Transitioning from Marshall to Superpave and Balanced Mix Design: Advancing Asphalt Mixture Performance in Nigeria

2nd International Workshop on Global Trends in Design & Construction of Durable Road Pavements

CABaT - NBRRI House, Abuja - November 24th – 28th, 2025

PRESENTATION OVERVIEW

- Asphalt Mix Design Evolution
- Modern Mix Design Approaches
- Benefits and Challenges
- Practical Applications
- Performance Test Steps
- Balance Mix Design Concepts
- Conclusion

Asphalt Mix Design Evolution

Early Empirical Methods to Performance-Based Design

Introduction to Marshall Mix Design

Traditional Asphalt Design

Marshall Mix Design was developed during World War II for asphalt mixture design.

Testing Compacted Specimens

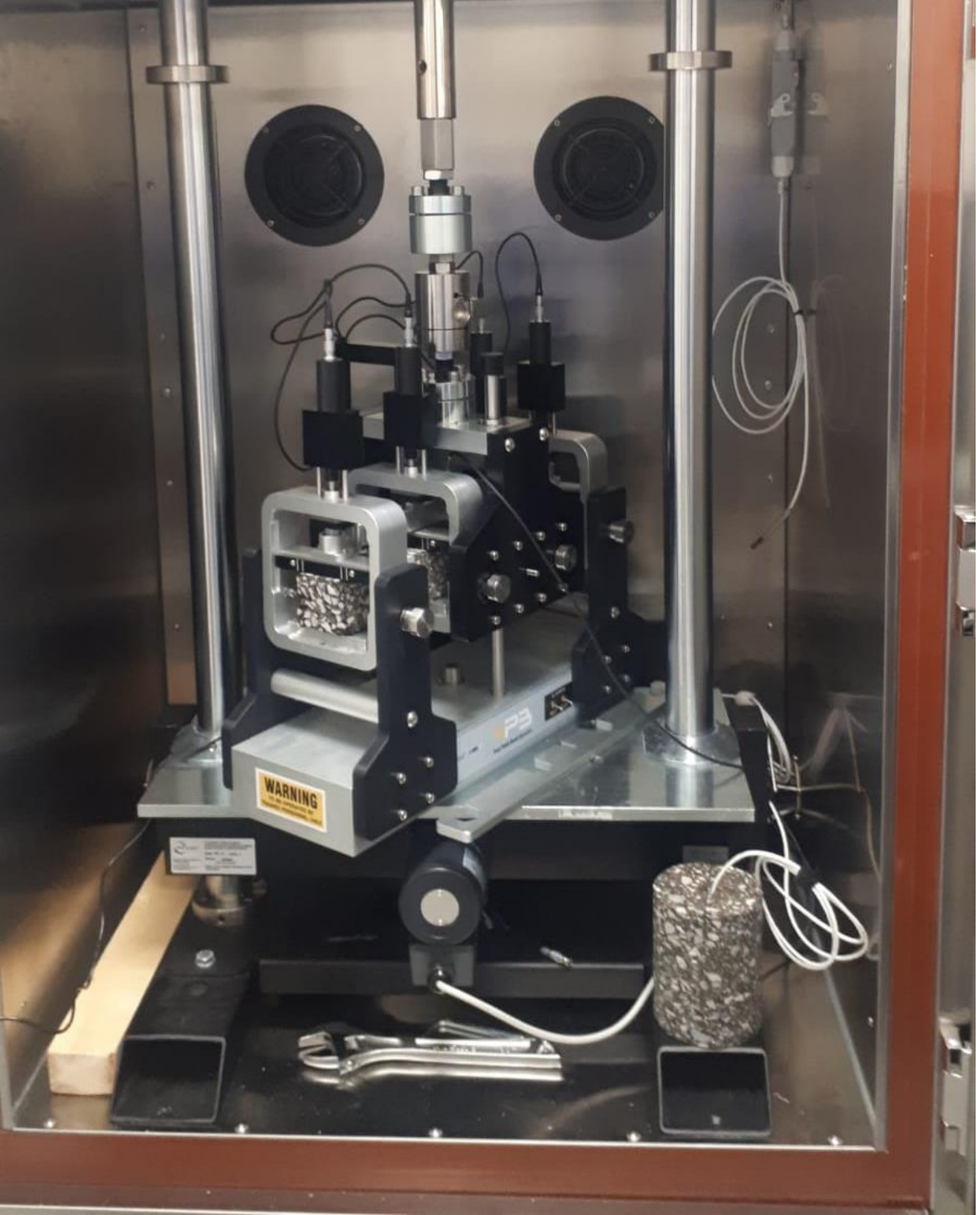
Compacting asphalt cylinders and measuring stability and flow determines binder content.

Process Components

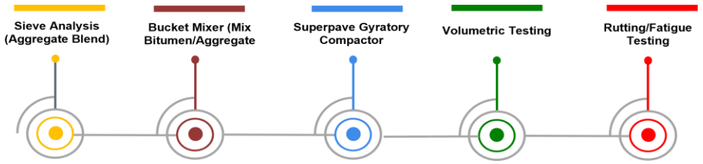
Includes aggregate selection, specific gravity, and volumetric analysis steps.

Modern Limitations

Method lacks consideration of modern traffic loads and environmental factors.



Limitations of Marshall Method



Lack of Field Simulation

Marshall method does not replicate real traffic loads or climate variations in testing.

Non-Representative Compaction

Compaction method fails to mimic in-service pavement densification accurately.

Absence of Performance Testing

Marshall lacks tests for long-term durability, rutting, and cracking resistance.

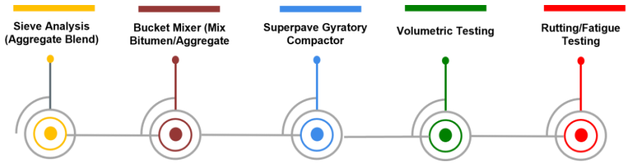
Need for Advanced Methods

Modern mix design methods incorporate real-world performance criteria for accuracy.

Modern Mix Design Approaches

Sustainable and Smart Asphalt: Advancing Mix Design with Technology

Introduction to Superpave



Superpave Overview

Superpave is a mix design method developed to improve pavement performance over traditional methods.

Data Integration

It incorporates traffic and climate data to tailor pavement design for specific conditions.

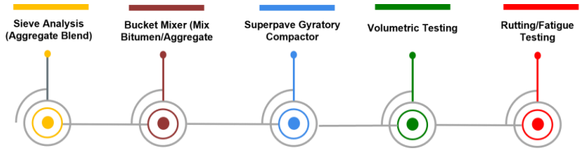
Performance Testing

Superpave includes testing for moisture susceptibility, rutting, and fatigue cracking.

Global Adoption

The method is widely used internationally for creating durable, reliable pavements.

Introduction to Superpave



Primary product of the Strategic Highway Research Program (SHRP)

$50M for asphalt mix research

Represents a fundamental change in design philosophy

First introduced in 1992, has evolved considerably since through extensive research

Created a system of asphalt mixture design

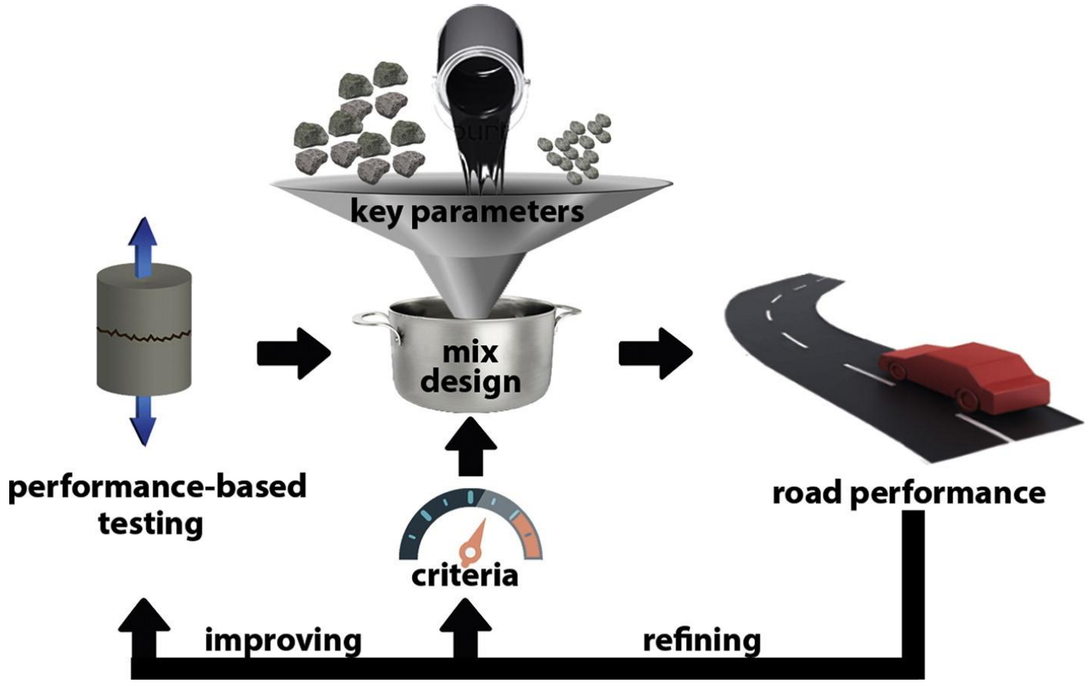
Asphalt specification,
Volumetric mix design,
Mixture analysis

Addressing two primary modes of distress

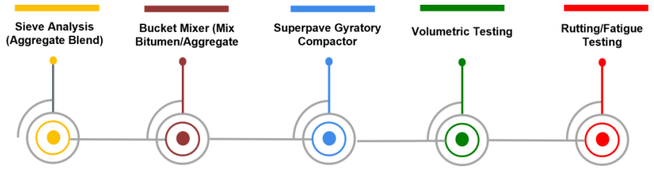
Rutting
Fatigue cracking

While considering binder-related contributing factors:

Climate
Traffic
Degree of Risk & Reliability



Balanced Mix Design (BMD) Concept



Performance-Based Optimization

BMD balances cracking and rutting resistance to optimize asphalt mixture performance.

Laboratory Testing Methods

Tests like IDEAL-CT and Hamburg Wheel Track evaluate cracking and rutting in asphalt mixes.

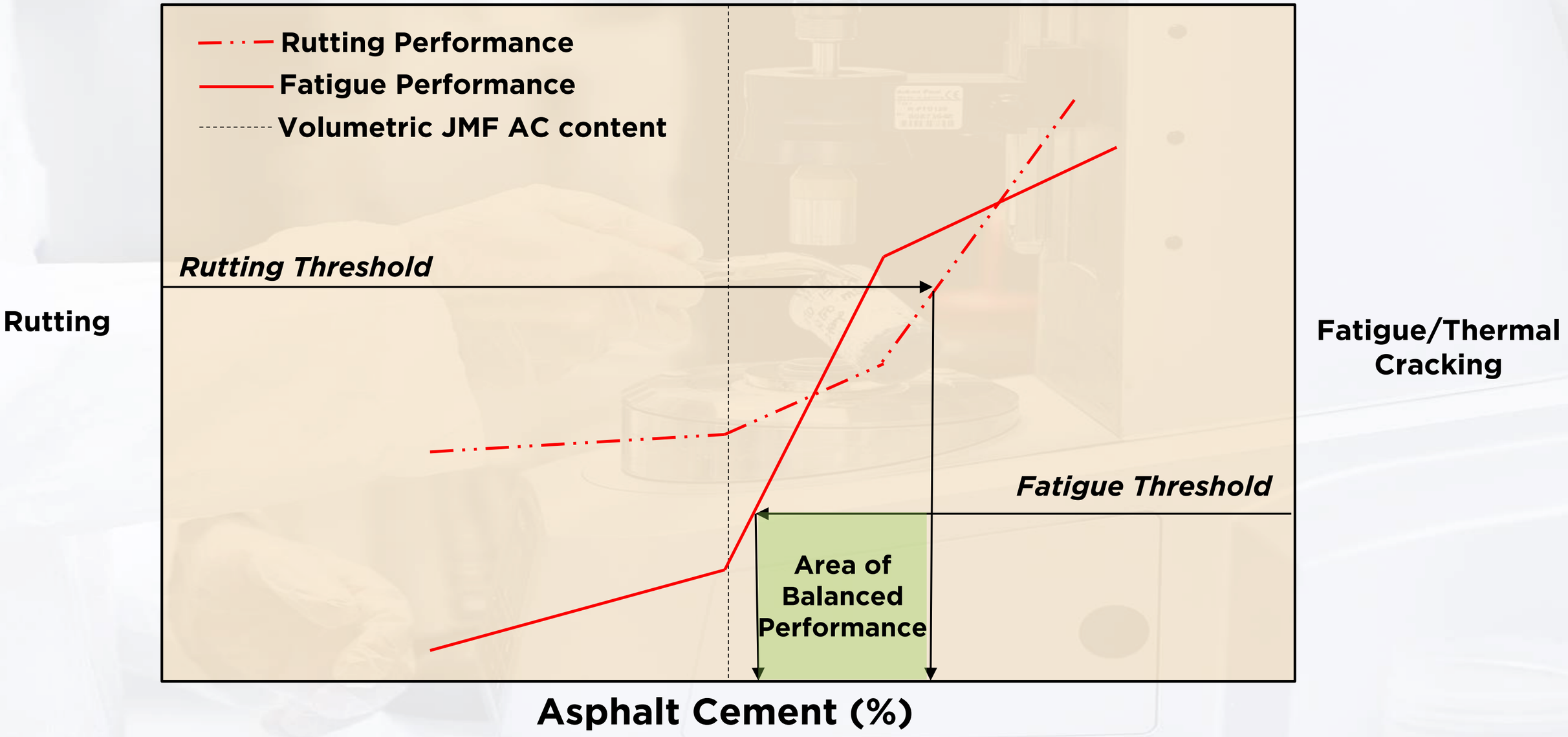
Flexible Mix Design

BMD relaxes volumetric requirements when performance criteria are satisfied.

Global Adoption Benefits

BMD supports durable pavements and use of recycled materials and new additives worldwide.

Performance-Based Design Example



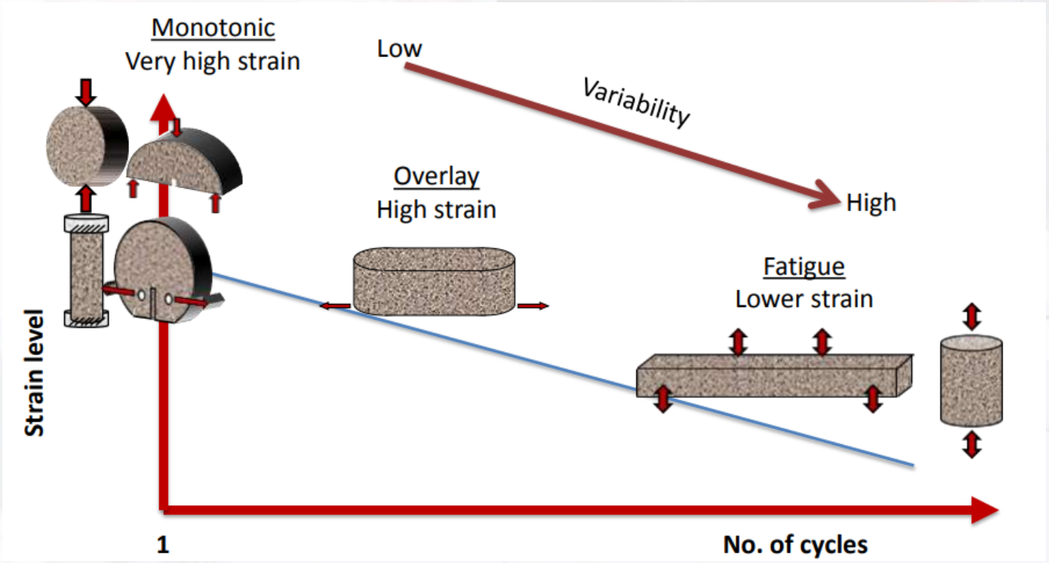
BMD Test Methods

Thermal Cracking
Low temp stiffness

DCT
SCB
IDT
TSRST

Fatigue Cracking
Intermediate Temp stiffness

Reflection | Bottom-up | Top-Down



Rutting
High Temp Stiffness

HWTD
APA
Flow Number
Rolling Rutting Test

< -28°C/0°F | 21°C/70°F | < 58°C/136°C

Temperature (°C/°F)

Innovation Road Map Toward Mechanistically Designed Mixes

- Sensitivity to aggregate and AC variations
- Different aging methods

MIX DESIGN (LAB) → **PRODUCTION** → **PLACEMENT** → **QC/QA**

- Understanding pavement purpose and mix strength limits
- Reproducibility and repeatability of the test methods
- Simplicity
- Aging methods
- Selection of performance thresholds
- Simulating distress

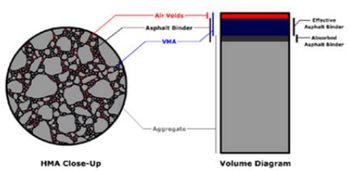
- Design air voids vs. in-place density
- Compaction methods
- Paving methods

- Time, simplicity of test methods
- Cost

PILLARS OF THE APPROACHES

VOlumetrics

- VMA, VFA, air voids
- Asphalt Content
- Tensile Strength Ratio



Balanced Mix Design (BMD)

Rutting

- Hamburg Wheel Tracking Test (HWTT)
- Asphalt Pavement Analyser (APA)
- AMPT - Flow Number

Cracking

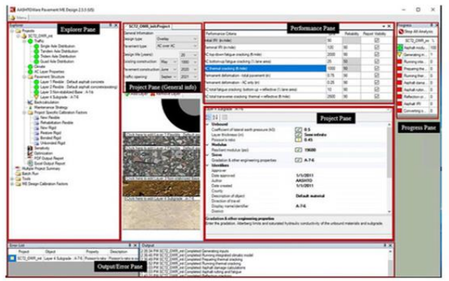
- Disc-shaped Compact Tension Test
- Indirect Tensile Asphalt Cracking Test
- Semi-Circulat Bend Test (SCB)

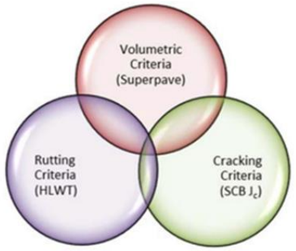
Water Sensitivity

- Tensile Strength Ratio (TSR)
- Hamburg Wheel Tracking Test (HWTT)

Pavement ME

- Dynamic Modulus
- Low temperature Cracking





Post-Construction Performance Validation

Field Testing and Data Collection

- **Visual Inspection:** Conduct a thorough visual survey to identify any immediate surface distresses, such as cracking, rutting, or bleeding, and ensure proper drainage and seamless transitions at joints.
- **Compaction Testing:** Verify the level of compaction, a critical factor in pavement life, using devices like a **nuclear density gauge** or a **light-weight deflectometer (LWD)**. This confirms the material has achieved the required density to resist deformation.
- **Surface Profile Measurement:** Measure the surface's transverse and longitudinal profiles using tools like a **laser surface profiler** to determine the International Roughness Index (IRI) and identify permanent deformation (rutting).
- **Deflection Testing:** Assess the structural strength of the pavement layers and subgrade using a **Falling Weight Deflectometer (FWD)** or LWD to measure the pavement's elastic stiffness and identify underlying support issues.
- **Skid Resistance Testing:** Measure the surface's skid resistance to ensure it meets safety standards.

Post-Construction Performance Validation

Core Sampling and Laboratory Analysis

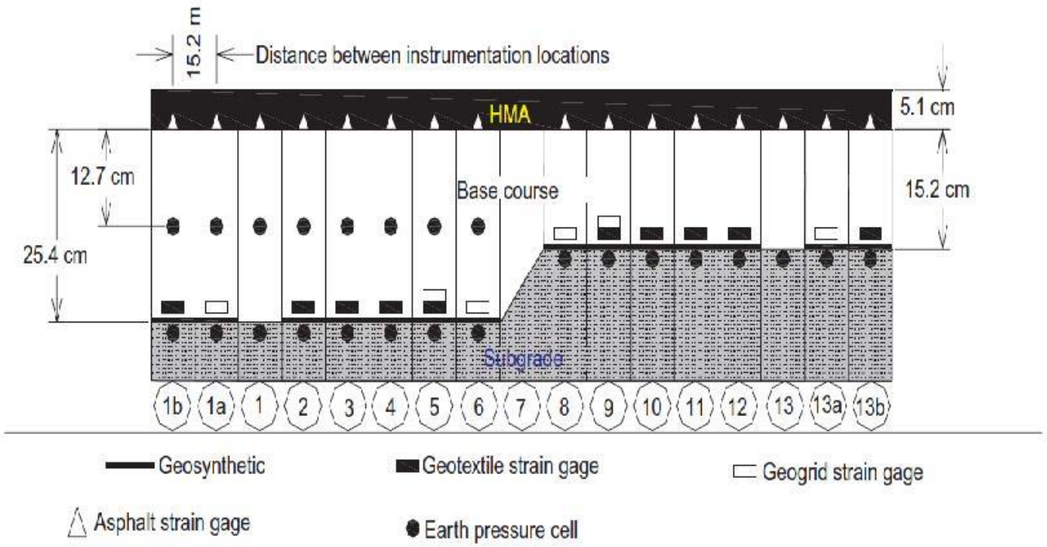
- **Laboratory Testing of Cores:** Transport core samples to a laboratory for detailed analysis:
- **Layer Thickness Verification:** Confirm the actual thickness of each pavement layer matches design specifications.
- **Density and Air Voids Analysis:** Measure the density and air void content in the lab to validate field compaction results and ensure optimal performance characteristics.
- **Asphalt Content and Gradation:** Determine the percentage of asphalt binder and aggregate gradation to confirm the mix meets the approved design.
- **Performance-Based Testing:** Conduct tests to evaluate properties like cracking resistance, modulus (stiffness), and moisture susceptibility using methods such as the **Marshall Stability Test**, **Dynamic Shear Rheometer (DSR)**, or **Bending Beam Rheometer (BBR)**, depending on the project requirements.

In-Situ Pavement Data Acquisition

Non-Destructive Testing (NDT) and Surface Monitoring

These techniques are used to evaluate overall pavement conditions without damaging the structure and are often mobile and high-speed. Integrated directly into the pavement layers, often during construction.

- **Structural response:**
  - **Strain:** Measured using embedded sensors like strain gauges to understand how the pavement deforms under load, which is crucial for predicting fatigue.
  - **Pressure:** Collected by pressure cells to measure the vertical stress on the pavement layers.
- **Surface distress:**
  - **Cracking:** Recorded and categorized, noting the type, width, and location of cracks.
  - **Rutting:** Measured to assess permanent deformation in wheel paths.
  - **Roughness:** Assessed using lasers to measure the longitudinal profile of the road surface.
- **Traffic and environmental data:**
  - **Traffic loads:** Collected using systems like Weigh-in-Motion (WIM) to get detailed information about vehicle axle loads.
  - **Temperature:** Measured at various depths to understand its impact on pavement performance.

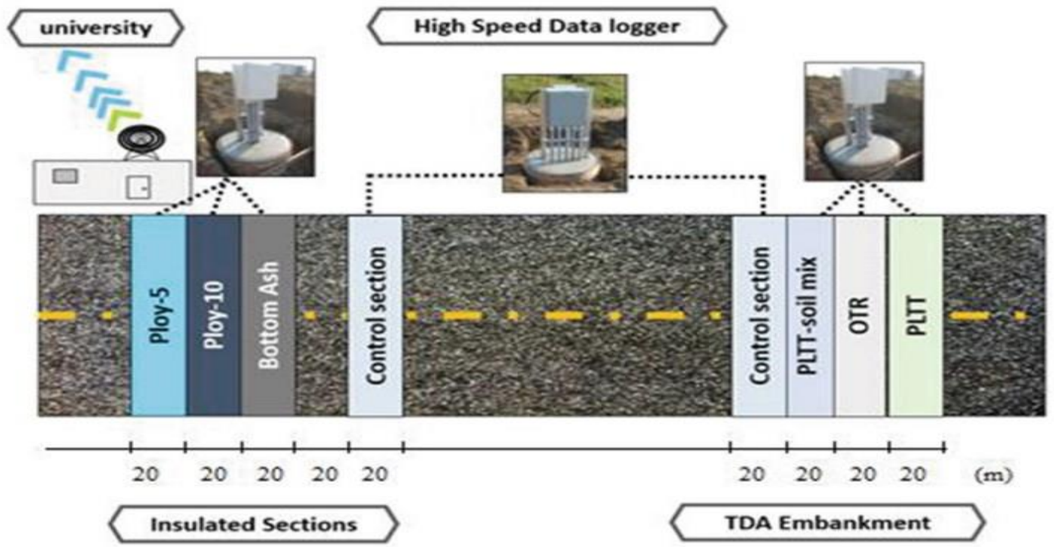


Case Studies or Examples

Edmonton, Canada – Insulated Layers, Strain Gauges, Temperature and Moisture Sensors

Purpose: In 2016, Hashemian and Bayat [55] conducted a study on the Integrated Road Research Facility (IRRF) built in Edmonton, Alberta, Canada, in 2012.

- The research aimed to assess the effects of cold weather on pavement performance and explore the use of waste and repurposed materials.
- The test road was divided into three main sections: insulated segments, pavement monitoring areas, and tire fill embankments utilizing **shredded off-the-road (OTR)** and **passenger/light truck tires (PLTT)**.
- To monitor the pavement's performance over time, **temperature**, **settlement**, and **moisture sensors** were installed in the tire-filled and insulated sections. The insulated portions employed materials such as bottom ash and polystyrene boards beneath the base course to prevent subgrade freezing.
- The results from **monitoring** and **Falling Weight Deflectometer (FWD)** testing showed that these insulating layers provided effective protection, with bottom ash and polystyrene proving to be the most effective.
- Among the various **insulating materials**, the bottom **ash layer**, along with the **5 cm (Poly-5)** and **10 cm (Poly-10) polystyrene** layers, offered the highest level of protection **against subgrade freezing.**
- Figure 2-13 presents the schematic layout of the test road

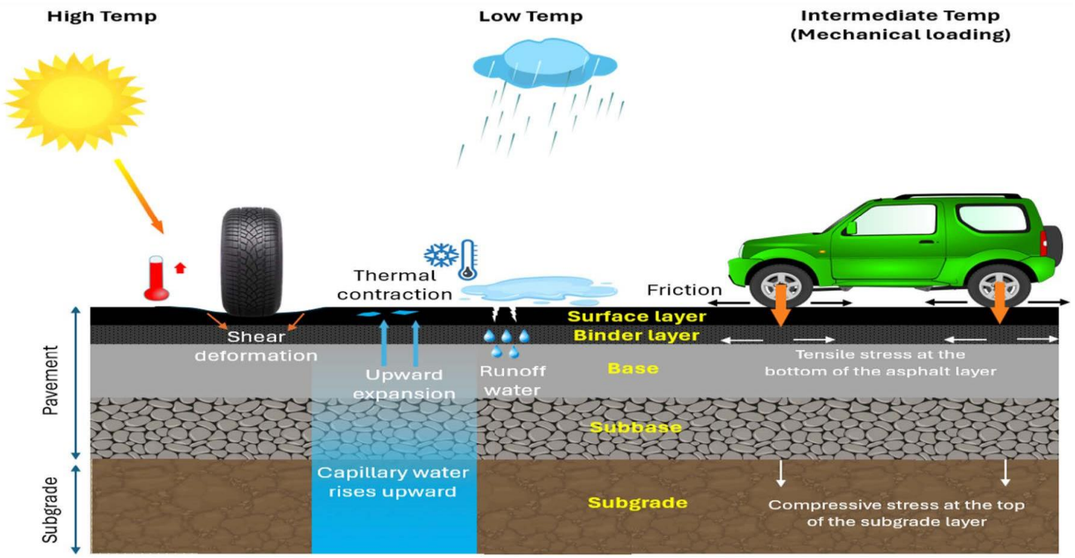


- **Credit** - Hashemian, L. & Bayat, A. (2016). Three Years' Monitoring of IRRF Instrumented Test Road. Springer International Publishing. pp. 829–843.

In-Situ Pavement Data Acquisition

Applications of the Data

- **Pavement management:**
  - **Maintenance planning:** Data informs decisions on when and where maintenance is needed, prioritizing the most critical repairs.
  - **Performance prediction:** AI and other modeling tools use the data to forecast future pavement conditions and guide long-term planning.
- **Design and construction:**
  - **Validating models:** Data from instrumented sections can be used to compare against theoretical calculations and refine pavement design models.
  - **Quality control:** Real-time data can help assess the quality of materials and construction processes.
- **Asset management:**
  - **Inventory and ranking:** Data collection helps agencies create a comprehensive inventory and rank roads based on their condition, guiding budget allocation.
  - **Long-term monitoring:** Provides a historical record of pavement conditions, helping to understand long-term performance and trends.

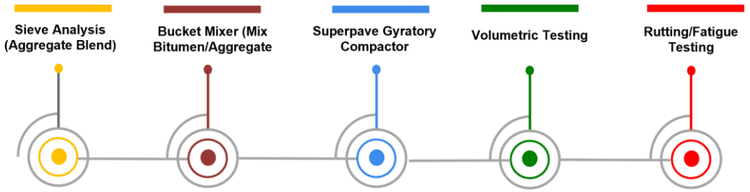


➢ **Figure:** Asphalt Pavement Distress Mechanisms Under Low, Intermediate, And High Temperature Conditions

Benefits and Challenges

From Tradition to Technology: The Journey of Asphalt Mix Design

MARSHALL AND SUPERPAVE MIX TECHNOLOGY



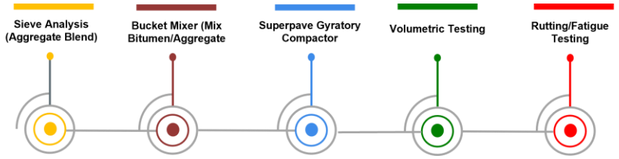
Marshall - Older empirical mix design method

- Based on test values established through observed field performance
- No real relationship between tests and pavement performance
- Combination of “Art and Science”

Superpave - Performance Based mix design method

- Relates pavement performance directly to lab mix design properties

Benefits of Transitioning to Superpave and BMD



Improved Pavement Performance

Superpave and BMD enhance pavement durability and resistance to traffic and environmental damage.

Scientific Mix Design

These methods use data-driven approaches to tailor asphalt mixes to specific conditions.

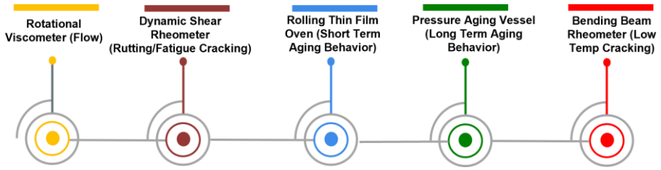
Sustainability Support

Supports recycled materials and innovative technologies to promote environmental sustainability.

Cost and Safety Benefits

Enhanced testing reduces maintenance costs and improves road safety over time.

Implementation Challenges in Nigeria



Infrastructure and Equipment Gaps

Nigeria faces lack of infrastructure and limited access to advanced testing equipment for Superpave and BMD.

Training and Resistance

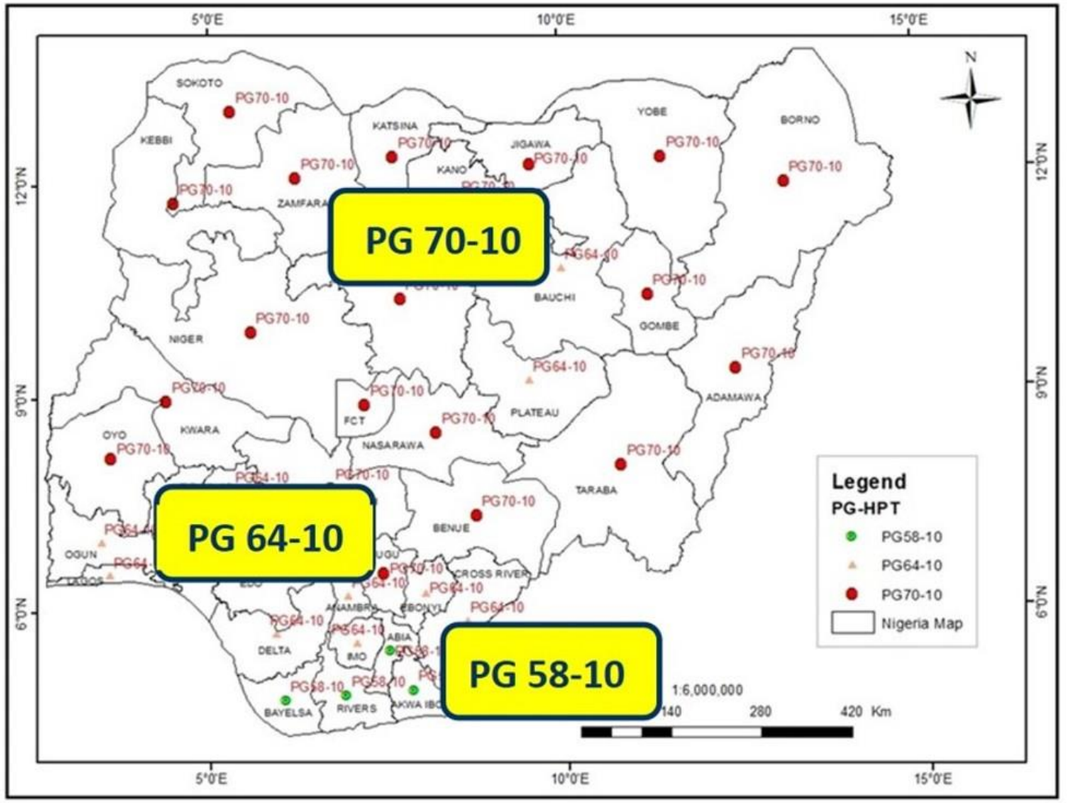
Insufficient training and resistance to change hinder adoption of new road construction methods.

Policy and Financial Constraints

Need for policy support, stakeholder engagement, and overcoming financial limitations is critical.

Material Variability Challenges

Variability in local materials complicates implementation and requires adaptation in processes.



Practical Applications

From Lab to Pavement: Practical Strategies in Performance-Based Mix Design

Case Studies or Examples

Road Potholes - October 26, 2025, News

“The State Government is aware of the potholes that have appeared on some roads as a result of the heavy and prolonged rainfall in recent weeks,” the statement read. “Government wishes to assure members of the public that as the rains subside; rehabilitation work will begin in earnest to ensure proper and durable reconstruction of the affected portions.

“Furthermore, desilting of drainages and clearing of blocked water channels will also commence in various parts --- to reduce flooding and prevent further damage to road infrastructure.”

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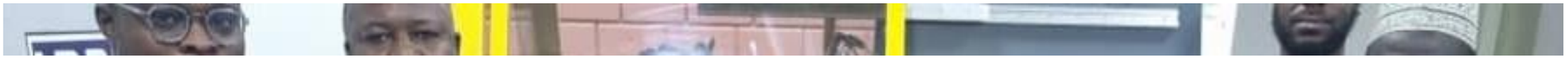
Improved Pavement Performance

Superpave demonstrated better rutting resistance and longer pavement life than Marshall designs.

Training and Promotion

National workshop by NBRRI and NITHE trained engineers to promote Superpave adoption.

Recommendations and Way Forward



Standardized Testing Protocols
Develop and implement uniform testing procedures for accurate mix evaluation.

Infrastructure Investment
Invest in modern laboratory infrastructure to support advanced mix design techniques.

Stakeholder Engagement
Engage key stakeholders to build consensus and support for adoption.

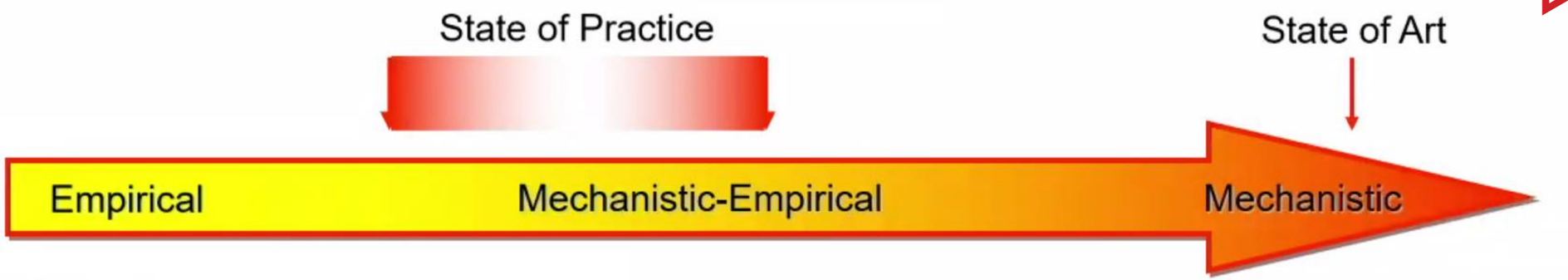
Pilot Projects and Collaboration
Initiate pilot projects and collaborate internationally to validate and accelerate implementation.

ASPHALT MIXTURE PERFORMANCE TESTING

EVALUATING DURABILITY AND STRENGTH OF ROAD MATERIALS

WHY PERFORMANCE TESTING IS ESSENTIAL

Pavement Design Timeline



1920s – PR
1929-45 – *CBR Method*
1945 – HRB soil class.
1947 – Kansas SHC
1953 – U.S. Navy
1960-93 - AASHTO

1953 – Kerkhoven & Dormon
1982 – AI method

2008-2022 – AASHTO's MEPDG
Pavement ME

2014-2022 - FlexPAVE

Full Constitutive Modeling to predict directly distresses and failure in pavement systems

Integration of pavement structural design and material design

TYPES OF PERFORMANCE TESTS & THEIR RELEVANCE

Rutting Resistance Tests

Evaluate asphalt's ability to resist permanent deformation under repeated loads using wheel tracking and APA tests.

Cracking Resistance Tests

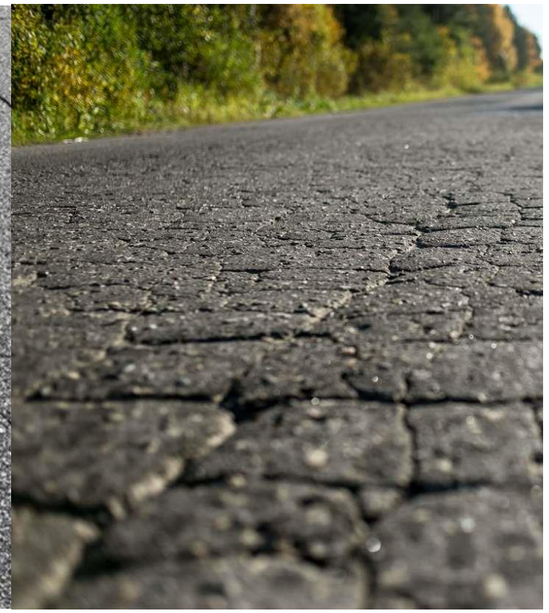
Assess flexibility and fracture energy with Ideal-CT, SCB, and DCT tests for crack tolerance evaluation.

Fatigue Performance Tests

Simulate long-term traffic loading with Four-point beam and Overlay tester to predict fatigue cracking.

Moisture Susceptibility Tests

Use Tensile Strength Ratio (TSR) to ensure asphalt maintains strength and durability in wet conditions.



HAMBURG & APA TEST

Purpose of Hamburg Test

Simulates rutting and moisture damage with repeated wheel loads in water at high temperature.

APA Test Methodology

Uses pressurized hoses and temperature control to replicate field wheel loading conditions.

Relevance to Nigerian Conditions

Tests address rutting issues caused by high temperatures and heavy traffic in Nigeria.

Designing Durable Pavements

Identifying mixtures with high rutting resistance helps maintain smooth, durable roads.

IDEAL-CT, SCB & DCT TEST

Ideal-CT Test Purpose

Measures Crack Tolerance Index to evaluate asphalt mixture resistance to tensile cracking.

SCB Test Function

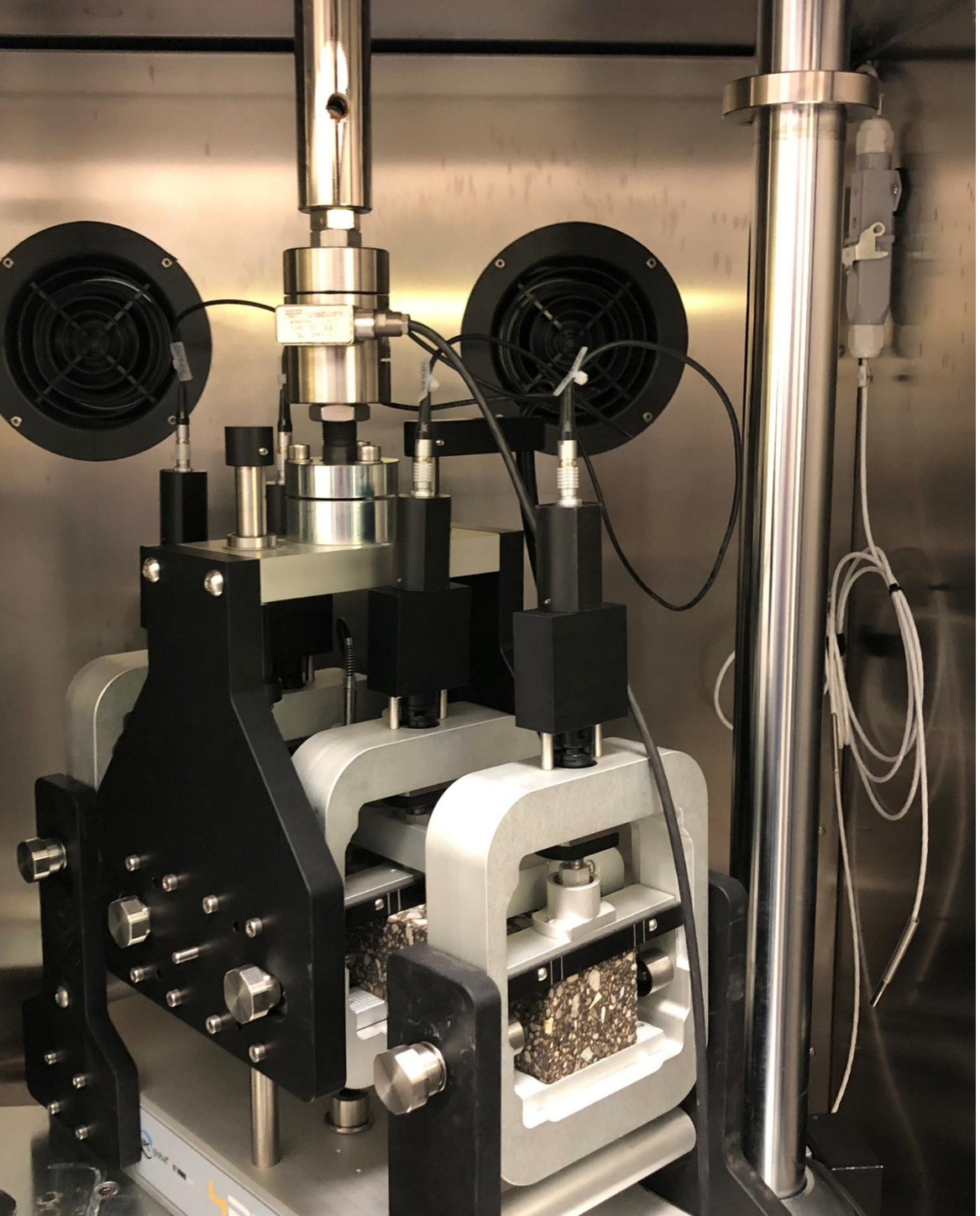
Assesses fracture energy and flexibility by loading a notched semicircular specimen until failure.

DCT Test Application

Evaluates energy to propagate cracks in disk-shaped specimens, focusing on low-temperature cracking.

Importance in Mix Design

Guides adjustments in binder and aggregate to improve durability and extend pavement life.



FOUR_POINT BEAM & OVERLAY TEST

Fatigue Performance Tests

These tests evaluate asphalt mixtures' resistance to repeated loads without cracking over time.

Four-Point Beam Test

Simulates traffic by applying cyclic bending to measure cycles until asphalt beam failure.

Overlay Tester Function

Applies repeated tensile loads to bonded specimen to assess potential reflective cracking in overlays.

Importance for Pavement Design

Helps engineers design durable mixes for rehab and high-traffic areas, improving sustainability.

STEP-BY-STEP PREPARATION FOR PERFORMANCE TESTS

Compaction and Specimen Formation

Use Superpave Gyratory Compactor to achieve target air voids and correct specimen dimensions.

Specimen Notching

Ideal-CT uses cylindrical samples without notching; SCB and DCT require precise notching with tile saw.

Conditioning and Mounting

Condition specimens at test temperature; mount securely in water baths or beam supports depending on test.

Standardization and Training

Uniform sample preparation and staff training ensure reliable results across Canada labs.

Heat Equipment and Batched Materials

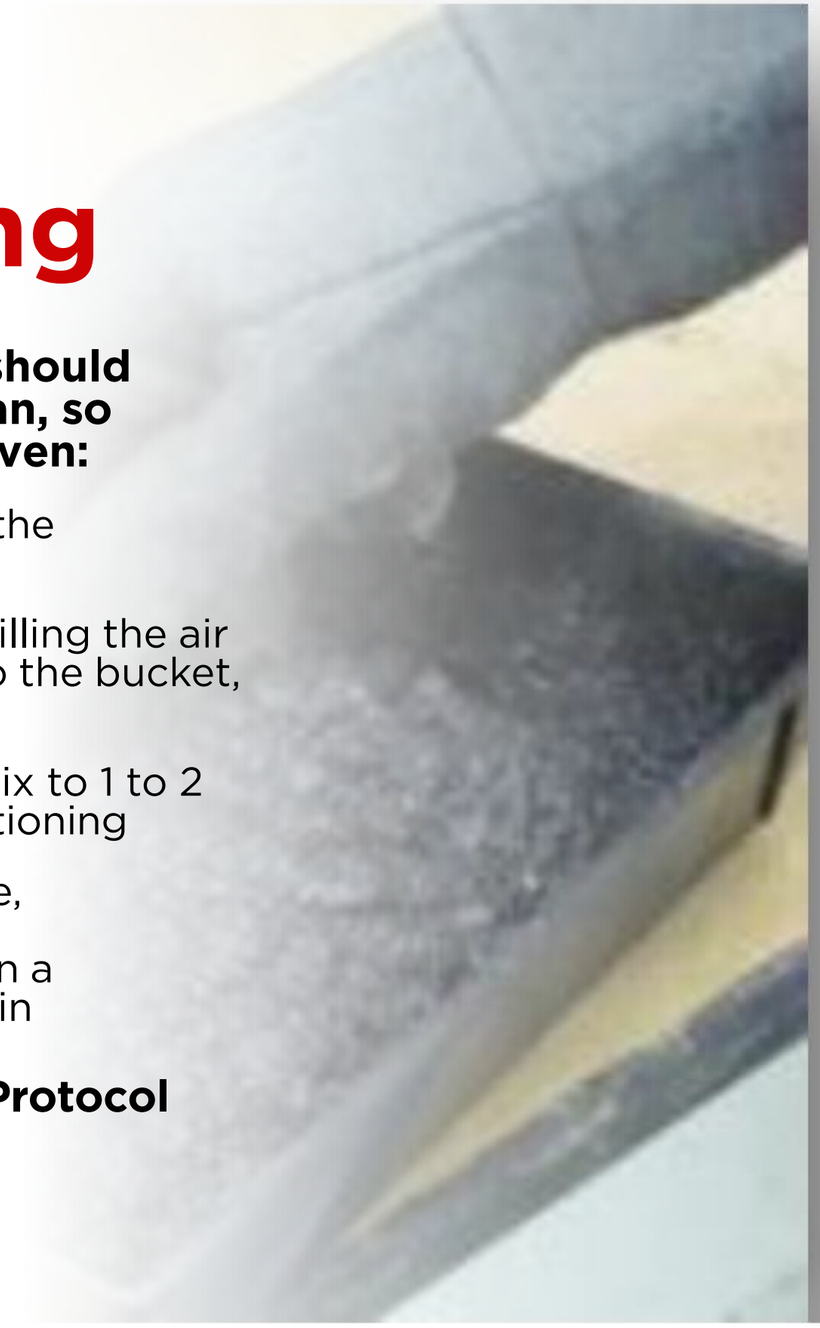
- **Heat asphalt, aggregates, molds, plates, scrapers, etc.**
  - Asphalt binder is modified before this process with polymer, softeners, adhesives, anti-strips, etc.…usually by the manufacturer.

Laboratory Mixing of Materials

- **Pour batched, heated aggregate in bucket/bowl**
- **Make a “hole” for the asphalt in the middle of the aggregate**
- **Add asphalt**
- **Mix aggregates and asphalt until coated**
  - Usually about 2 minutes; be consistent
  - See manufacture for other additives like fiber, etc.

Mixture Conditioning

- **After mixing, sample should be spread evenly in pan, so the heating/aging is even:**
  - Remember to scrape the bucket/bowl
    - Fines are key to filling the air voids and stick to the bucket, spatula, etc.
  - Speciation - Spread mix to 1 to 2 inches thick for conditioning
    - The more mixture, the large the pan required to obtain a similar thickness in the pan
- **Follow AASHTO R30 Protocol**



Laboratory Compaction of Mixture

- Transfer mixed condition materials into molds
- Compact according to specification and mixture type
- Label for Identification

TEST PROCEDURES HAMBURG (HWT) & APA

HWT Test Method

Uses a steel wheel on submerged asphalt specimen in heated water to simulate rutting and moisture damage. Measures rut depth up to 20,000 passes.

APA Test Method

Applies pressure with loaded wheel on asphalt in temperature-controlled chamber to evaluate deformation resistance.

Specimen Preparation

Specimens compacted with Superpave Gyratory Compactor targeting air voids, conditioned at test temperature, and securely mounted.

Regional Importance

Tests are vital for Canada’s cold climate and heavy traffic, ensuring pavement durability and reduced maintenance costs.

PREPARATION & TESTING FOR WHEEL RUTTING TESTS

Compaction with Gyratory

Specimens are compacted using a Superpave Gyratory Compactor to reach target air voids.

Temperature Conditioning

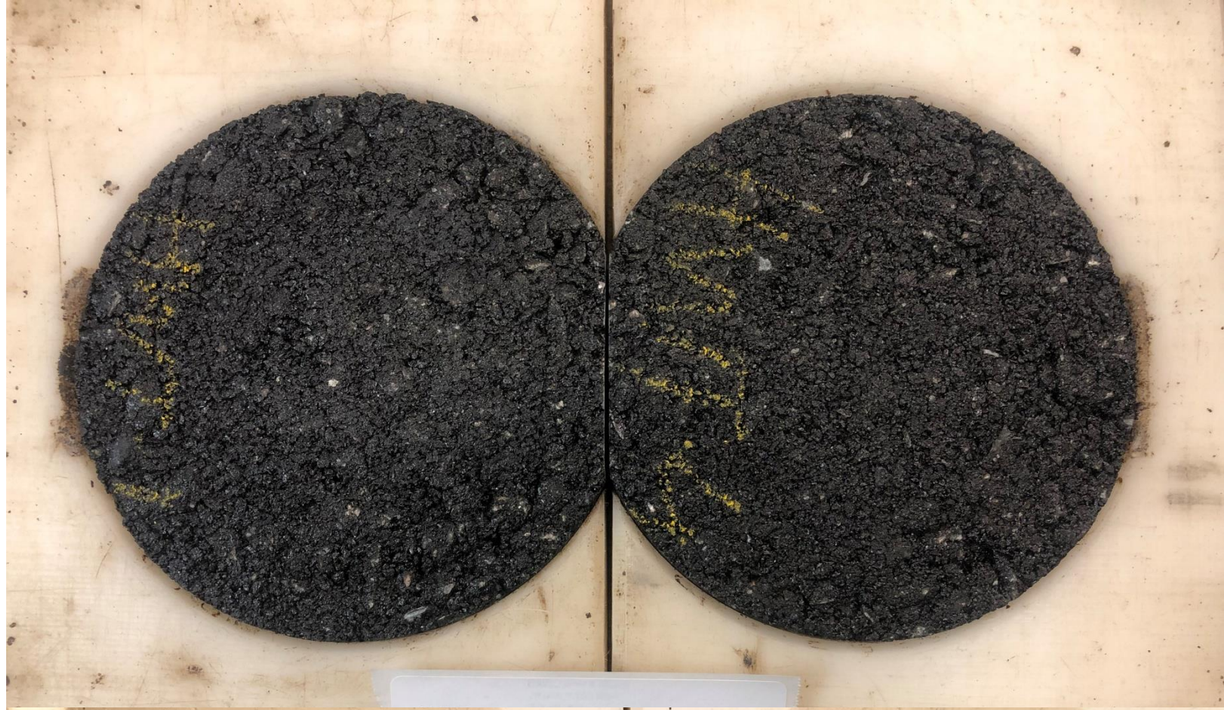
Specimens are conditioned at 50°C to simulate real field temperature conditions.

Wheel Loading Test

Conditioned specimens undergo repeated wheel loading on Hamburg or APA devices.

Rut Depth Measurement

Rut depth is measured periodically to evaluate mixture's resistance to deformation.



TEST PROCEDURES
IDEAL-CT, SCB, DCT

Ideal-CT Test Purpose

Measures Crack Tolerance Index using cylindrical specimen under controlled tension.

SCB Test Evaluation

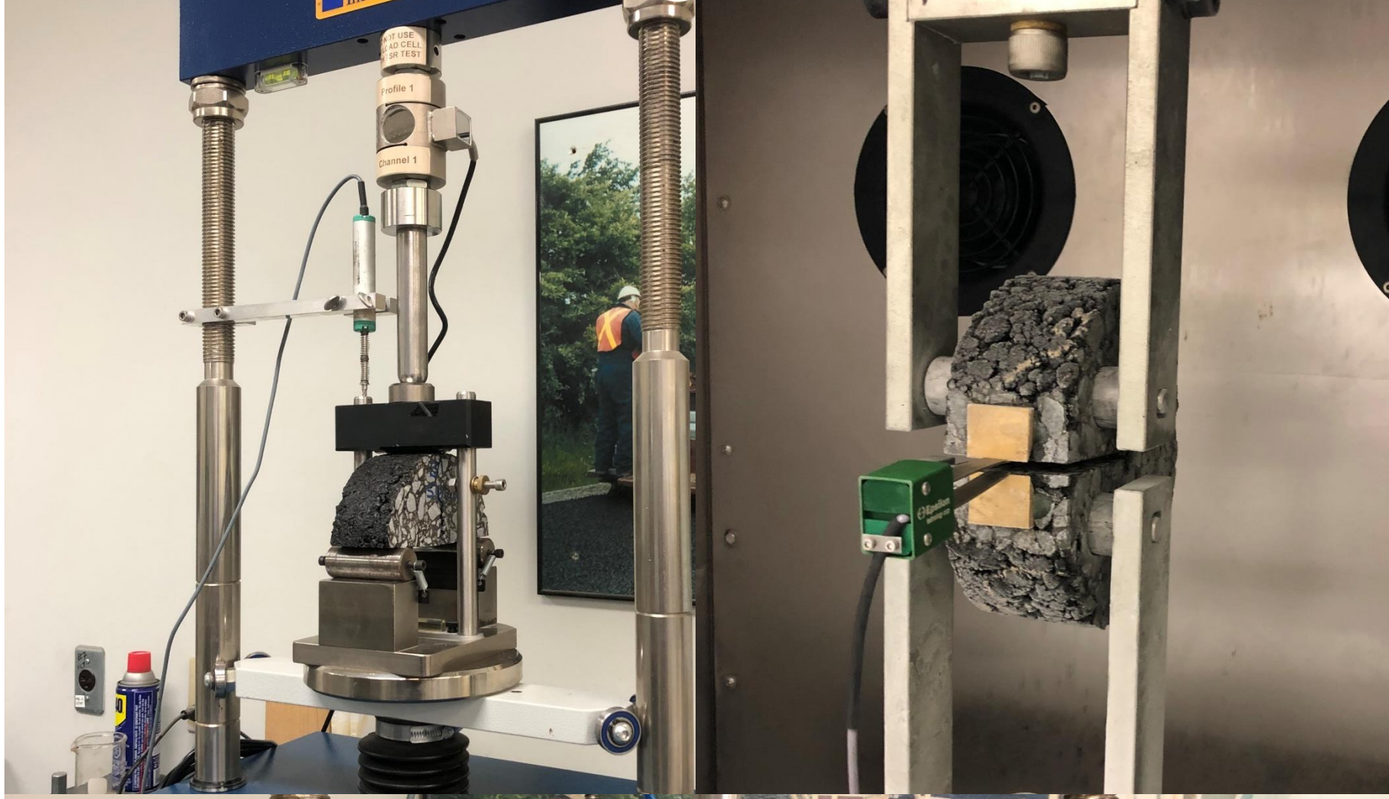
Assesses fracture energy and flexibility with a notched semi-circular specimen under load.

DCT Test Application

Analyzes low-temperature cracking by pulling disk-shaped specimen to measure crack growth.

Sample Preparation and Significance

Involves compacting, notching, and conditioning specimens to evaluate crack resistance effectively.



PREPARATION & TESTING FOR CRACKING TESTS

Critical Role of Sample Preparation

Accurate sample preparation ensures repeatable and precise test results for effective mix design.

Precise Specimen Compaction

Specimens compacted with gyratory compactor to achieve target air voids for reliable tests.

Uniform Specimen Cutting

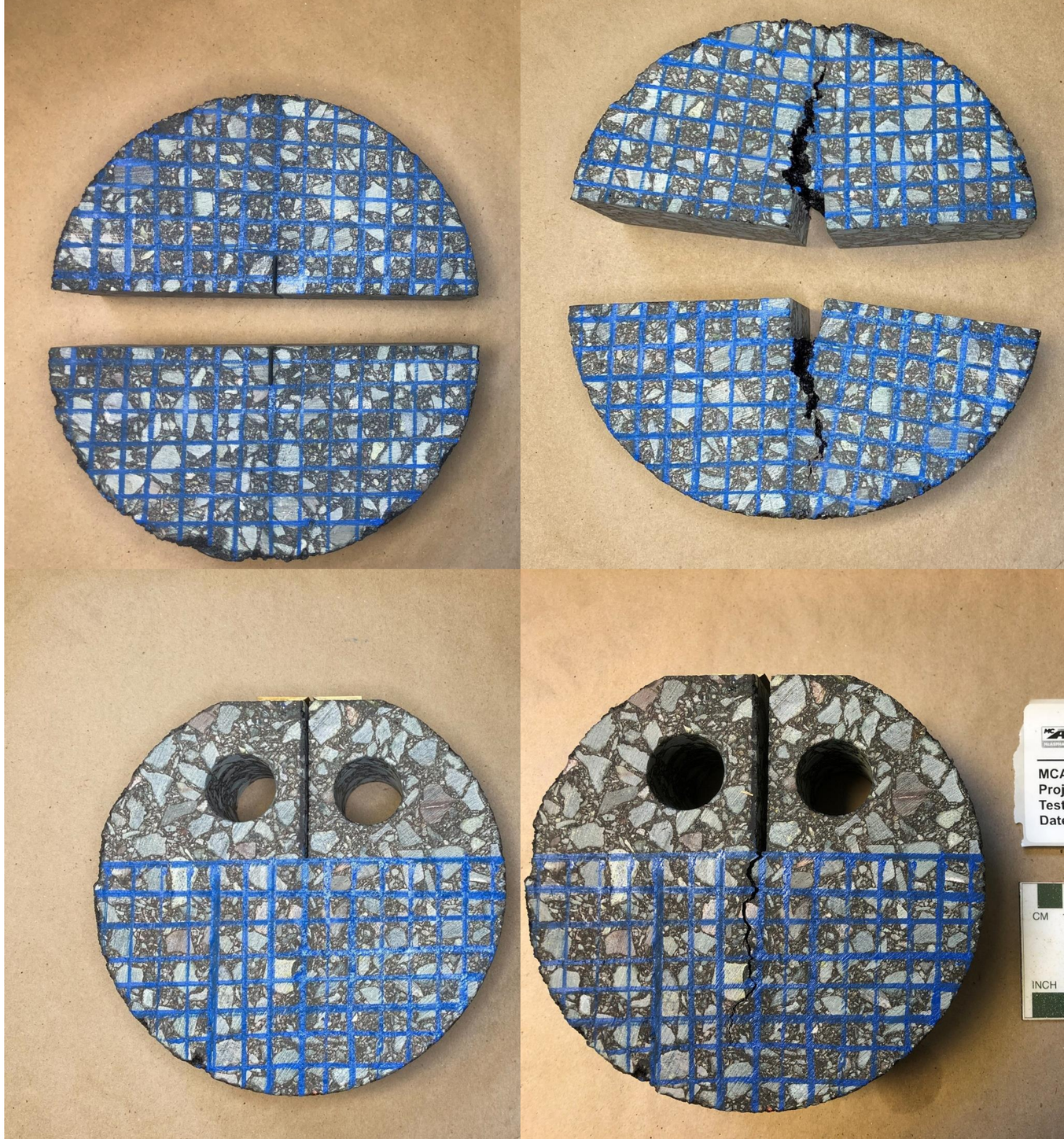
Specimens cut to exact dimensions to ensure consistency across all samples.

Notch Introduction for Testing

A central notch is added to specimens for controlled cracking in SCB and DCT tests.

Specimen Conditioning

Specimens conditioned at appropriate temperatures to simulate test conditions accurately.



TEST PROCEDURES
FOUR POINT BEAM & OVERLAY

Purpose of Fatigue Tests

Simulate long-term traffic loading effects on asphalt mixtures to predict durability and performance.

Four-Point Beam Test

Applies cyclic loading to measure beam specimen's resistance to strain and fatigue over time.

Overlay Tester Function

Evaluates reflective cracking potential by applying displacement cycles to bonded specimens.

Sample Preparation

Cutting, conditioning, and mounting specimens precisely ensures accurate fatigue testing results.

PREPARATION & TESTING FOR FATIGUE TESTS

Slab Compaction Process

Use rolling wheel compactor to achieve uniform asphalt slab density and air voids.

Specimen Cutting Dimensions

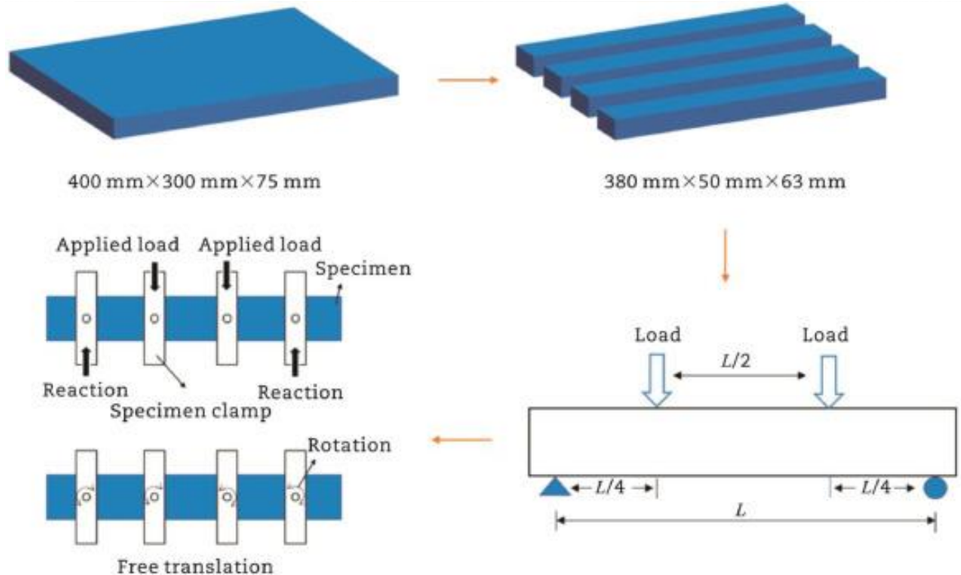
Cut slabs into beams of 380mm length, 63mm width, and 50mm height for testing.

Specimen Conditioning

Condition specimens at test temperature to simulate real field conditions before testing.

Fatigue Testing Setup

Mount beams in fatigue test frame and apply cyclic loading until failure occurs.



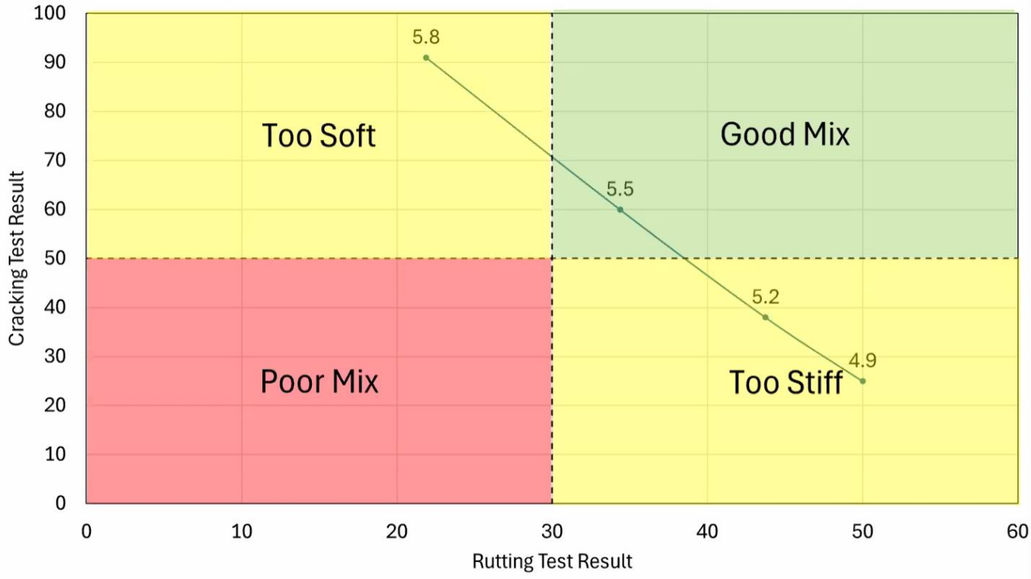
CONCLUSION AND FUTURE OUTLOOK

Importance of Performance Testing
Performance testing ensures durable pavements by evaluating asphalt under realistic conditions. It supports reliable pavement design.

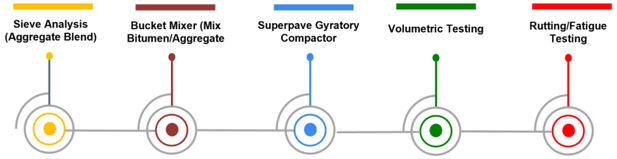
Transition to Modern Methods
Moving from empirical Marshall methods to Superpave and Balanced Mix Design improves mixture reliability and infrastructure resilience.

Proven Benefits and Case Studies
Studies show Superpave mixes offer superior mechanical performance and cost-effectiveness compared to traditional methods.

Encouragement for Adoption
Despite challenges, investment in training, equipment, and research can facilitate adoption of advanced testing in Canada.



CONCLUSION AND FUTURE OUTLOOK



Advancement in Asphalt Design

Transitioning to Superpave and Balanced Mix Design improves asphalt durability and performance in Nigeria.

Benefits of Modern Methods

These methods offer enhanced adaptability, durability, and cost-effectiveness for road construction projects.

Strategic Implementation

Success depends on collaboration and strategic planning among stakeholders for effective adoption.

Workshop Objectives

Equip participants with knowledge and tools to lead the transition to modern asphalt design methods.

McASPHALT

Engr Michael Esenwa, P.Eng, MNSE
+1 647 296 5007; +234 706 735 3828
mesenwa@mcasphalt.com

THANK YOU