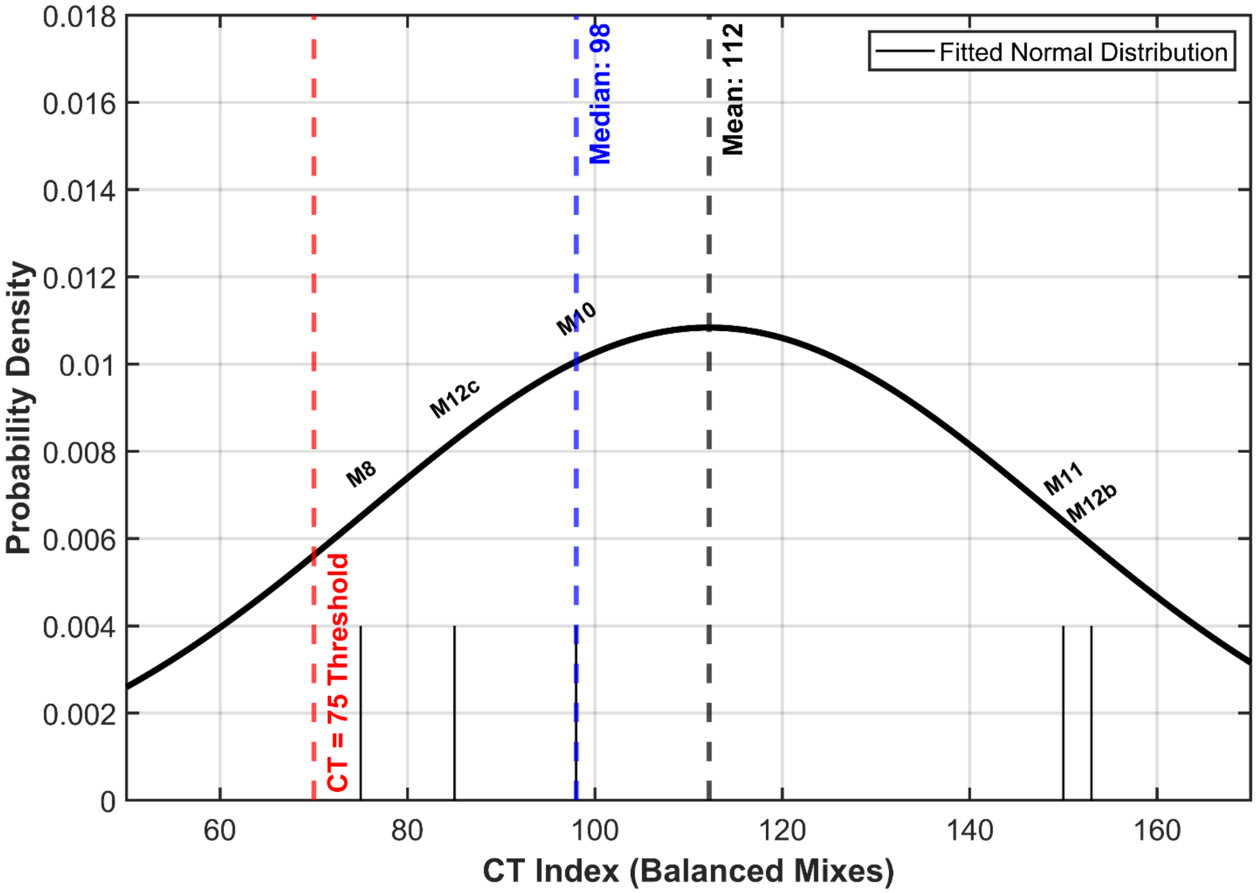


FIGURE 5.3 Distribution of IDEAL-CT Index for NM Balanced Mixes

The CT_{Index} value of 75 corresponds directly to the lower bound of the balanced mixture distribution and is also consistent with the minimum criterion adopted by several state agencies, providing a statistically and practically defensible threshold for New Mexico mixtures. The mean value of 112 and the nationally common preferred threshold of 100 are closely aligned, supporting a two-tier recommendation: CT Index ≥ 75 as a minimum and CT Index ≥ 100 as a preferred value.

5.5.5 IDEAL-RT Index Distribution

IDEAL-RT testing was performed on a subset of the balanced NM mixtures (M#11, M#12a, M#12b, M#12c). The RT Index values ranged from 77 (M#11, FM-RH, PG 64-22, 15% RAP) to 134 (M#12c, LC-STA, PG 76-22, 0% RAP), with both the mean and median approximately 97. Figure 5.4 presents the fitted normal distribution with the RT = 80 threshold boundary.

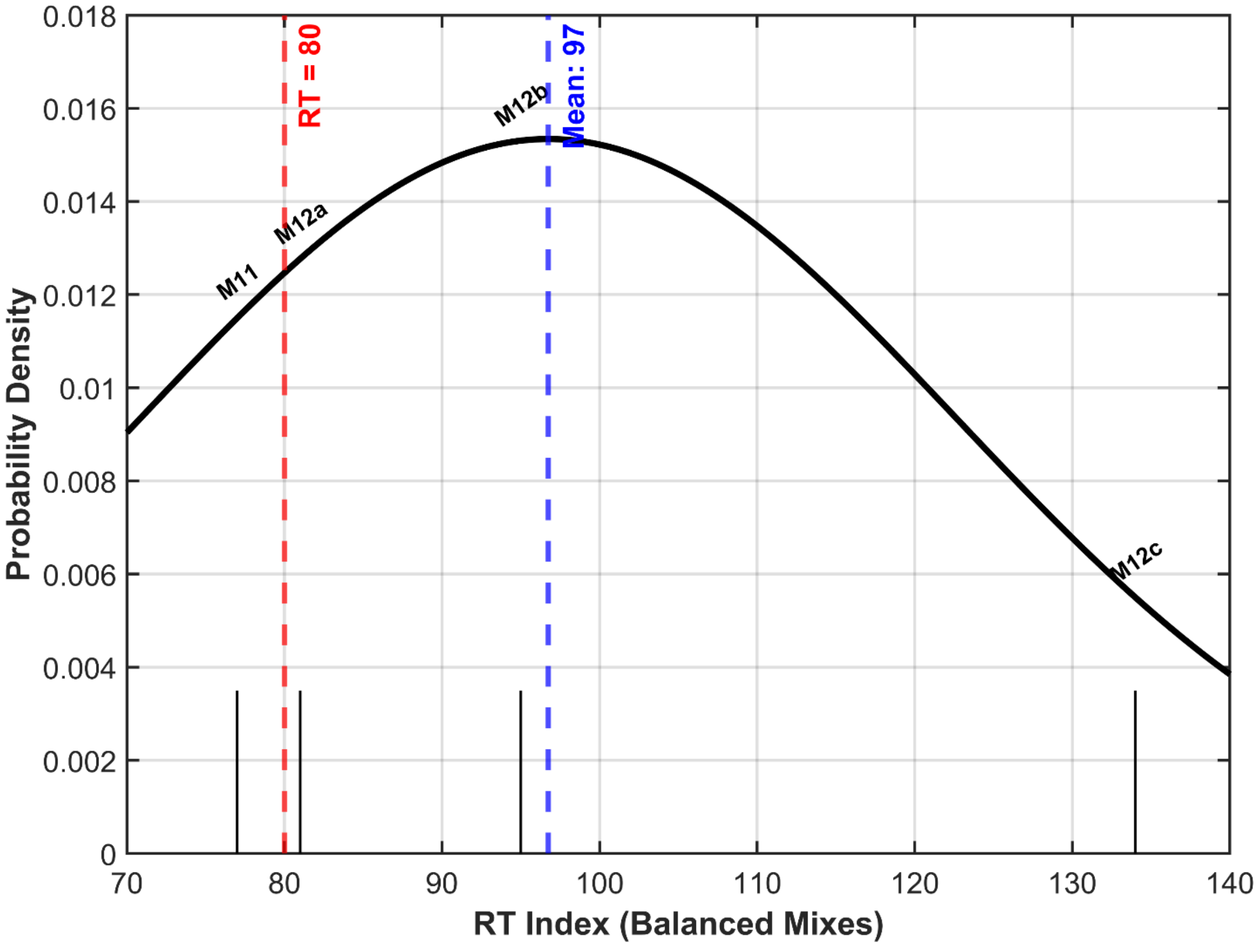


FIGURE 5.4 Distribution of IDEAL-RT Index for NM Balanced Mixes

The RT_{Index} value of 80 corresponds to the lower bound of the balanced mixture distribution and aligns well with the minimum RT_{Index} threshold reported in several published Balanced Mix Design frameworks. In addition, the mean RT_{Index} of the balanced New Mexico mixtures was approximately 97, which is close to the commonly used preferred threshold of 100. Based on these findings, a two-tier criterion is recommended for IDEAL-RT: a minimum RT_{Index} of 80 and a preferred RT_{Index} of 100.

Table 5.3 summarizes the statistical parameters derived from the balanced mixture distributions for each test method.

TABLE 5.3 Statistical Summary of Performance Test Distributions for Balanced NM Mixtures

Performance Metric	Test Method	Mean	Median	Minimum	+1 SD
HWTT Rut Depth @ 20k passes (mm)	HWTT (AASHTO T 324)	5.0 mm	5.2 mm	3.9 mm (−1 SD)	6.1 mm +1 SD)
Flexibility Index (FI)	I-FIT	10.4	11.2	8.0 (min)	—
CT Index	IDEAL-CT	112	98	75 (min)	—
RT Index	IDEAL-RT	97	97	80 (min)	—

5.6 RECOMMENDED PERFORMANCE THRESHOLDS FOR NEW MEXICO

Based on the performance evaluation of the nineteen New Mexico asphalt mixtures and the statistical distribution analysis of the balanced mixture subset, preliminary performance thresholds are recommended for BMD implementation in New Mexico. The recommended criteria are organized by performance category and test method and presented as both minimum and preferred thresholds to allow for a tiered implementation approach. Minimum thresholds represent the lower bound of acceptable performance boundary of the balanced mixture distribution; preferred thresholds represent performance consistent with the mean of the distribution, providing a target for higher-quality mix designs.

The proposed framework retains the Hamburg Wheel Tracking Test (HWTT) as the primary rutting performance indicator, given its widespread use in state BMD programs, its sensitivity to moisture damage (stripping), and its direct relevance to field rutting performance under heavy wheel loading. The IDEAL-RT is recommended as a supplementary rutting test, particularly valuable for rapid quality control screening. For cracking, the I-FIT is the primary recommended test given its widespread adoption and the strong statistical alignment of its threshold with the NM balanced mixture distribution. The IDEAL-CT is recommended as a supplementary cracking test.

TABLE 5.4 Recommended Performance Thresholds for New Mexico Balanced Mix Design

Performance Category	Test Method	Performance Parameter	Recommended Threshold
Rutting Resistance	HWTT @ 50°C (AASHTO T 324)	PG 64 or lower — No. passes @ 6 mm rut depth	≥ 10,000 passes
		PG 70 — No. passes @ 6 mm rut depth	≥ 15,000 passes
		PG 76 or higher — No. passes @ 6 mm rut depth	≥ 20,000 passes

Performance Category	Test Method	Performance Parameter	Recommended Threshold
Cracking Resistance	IDEAL-RT	RT Index (Minimum / Preferred)	≥ 80 (Min) / ≥ 100 (Preferred)
	I-FIT (Flexibility Index)	FI (Minimum / Preferred)	≥ 8 (Min) / ≥ 10 (Preferred)
	IDEAL-CT	CT Index (Minimum / Preferred)	≥ 75 (Min) / ≥ 100 (Preferred)

5.7 CONSISTENCY WITH NATIONAL PRACTICE

The recommended thresholds for New Mexico are broadly consistent with criteria adopted by leading BMD states while being grounded in local data. The HWTT pass-count thresholds are aligned with those used by Texas, Illinois, and Louisiana, all of which differentiate requirements by binder grade. The I-FIT FI minimum of 8.0 is the most widely adopted threshold in the United States, originally established by the Illinois DOT and subsequently validated in numerous studies. The IDEAL-CT minimum of 75 and preferred value of 100 are consistent with the thresholds reported in the original IDEAL-CT development research and adopted by several state agencies. The IDEAL-RT minimum of 80 is consistent with values reported in the Texas BMD implementation literature.

The fact that the NM-specific statistical analysis independently converges on threshold values largely consistent with national practice provides mutual validation: it confirms both that the New Mexico balanced mixtures are performing comparably to well-performing mixtures in other states, and that the nationally adopted thresholds are appropriate for NM materials and conditions. The primary area of NM-specific differentiation is the supplementary HWTT rut depth criterion of 6 mm, which is more stringent than the typical 12.5 mm criterion and reflects the generally high rutting resistance of the balanced NM mixture population.

5.8 INFLUENCE OF BINDER GRADE AND RAP CONTENT

The performance results consistently demonstrate the dominant influence of asphalt binder grade on both rutting and cracking resistance. Mixtures with higher PG binder grades (PG 76 or higher) generally exhibited superior rutting resistance, evidenced by significantly lower HWTT rut depths and higher RT Index values, but in many cases showed reduced cracking resistance as measured by I-FIT FI. Conversely, mixtures with softer binders (PG 58-28) tended to exhibit excellent cracking resistance but sometimes failed to meet rutting criteria, particularly under the HWTT. This trade-off between rutting and cracking resistance is the fundamental motivation for the Balanced Mix Design framework.

RAP content also exerted a measurable influence on performance. High RAP contents (35%) consistently reduced cracking resistance, as reflected in lower FI values and, in some cases, reduced IDEAL-CT indices. The reduction in cracking resistance associated with RAP is attributable to the increased effective binder stiffness resulting from the incorporation of aged binder. This observation underscores the importance of evaluating cracking resistance for RAP-rich mixtures and, where necessary, adjusting binder grade or incorporating rejuvenators to maintain acceptable FI values. The threshold framework proposed in this study is applicable regardless of RAP content; however, designers should be mindful that RAP-rich mixtures are more likely to approach the minimum cracking thresholds.

5.9 LIMITATIONS AND NEED FOR CONTINUED CALIBRATION

The thresholds proposed in this chapter are designated as preliminary, reflecting the scope and dataset of the present study. While the nineteen NM mixtures evaluated represent a broad range of materials and conditions, the dataset is not exhaustive, and additional mixture types, including plant-produced mixtures from all NMDOT districts, open-graded friction courses, and mixtures incorporating polymer-modified binders, remain to be evaluated. The IDEAL-RT dataset in particular is limited to four mixtures, and the RT Index thresholds should be treated as provisional until a larger dataset is available.

It is recommended that NMDOT continue collecting performance test data as BMD is phased into routine mix design practice, and that the thresholds proposed herein be formally reviewed and updated following the accumulation of field performance data that can be used to validate the laboratory-to-field relationship. The development of field performance correlation data, linking laboratory BMD test results with observed pavement distress rates in New Mexico, is identified as a key priority for future research to support the long-term refinement and full adoption of the BMD framework.

Note — Selection of Projects for Implementation: The project advocate has been contacted regarding implementation of the BMD framework in a construction project. Apparently, advocate is suggesting doing a few more mix testing in 2nd Phase of this study.

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CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This study was conducted to develop a Balanced Mix Design (BMD) framework for the New Mexico Department of Transportation (NMDOT). The study consisted of four interconnected components: (1) development of a performance-based Balanced Mix Design (BMD) procedure for determining the balanced asphalt binder content; (2) proposal and evaluation of three performance-index-based methods for identifying the balanced asphalt content; (3) comprehensive performance evaluation of nineteen asphalt mixtures representative of New Mexico materials and production practices; and (4) statistical development of preliminary New Mexico-specific rutting and cracking performance thresholds for BMD implementation. The principal conclusions from each component are presented below.

- A performance-modified volumetric Balanced Mix Design procedure was developed for NM asphalt mixtures. Starting from a conventional Superpave volumetric design, the optimum asphalt binder content is refined through direct laboratory performance testing to achieve an appropriate balance between rutting and cracking resistance.
- A key contribution of this study is the development of three independent performance-based methods for determining balanced asphalt content: the HWTT–I-FIT method, the IDEAL-RT–IDEAL-CT method, and the Combined Performance Index method. The convergence of all three methods across PG 64, PG 70, and PG 76 binder grades, with balanced asphalt content differences of no more than 8% among methods, confirms that the proposed BMD framework is robust, internally consistent, and not dependent on any single test method
- A comprehensive performance database was developed for New Mexico asphalt mixtures, encompassing both laboratory-compacted and field-produced specimens. Of the nineteen mixtures evaluated, twelve were classified as balanced and seven as unbalanced based on established BMD performance criteria.
- Preliminary performance thresholds were developed for NMDOT. The recommended minimum criteria are as follows: HWTT rut resistance of 10,000, 15,000, and 20,000 wheel passes to reach a 6 mm rut depth for PG 64, PG 70, and PG 76 binder grade mixtures, respectively; an I-FIT Flexibility Index of FI $\geq$ 8 (preferred FI $\geq$ 10); an IDEAL-CT cracking index of CT Index $\geq$ 75 (preferred CT Index $\geq$ 100); and an IDEAL-RT rutting index of RT Index $\geq$ 80 (preferred RT Index $\geq$ 100).

6.2 RECOMMENDATIONS FOR FUTURE STUDIES

Based on the findings of this study, the following recommendations are made for the implementation of Balanced Mix Design by the New Mexico Department of Transportation:

1. **Adapting the HWTT–I-FIT method as the standard BMD design protocol.** The Hamburg Wheel Tracking Test and Illinois Flexibility Index Test, applied at the balanced asphalt content determined through the proposed performance-modified volumetric procedure, could be incorporated into NMDOT mix design verification for all new surface and binder course designs. The IDEAL-RT and IDEAL-CT tests are recommended as supplementary tools for routine production-level quality control, given their demonstrated consistency with primary test results and their operational simplicity.
2. **Implementing the preliminary performance thresholds for design criteria.** The preliminary two-tier performance criteria developed in this study are recommended for NMDOT pilot projects and future asphalt mix designs. To be considered acceptable, a mixture must satisfy the following minimum criteria: a cracking Flexibility Index (I-FIT) of FI ≥ 8 or a CT Index (IDEAL-CT) of CT Index ≥ 75; a rutting RT Index (IDEAL-RT) of RT Index ≥ 80; and the specified HWTT pass-count requirement for the applicable binder grade. Mixtures exhibiting FI ≥ 10, CT Index ≥ 100, RT Index ≥ 100, and an HWTT rut depth not exceeding 6 mm at the required number of wheel passes are considered to meet the preferred performance level.
3. **Establishing pilot projects and expanding the NM performance database.** A few representative pilot projects across different NMDOT districts are recommended for initial BMD implementation. Plant-produced mixture samples should be tested using the full BMD test suite, and pavement cores should be extracted at 2 and 5 years post-construction for distress evaluation. The resulting dataset, targeting a minimum of 15 additional plant-produced mixtures, will enable a formal review of the preliminary thresholds and support the development of laboratory–field performance correlations necessary for long-term BMD specification adoption.
4. **Development of a formal threshold calibration and field validation program.** The preliminary thresholds proposed in this study should be formally reviewed and updated following the accumulation of sufficient plant-produced mixture data and at least one full pavement distress inspection cycle on pilot projects. The long-term goal is the development of New Mexico-specific laboratory–field performance relationships that directly link BMD test results to observed rutting and cracking distress, providing the evidentiary foundation for integrating BMD criteria into NMDOT standard construction specifications.

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