Balanced Mix Design (BMD) for Asphalt Mixtures

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Background

- Superpave was originally intended to provide a performance-based specification for asphalt binders and mixtures.

- Performance-based mixture tests were included in Levels 2 and 3; however, these design levels were never implemented.

Reasons Why Performance Predictions Needed

- Incorporation of more recycled materials in mixtures over time

  Reclaimed asphalt pavement, recycled asphalt shingles, ground tire rubber, etc.

- Utilization of binders formulated with various modifiers versus conventionally neat asphalt binders

  Re-refined engine oil bottoms, air blown asphalt, rubber, polymers, polyphosphoric acid, etc.

- Utilization of innovative technologies

  Warm mix asphalt, asphalt rejuvenators, bio-binders, etc.

Background

- This has led to a renewed interest using a balanced mixture design (BMD) concept.

- A BMD is defined 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."

Background - FHWA BMD Task Force

- Approach 1

  Volumetric Design with Performance Verification

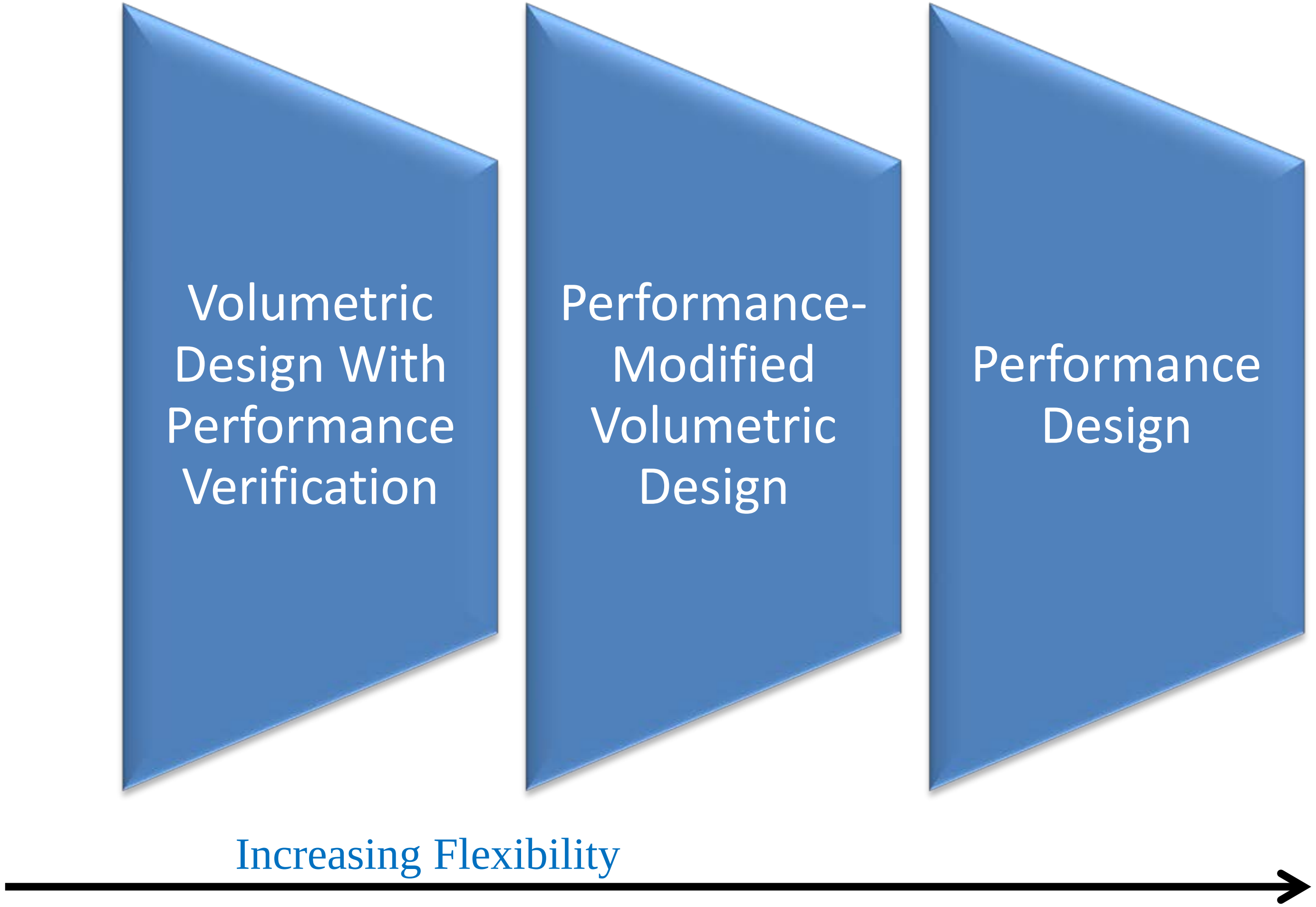
- Approach 2

  Performance Modified Volumetric Design

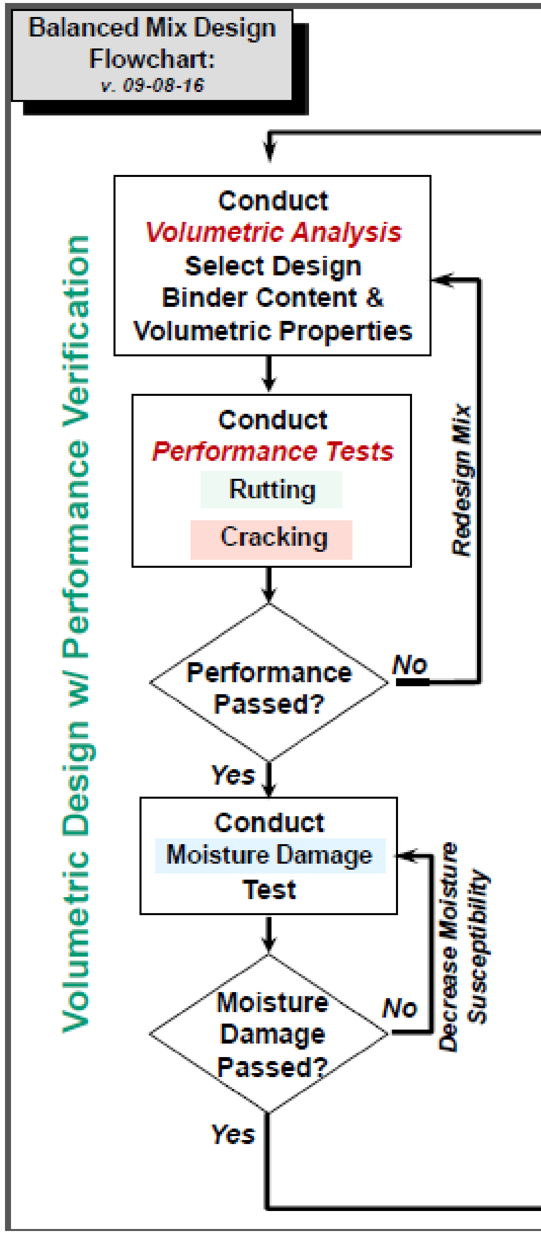
- Approach 3

  Performance Design

Three Approaches

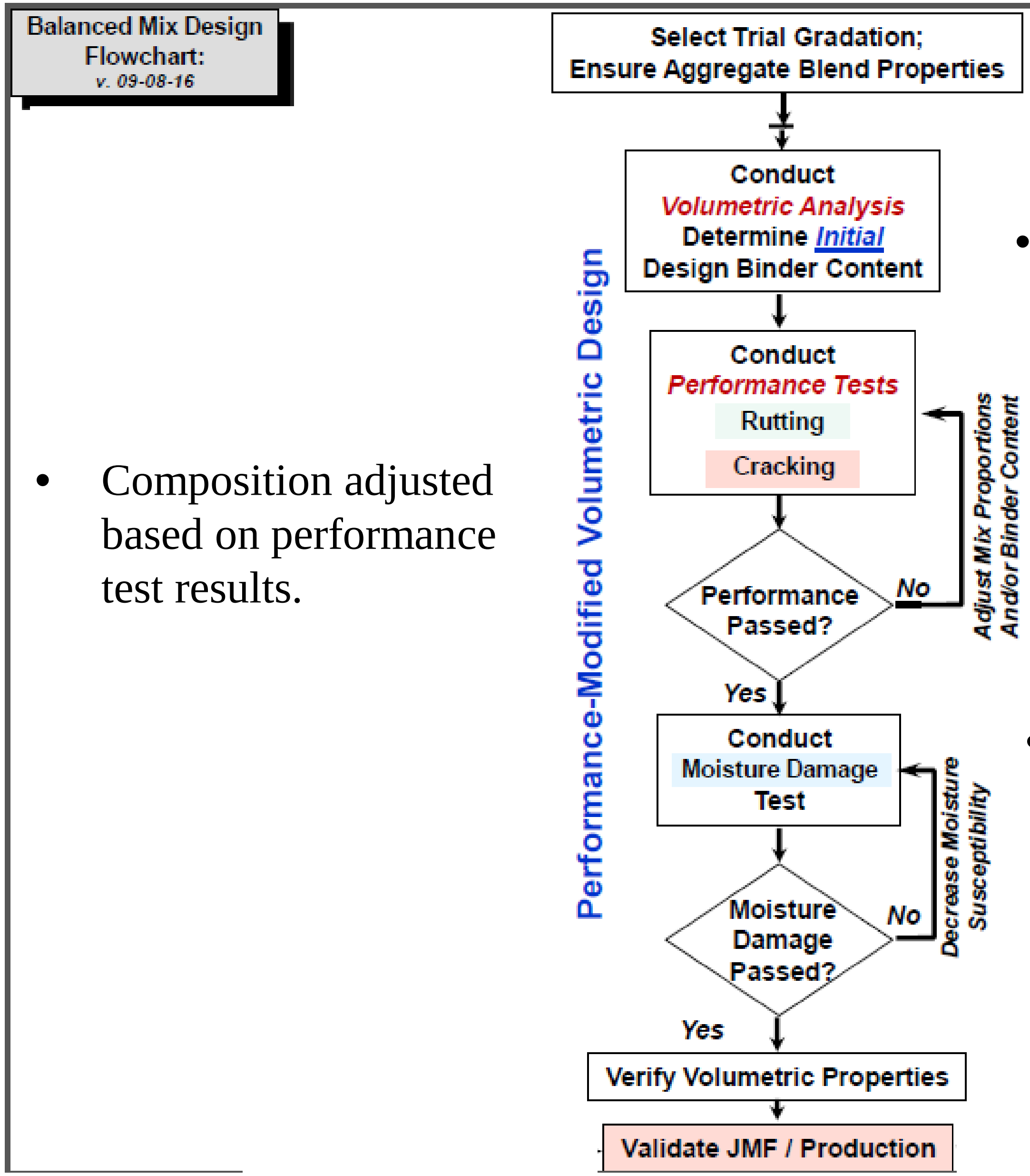


Volumetric Design With Performance Verification



- Current volumetric design followed by performance testing at optimum binder content.
- Start over and re-design the mix if performance test criteria not met.
- Volumetric properties have to fall within existing AASHTO M 323 limits.

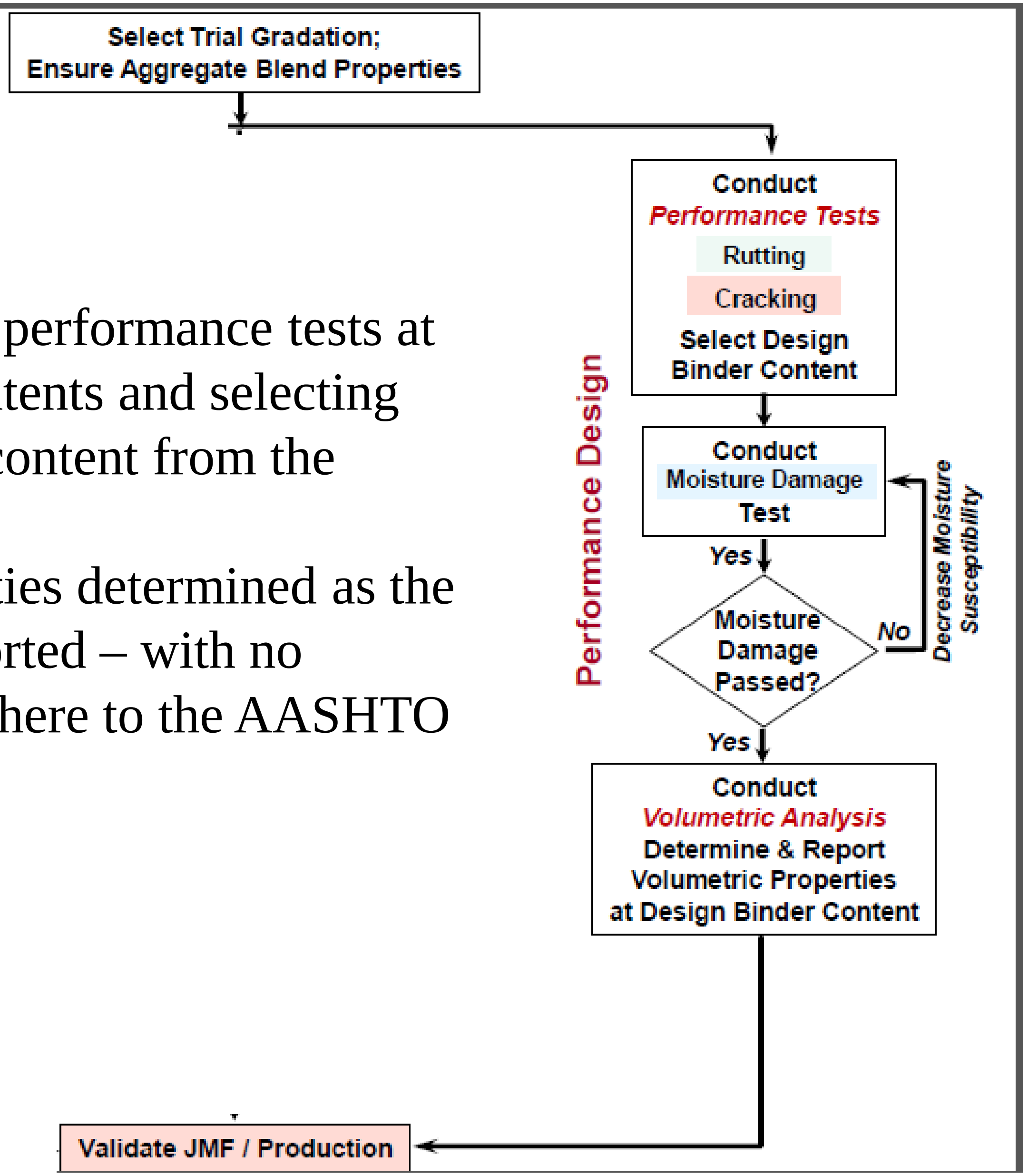
Performance-Modified Volumetric Design



- Composition adjusted based on performance test results.
- Initial volumetric design is a guide.
- Final volumetric properties may vary from AASHTO M 323 limits.

Performance Design

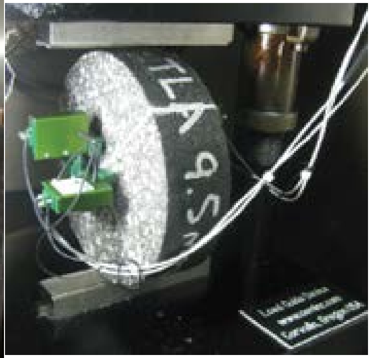
- Conduct a suite of performance tests at varying binder contents and selecting the design binder content from the results.
- Volumetric properties determined as the 'last step' and reported – with no requirements to adhere to the AASHTO M 323 limits.



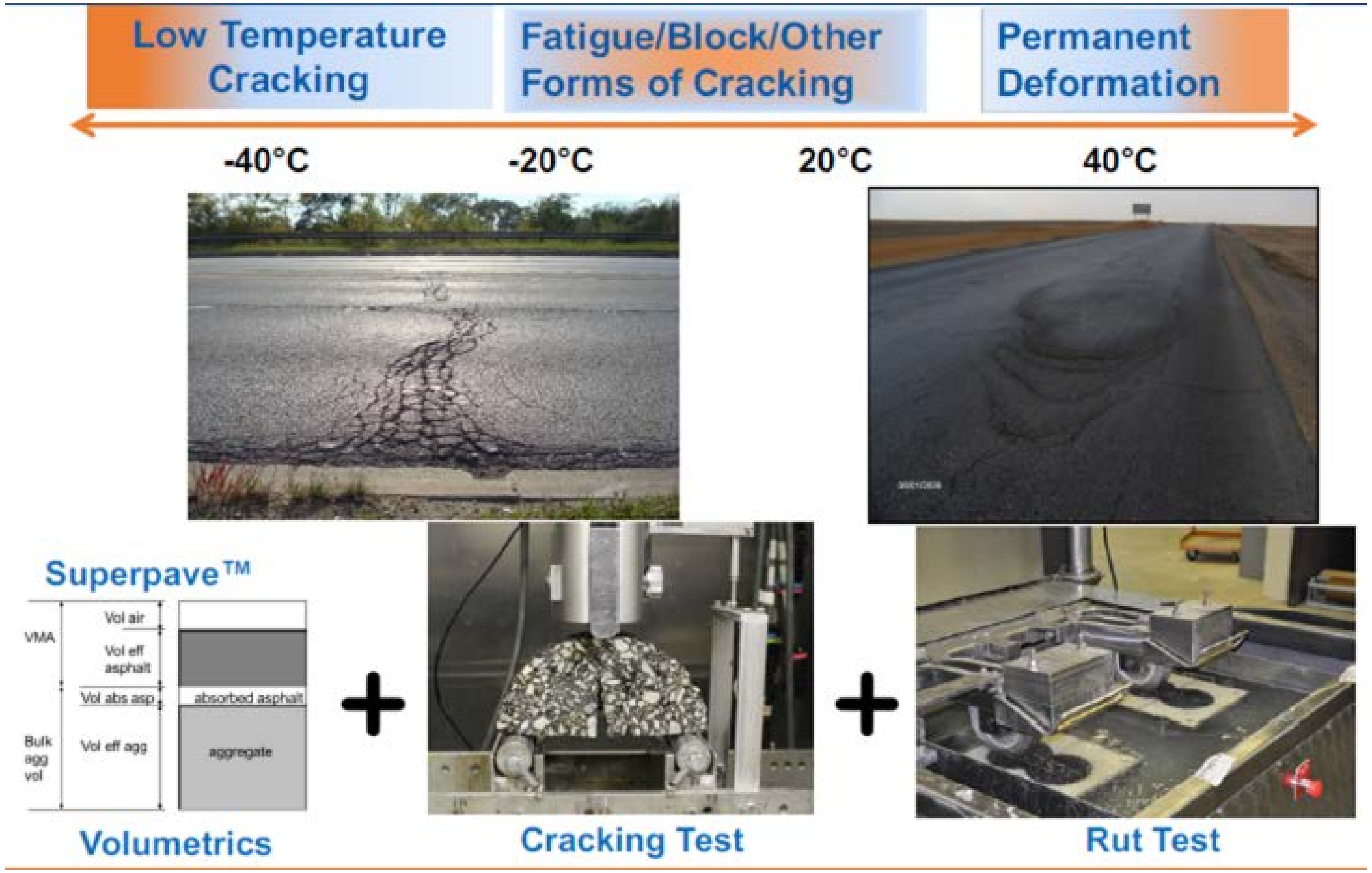
Performance Tests for Balanced Mix Design

Rutting Resistance

Cracking Resistance

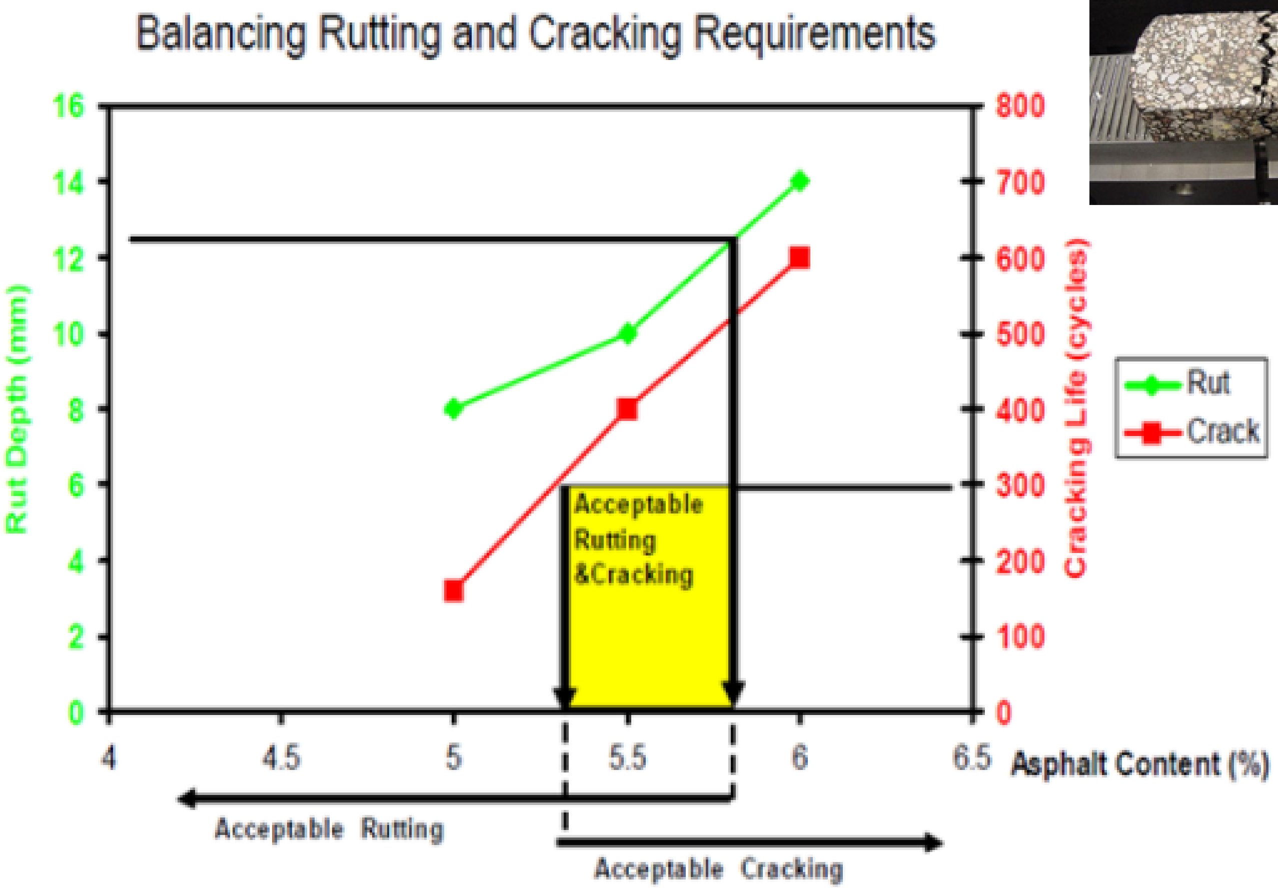


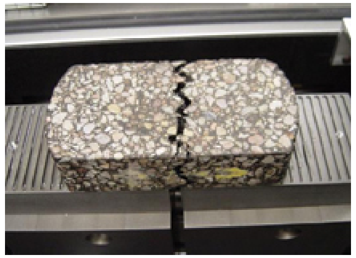
Example: Volumetric Design With Performance Verification



Dr. Imad Al-Qadi University of Illinois

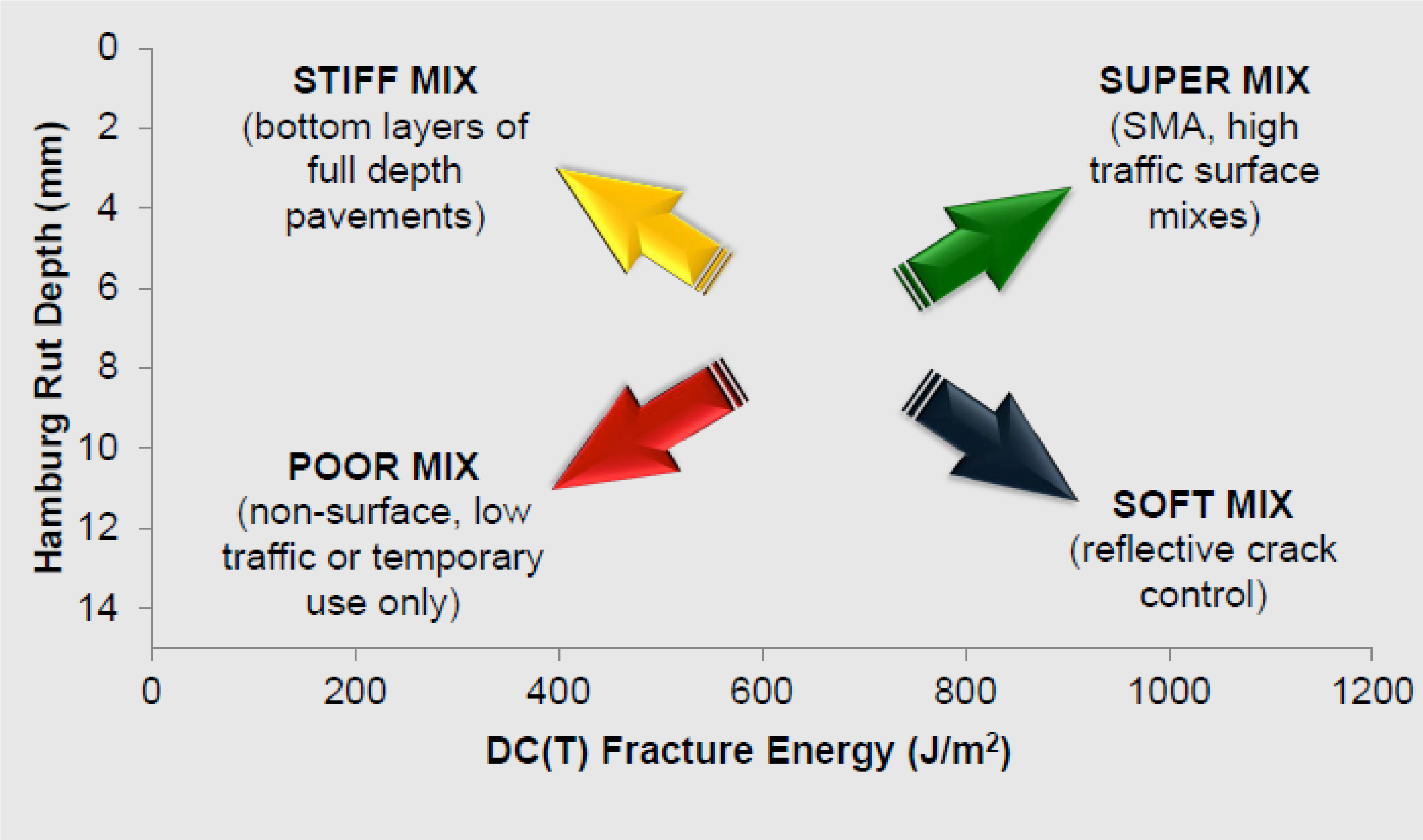
Example: Performance-Modified Volumetric Design





TxDOT

Example Performance Space Diagrams



Dr. Bill Buttlar University of Missouri

Research Study: Balanced Mix Design Sensitivity to Production Tolerance Limits and Binder Source

Balanced Mix Design

Will Production limits and Binder Source lead to

Unbalanced Mix Design?

Background - Production Considerations & BMD

- What happens to a balanced mixture design during production?

  Binder content, aggregate gradations, source of the asphalt binder, etc. are all dynamic during production. They also vary season to season.

- To account for production variability, State transportation agencies generally establish a set of <u>production tolerances</u> which they incorporate in their specifications.

Study Objective

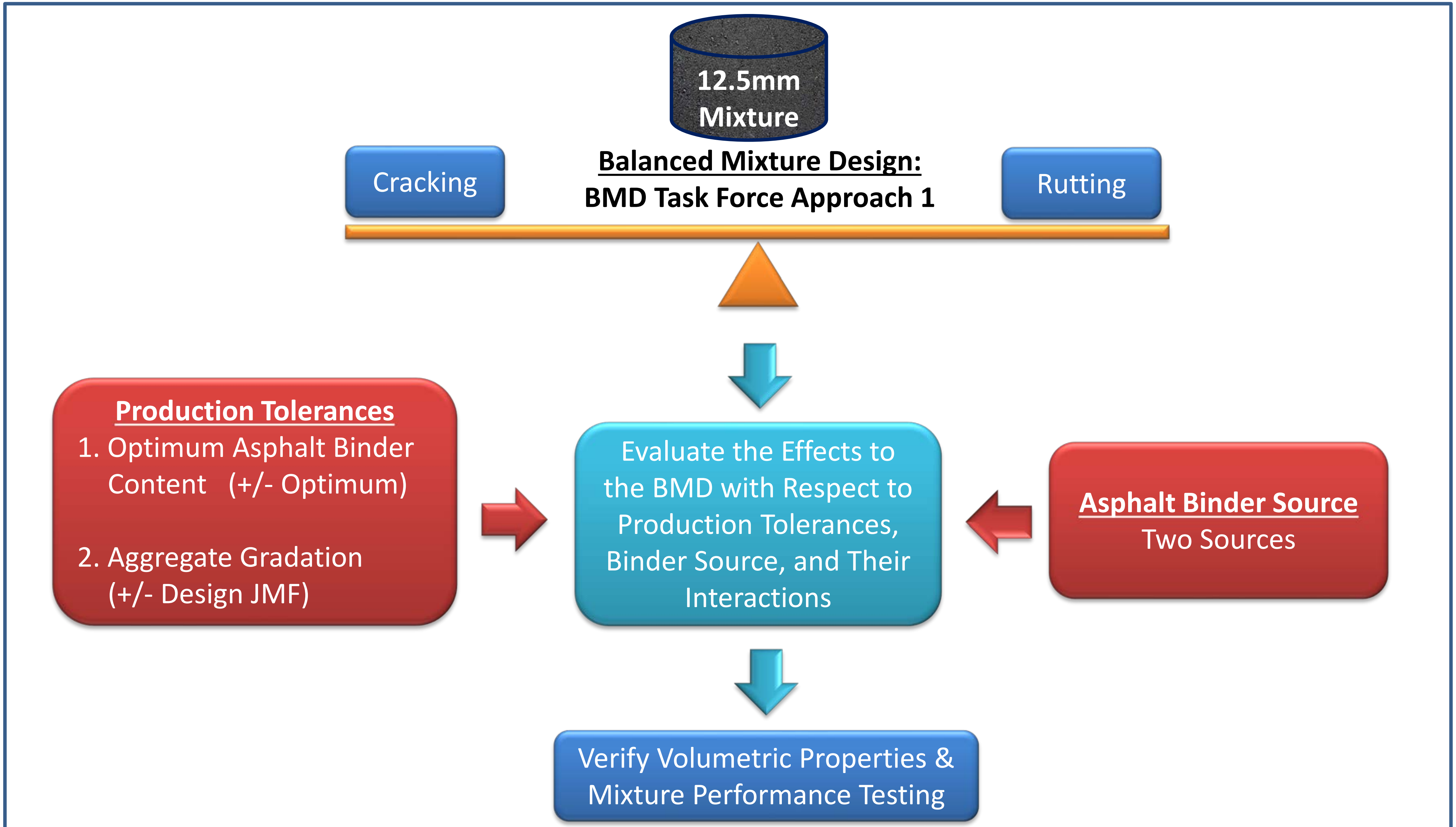
- To determine if a **balanced** mixture design can become **unbalanced** during production because of these common production variables:

  - Asphalt Binder Content
    (governed by the allowable production tolerance in the specification)

  - Aggregate Gradation
    (governed by the allowable production tolerances in the specification)

  - Asphalt Binder Source
    (not governed and may vary season-to-season)

Experimental Plan



Production Tolerances

MassDOT Quality Assurance Specification for Hot Mix Asphalts Section 450 was utilized to determine the acceptable tolerances:

1. Asphalt Binder Content

   ±0.3% of the design optimum

2. Aggregate Gradation

   Allowable deviation from Job Mix Formula varies by individual sieve size.

3. Asphalt Binder Source (*not part of MassDOT QA Specifications)*

   Two different PG64-28 asphalt binders from different sources were utilized, designated as A and B.

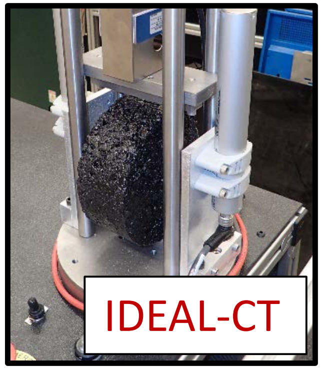
Mixture Performance Testing

Rutting / Moisture Susceptibility

Hamburg Wheel Tracking Device (HWTD) Test

Cracking

Intermediate Temperature



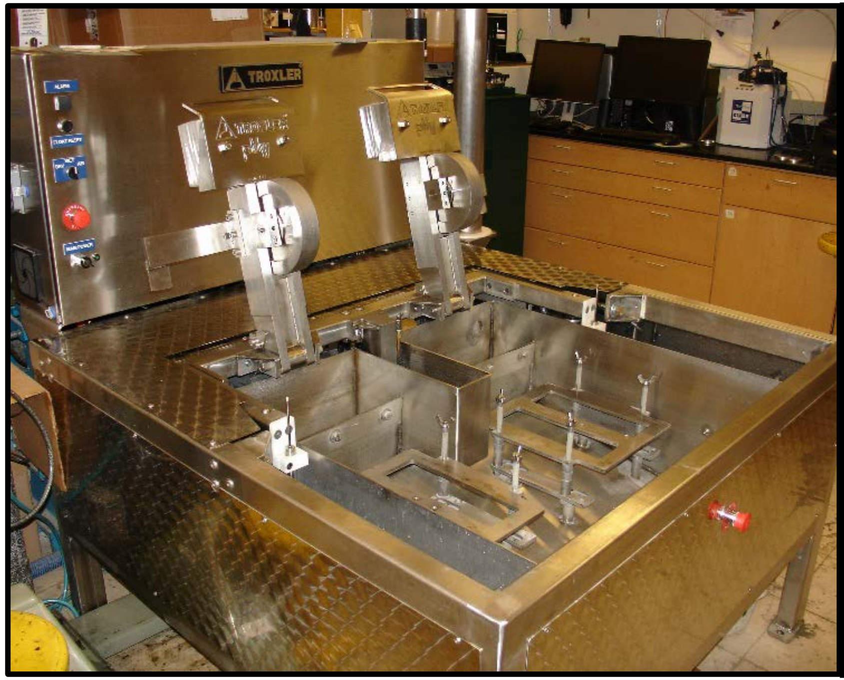
1. Illinois Flexibility Index Test (IFIT)
2. Indirect Tensile Asphalt Cracking Test (IDEAL-CT)

Low Temperature

Mixture Testing in Bending Beam Rheometer (BBR)

Rutting / Moisture Susceptibility - HWTD

AASHTO T324:Standard Method of Test for Hamburg Wheel-Track Testing
of Compacted Hot Mix Asphalt (HMA)

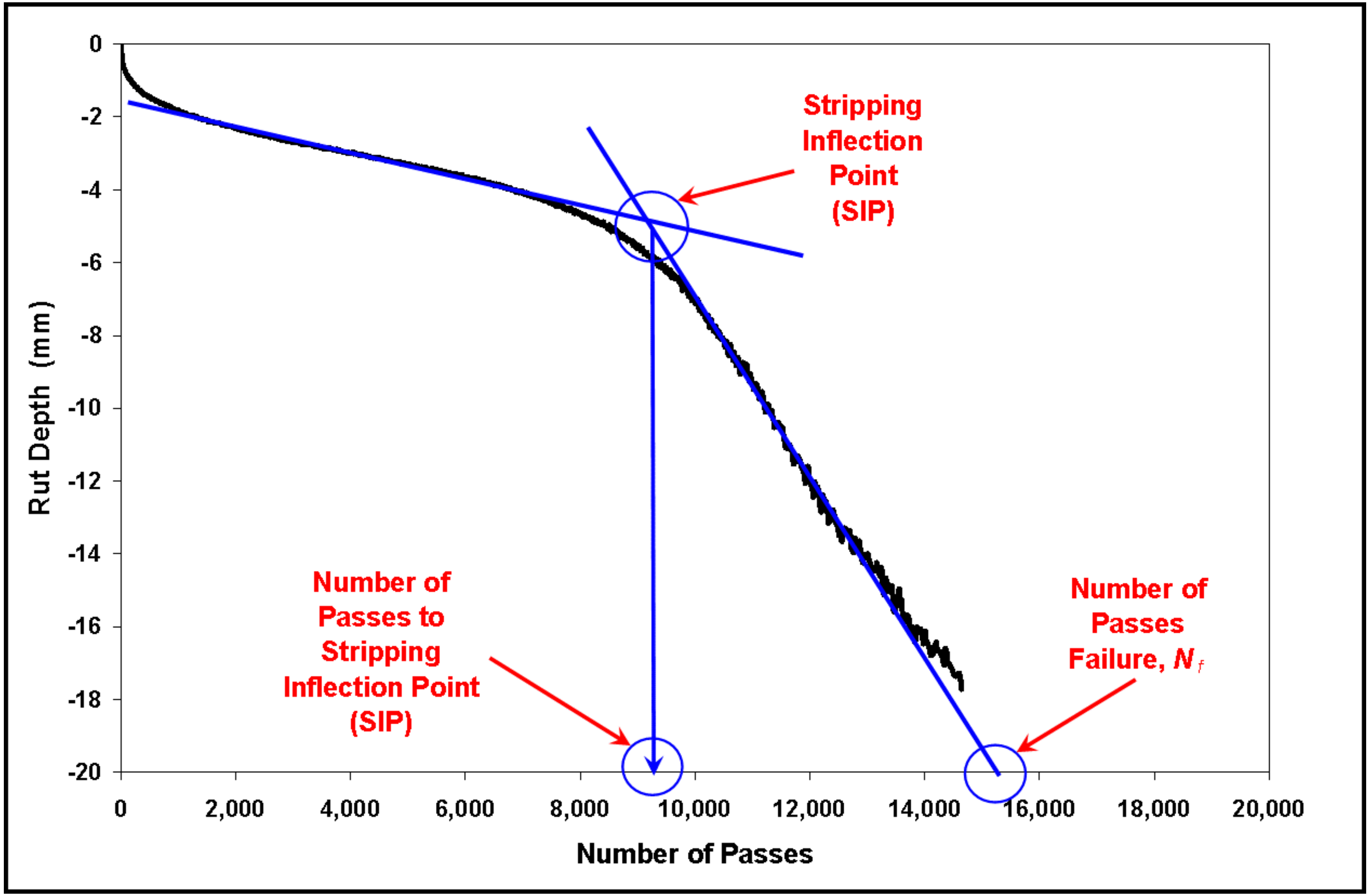


Water at 45ºC (113ºF) • Duration of 20,000 passes • SGC specimens at 7.0±1.0% air voids

<u>MassDOT Pass/Fail Criteria</u>

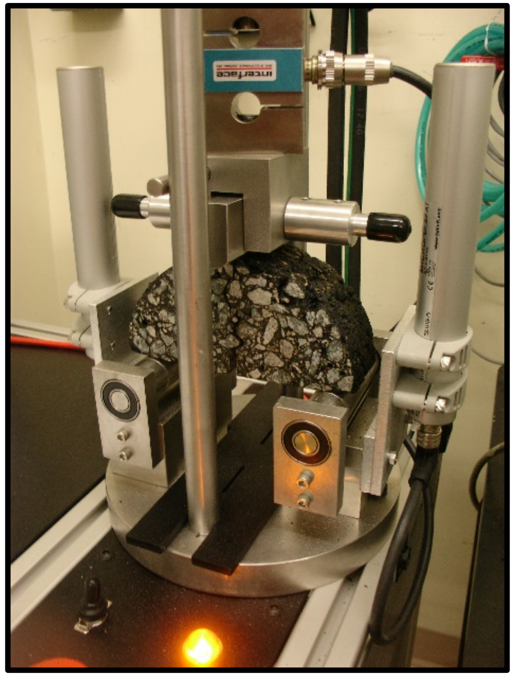
Maximum rut depth of 12.5 mm after 20,000 passes combined with no SIP before 15,000 passes.

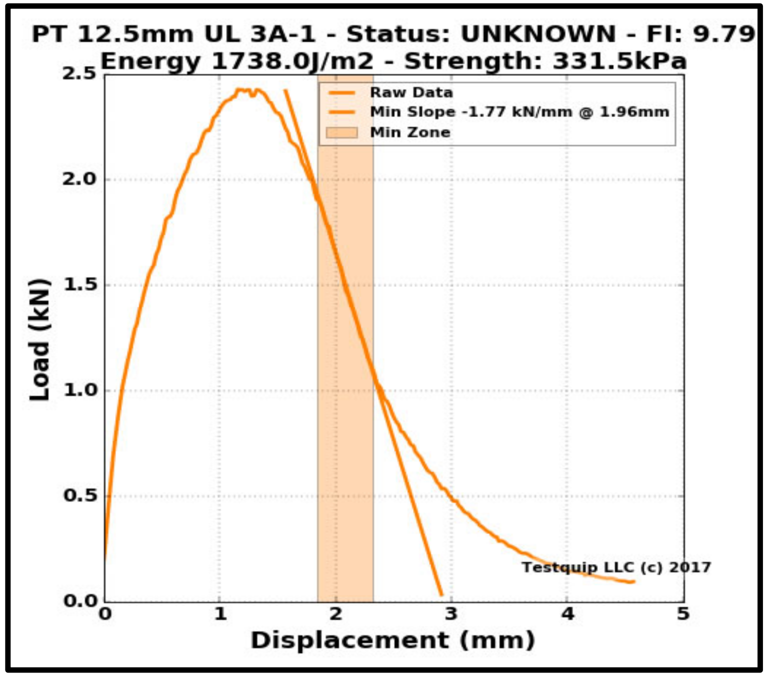
Stripping Inflection Point (SIP) - HWTD



Intermediate Temperature Cracking – IFIT SCB

AASHTO TP 124: Standard Method of Test for Determining the Fracture Potential of Asphalt Mixtures Using the Flexibility Index Test (FIT)





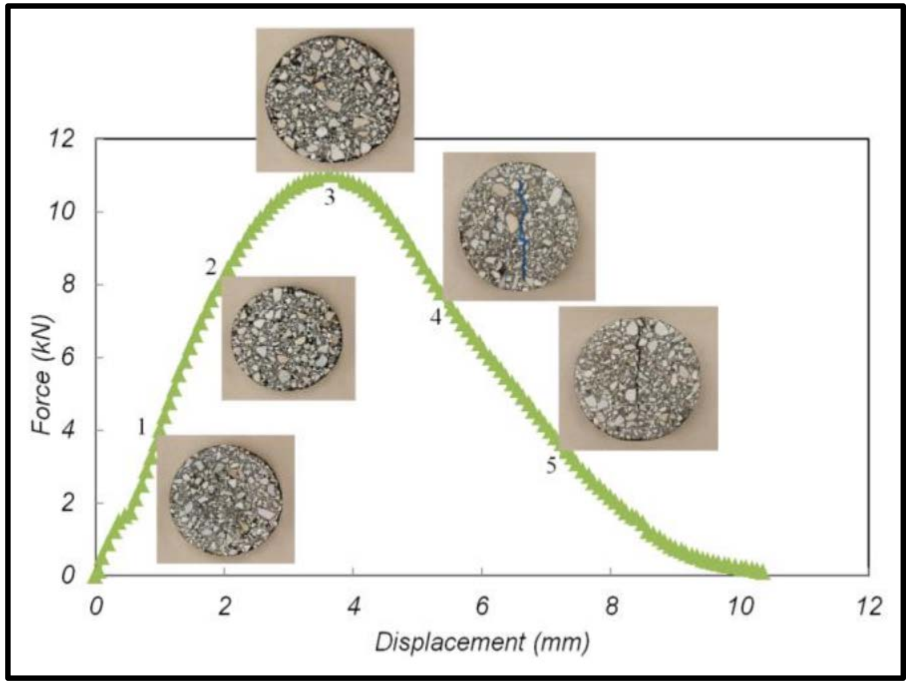
Test temperature of 25ºC (77ºF) • Loading rate of 50 mm/min • Air voids of 7.0±1.0%

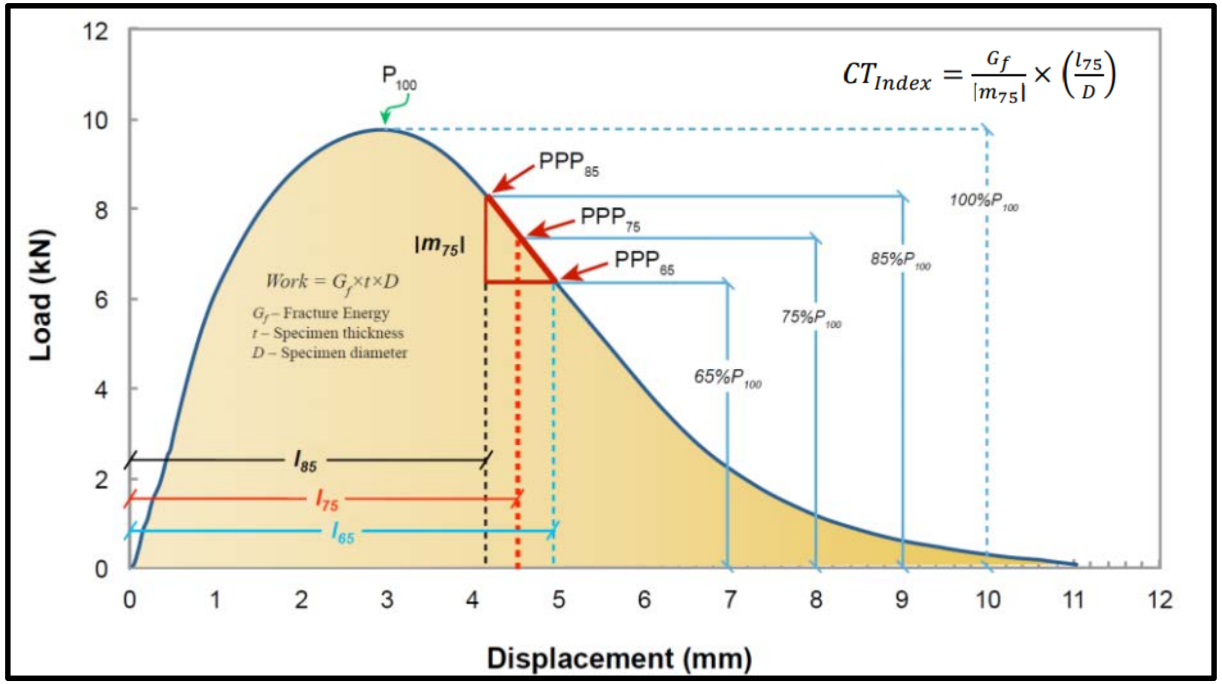
Recommended Pass/Fail Criteria

A Flexibility Index (FI) of greater than 8.0 has been used as a pass/fail criterion to distinguish mixtures (Al-Qadi et al., 2015).

Intermediate Temperature Cracking – IDEAL-CT

ASTM WK60859: New Test Method for Determination of Cracking Tolerance Index of Asphalt Mixture Using the Indirect Tensile Cracking Test at Intermediate Temperature





Test temperature of 25ºC (77ºF) • Loading rate of 50 mm/min • Air voids of 7.0±1.0%

<u>Recommended Pass/Fail Criteria</u>

A minimum CT_{Index} of 65 was recommended for Texas dense-graded mixes.

Low Temperature Cracking – Mixture BBR

AASHTO TP 125: Standard Method of Test for Determining the Flexural Creep Stiffness of Asphalt Mixtures Using the Bending Beam Rheometer (BBR)

Test temperature = -18ºC • Beam size = 12.7 mm x 6.35 mm x 127 mm

<u>Recommended Pass/Fail Criteria</u>

Slope (m-value) should not to exceed 0.12 and creep stiffness (S) should not to exceed 15,000 MPa when testing at 60 seconds.

Balanced Mixture Design

Sieve Size (mm)	Percent Passing by Weight	
	12.5 mm Mixture	12.5 mm Superpave Specification
19.0	100	100 min
12.5	94.0	90-100
9.5	86.0	90 max
4.75 (No. 4)	61.0	-
2.36 (No. 8)	42.0	28-58
1.18 (No. 16)	29.0	-
0.60 (No. 30)	19.0	-
0.30 (No. 50)	13.0	-
0.15 (No. 100)	7.0	-
0.075 (No. 200)	4.0	2-10
Optimum Binder Content, %	5.5%	-

Test	Property	12.5 mm Mixture	12.5 mm Superpave Specification
Volumetric Properties	Air Voids, %	4.3%	4%
	Voids in Mineral Aggregate (VMA), %	15.5%	15% min.*
	Voids Filled with Asphalt (VFA), %	72.1%	65-78%
	Dust to Binder Ratio	0.82	0.6-1.2
Rutting	HWTD rutting at 10,000 passes, mm	1.1	-
	HWTD rutting at 20,000 passes, mm	1.6	< 12.5 mm*
	HWTD Stripping Inflection Point	NONE	SIP >15,000*
Cracking	IFIT Flexibility Index (FI)	9.0	>8.0
	IFIT Fracture Energy, J/m^2 (FE)	1,622	-

* MassDOT specification.

- A 12.5 mm mixture was developed using BMD Approach 1: Volumetric Design with Performance Verification.
- The trial aggregate gradations were developed using existing MassDOT approved mixture designs (N_{design} = 75).
- The mixtures were designed with the PG64-28 binder from Source A.

Production Tolerances – Asphalt Binder Content

- Per MassDOT specification, the binder content tolerance during production should be within ±0.3% optimum determined during the mixture design.

- Specimens of each mixture were fabricated at:
  - Lower limit (-0.3%)
  - Optimum
  - Upper limit (+0.3%)

Production Tolerances – Aggregate Gradation

Sieve Size (mm)	Design Gradation	Production Tolerance	Coarse Gradation	Fine Gradation
19.0	100	-	100	100
12.5	94.0	±6	88	100
9.5	86.0	±6	80	92
4.75 (No. 4)	61.0	±6	55	67
2.36 (No. 8)	42.0	±5	37	47
1.18 (No. 16)	29.0	±3	26	32
0.60 (No. 30)	19.0	±3	16	22
0.30 (No. 50)	13.0	±3	10	16
0.15 (No. 100)	7.0	±2	5	9
0.075 (No. 200)	4.0	±1	3	5

Production Tolerances – Asphalt Binder Source

- Two sources of PG64-28 were obtained from refineries that supply asphalts in the Northeast region.

- The two binder sources had the same PG, equivalent continuous PGs, but different relaxation properties in terms of ΔT_c.

Binder Source	Continuous Grade	PG Grade	Delta T_c (ΔT_c)
A	66.2-28.4	PG64-28	+2.3°C
B	65.6-27.7	PG64-28 (Borderline)	-6.0°C

A minimum ΔT_c of -5.0°C has been suggested as a preliminary criterion, therefore binders with a ΔT_c of -5.0°C or more negative are considered unacceptable.

- An asphalt binder with poor relaxation properties was included to determine if this would affect cracking to the degree that the mixture would become unbalanced.

Production Tolerances and Asphalt Binder Source:
Effects on Volumetric Properties

Binder Source	Aggregate Gradation	Asphalt Binder Content	Average Air Voids
A	Coarse	Lower Limit (-0.3%)	6.3 **F**
		Optimum	5.0
		Upper Limit (+0.3%)	4.3
	Design	Lower Limit (-0.3%)	5.0
		Optimum	4.1
		Upper Limit (+0.3%)	2.9
	Fine	Lower Limit (-0.3%)	4.7
		Optimum	3.7
		Upper Limit (+0.3%)	2.6 **F**

Binder Source	Aggregate Gradation	Asphalt Binder Content	Average Air Voids
B	Coarse	Lower Limit (-0.3%)	5.9 **F**
		Optimum	4.7
		Upper Limit (+0.3%)	4.0
	Design	Lower Limit (-0.3%)	4.0
		Optimum	3.2
		Upper Limit (+0.3%)	2.4 **F**
	Fine	Lower Limit (-0.3%)	4.6
		Optimum	3.5
		Upper Limit (+0.3%)	2.5 **F**

F = Failed the 4 ±1.3% production tolerance.

Production Tolerances and Asphalt Binder Source:

Effects on Rutting and Moisture Susceptibility Results

Asphalt Binder Source A

Binder Source	Aggregate Gradation	Asphalt Binder Content	Average Rut Depth at 10,000 passes, mm	Average Rut Depth at 20,000 passes, mm	Stripping Inflection Point
A	Coarse	Lower Limit (-0.3%)	2.9	3.2	NONE
		Optimum	2.5	2.9	NONE
		Upper Limit (+0.3%)	2.4	3.1	NONE
	Design	Lower Limit (-0.3%)	2.3	2.7	NONE
		Optimum	1.1	1.6	NONE
		Upper Limit (+0.3%)	3.3	3.7	NONE
	Fine	Lower Limit (-0.3%)	2.9	3.7	NONE
		Optimum	3.0	3.5	NONE
		Upper Limit (+0.3%)	3.7	4.5	NONE

All mixtures passed the HWTD in regard to both rutting and moisture susceptibility.
Because of this, no statistical analyses were needed.

Production Tolerances and Asphalt Binder Source:
Effects on Rutting and Moisture Susceptibility Results
Asphalt Binder Source B

Binder Source	Aggregate Gradation	Asphalt Binder Content	Average Rut Depth at 10,000 passes, mm	Average Rut Depth at 20,000 passes, mm	Stripping Inflection Point
B	Coarse	Lower Limit (-0.3%)	1.1	1.3	NONE
		Optimum	1.1	1.4	NONE
		Upper Limit (+0.3%)	1.3	1.9	NONE
	Design	Lower Limit (-0.3%)	2.8	3.7	NONE
		Optimum	1.5	2.0	NONE
		Upper Limit (+0.3%)	3.1	5.2	NONE
	Fine	Lower Limit (-0.3%)	1.0	1.4	NONE
		Optimum	1.7	2.4	NONE
		Upper Limit (+0.3%)	2.4	4.3	NONE

All mixtures passed the HWTD in regard to both rutting and moisture susceptibility. Because of this, no statistical analyses were needed.

Production Tolerances and Asphalt Binder Source:
Effects on Intermediate Temperature Cracking Results - IFIT

Binder Source	Aggregate Gradation	Asphalt Binder Content	Average FI	Average FE (J/m²)
A	Coarse	Lower Limit (-0.3%)	10.6	1,521
		Optimum	13.8	1,650
		Upper Limit (+0.3%)	13.7	1,492
	Design	Lower Limit (-0.3%)	9.0	1,754
		Optimum	9.0	1,622
		Upper Limit (+0.3%)	9.8	1,642
	Fine	Lower Limit (-0.3%)	7.4 **F**	1,436
		Optimum	10.1	1,484
		Upper Limit (+0.3%)	11.6	1,496
B	Coarse	Lower Limit (-0.3%)	7.6 **F**	1,258
		Optimum	11.0	1,384
		Upper Limit (+0.3%)	12.4	1,241
	Design	Lower Limit (-0.3%)	9.5	1.484
		Optimum	12.4	1,471
		Upper Limit (+0.3%)	16.4	1,405
	Fine	Lower Limit (-0.3%)	6.2 **F**	1,253
		Optimum	8.6	1,301
		Upper Limit (+0.3%)	11.7	1,258

F = Failed the minimum FI criteria of 8.0.

Production Tolerances and Asphalt Binder Source:
Effects on Intermediate Temperature Cracking Results - IFIT

- The mixture design could become unbalanced during production as 3 of 18 mixtures failed the proposed minimum FI of 8.0.

- If the minimum FI is changed to 10.0, then 8 of the 18 mixtures would fail. The use of this higher criterion might make it more difficult to balance the mixture design.

- If the minimum FI is changed to 6.0, then all mixtures would pass, and the mixture design would remain balanced; thus, **showing the importance of choosing a valid criterion.**

IFIT – Statistical Analysis of Data

Dependent Variable: FI	
Source	P-Value
Gradation	0.030
Binder Content	0.000
Binder Source	0.897
Gradation*Binder Content	0.820
Gradation*Binder Source	0.000
Binder Content*Binder Source	0.163
Gradation*Binder Content* Binder Source	0.678

Dependent Variable: FE	
Source	P-Value
Gradation	0.000
Binder Content	0.270
Binder Source	0.000
Gradation*Binder Content	0.168
Gradation*Binder Source	0.774
Binder Content*Binder Source	0.836
Gradation*Binder Content* Binder Source	0.935

- Aggregate gradation had a significant effect on both FI and FE.
- FI and FE did not agree with each other.
- Asphalt binder source had a significant effect on FE with binder source A providing the higher, or better, FE. This is in agreement with the ΔT_c relaxation property of binder A. The FI did not provide this agreement.

Production Tolerances and Asphalt Binder Source:
Effects on Intermediate Temperature Cracking Results – IDEAL-CT

Binder Source	Aggregate Gradation	Asphalt Binder Content	Average CT_{Index}
A	Coarse	Lower Limit (-0.3%)	79.9
		Optimum	94.8
		Upper Limit (+0.3%)	114.2
	Design	Lower Limit (-0.3%)	61.8 **F**
		Optimum	105.4
		Upper Limit (+0.3%)	120.9
	Fine	Lower Limit (-0.3%)	70.8
		Optimum	99.6
		Upper Limit (+0.3%)	122.9
B	Coarse	Lower Limit (-0.3%)	71.3
		Optimum	71.7
		Upper Limit (+0.3%)	116.4
	Design	Lower Limit (-0.3%)	60.6 **F**
		Optimum	87.4
		Upper Limit (+0.3%)	100.9
	Fine	Lower Limit (-0.3%)	49.9 **F**
		Optimum	87.3
		Upper Limit (+0.3%)	139.3

F = Failed the proposed minimum CT_{Index} criteria of 65.

Production Tolerances and Asphalt Binder Source:
Effects on Intermediate Temperature Cracking Results – IDEAL-CT

- The mixture design could become unbalanced during production as 3 of 18 mixtures failed the proposed minimum CT_{Index} of 65.

- All three mixtures that failed had the lower limit asphalt binder content.

- CT_{Index} increased with increasing binder content.

IDEAL-CT – Statistical Analysis of Data

Dependent Variable: IDEAL-CT	
Source	P-Value
Gradation	0.478
Binder Content	**0.000**
Binder Source	**0.014**
Gradation*Binder Content	**0.018**
Gradation*Binder Source	0.711
Binder Content*Binder Source	0.173
Gradation*Binder Content* Binder Source	0.166

- Binder source A provided a higher, or better, CT_{Index}. Binder source A also had the higher, or better, ΔT_c relaxation property.
- The statistical analyses for FI and CT_{Index} were not identical, although both tests provided the same conclusion that the mixture design could become unbalanced during production.

Production Tolerances and Asphalt Binder Source:
Effects on Low Temperature Cracking Results – Mixture BBR

Binder Source	Aggregate Gradation	Asphalt Binder Content	Average m-value	Average Stiffness MPa
A	Coarse	Lower Limit (-0.3%)	0.151 **F**	10,894
		Optimum	0.149 **F**	11,468
		Upper Limit (+0.3%)	0.144 **F**	11,434
	Design	Lower Limit (-0.3%)	0.153 **F**	10,234
		Optimum	0.150 **F**	11,943
		Upper Limit (+0.3%)	0.141 **F**	11,283
	Fine	Lower Limit (-0.3%)	0.139 **F**	12,975
		Optimum	0.137 **F**	12,325
		Upper Limit (+0.3%)	0.149 **F**	12,442
B	Coarse	Lower Limit (-0.3%)	0.147 **F**	9,628
		Optimum	0.151 **F**	9,088
		Upper Limit (+0.3%)	0.147 **F**	10,083
	Design	Lower Limit (-0.3%)	0.153 **F**	8,859
		Optimum	0.144 **F**	11,436
		Upper Limit (+0.3%)	0.152 **F**	10,184
	Fine	Lower Limit (-0.3%)	0.150 **F**	12,867
		Optimum	0.151 **F**	11,274
		Upper Limit (+0.3%)	0.154 **F**	10,546

F = Failed the suggested m-value criteria of < 0.12.

Production Tolerances and Asphalt Binder Source:
Effects on Low Temperature Cracking Results – Mixture BBR

- All mixtures were unbalanced according to m-value and balanced according to stiffness.

- Based on the closeness of the test results and a lack of pavement performance for these variations, new pass-fail criterion cannot be suggested.

Mixture BBR – Statistical Analysis of Data

Dependent Variable: m-value	
Source	P-Value
Gradation	0.702
Binder Content	0.773
Binder Source	0.057
Gradation*Binder Content	0.121
Gradation*Binder Source	0.123
Binder Content*Binder Source	0.753
Gradation*Binder Content* Binder Source	0.266

Dependent Variable: Stiffness	
Source	P-Value
Gradation	**0.000**
Binder Content	0.414
Binder Source	**0.000**
Gradation*Binder Content	**0.000**
Gradation*Binder Source	0.374
Binder Content*Binder Source	0.595
Gradation*Binder Content* Binder Source	0.269

- No variable had a significant effect on the m-value.
- Binder source A provided higher stiffnesses which does not agree with binder source A having the higher, or better, ΔT_c relaxation property.

Conclusions

- A balanced mixture design can become unbalanced when produced because of normal production variabilities.

- It is critically important to have confidence in the mixture performance tests used in a framework for a balanced mixture design.

- The statistical analyses demonstrated that certain combinations of variables might have to be tested to make sure that a mixture design will remain balanced.

- For intermediate-temperature cracking performance, one production variable which must be evaluated is the lower tolerance level for asphalt binder content.

Conclusions

- Five mixtures did not have air voids meeting the tolerance. Most of these mixtures performed well with no evidence that being outside this tolerance would always lead to an unbalanced mixture design in terms of the mixture performance tests that were used.

Recommendations

- Each transportation agency should evaluate the effects of their quality assurance tolerances on mixture performance in their framework for a balanced mixture design.

- Unless a transportation agency has a high degree of confidence in the tests they use to measure mixture performance, it is recommended that they still use volumetrics in their balanced mixture designs.

- To use the IFIT-FE and mixture BBR tests in a balanced mixture design, each transportation agency must determine the applicability of these tests to their mixtures and develop pass-fail criteria for them.

- Future studies need to include mixtures that are close to failing in rutting.

Thank you!