The Elements of Balanced Mix Design

Texas A&M Transportation Institute

Fujie Zhou, Ph.D., P.E.

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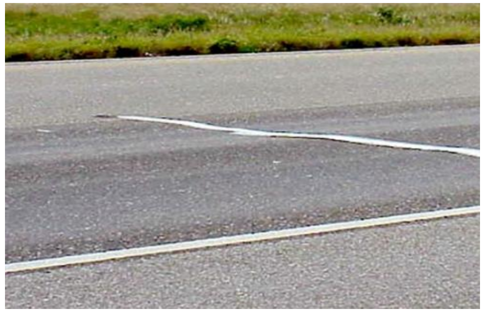
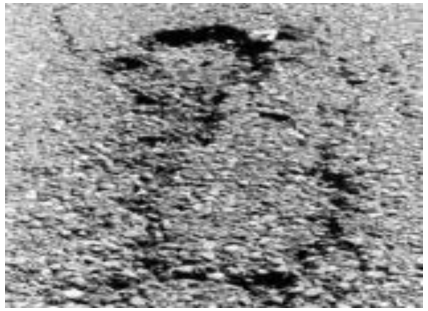
Outline

- Introduction
- Elements of balanced mix design (BMD)
  - Practical performance tests
  - Loose mix aging protocols
  - Performance acceptance criteria
- Production quality control and acceptance (QC/QA) and automation
- Cracking resistance of asphalt mixes and improvement
- Summary and conclusions

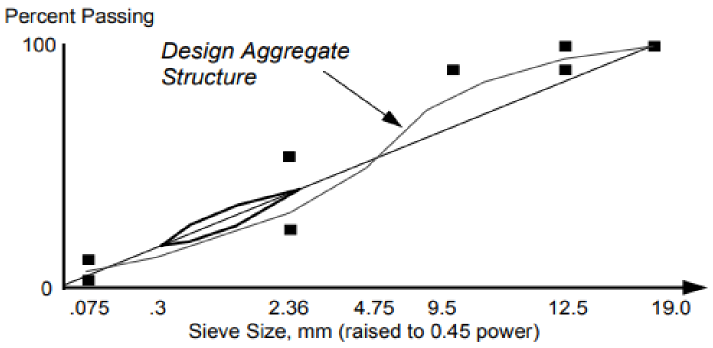
Introduction

- Pavement distresses swinging in last 3 decades
  - Before SHRP in late 1980s:
    - Rutting
  - Right after SHRP in early 1990s:
    - Moisture damage
  - One decade after SHRP in 2000s:
    - Cracking:
      - Reflective cracking
      - Fatigue cracking
      - Top-down cracking
      - Thermal cracking

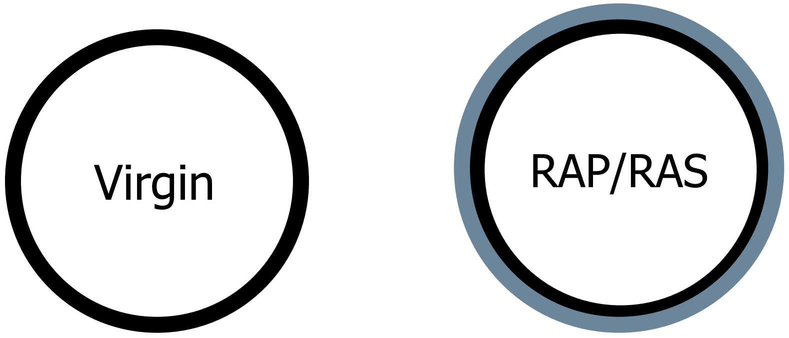
Introduction

- What led to pavement distresses swinging in last 3 decades
  - In surface
    - Stiffer binders: AC20 to PG76-22
    - Less asphalt binder content
    - Coarse gradation
    - Recycled materials
    - Binder quality
  - Root problem
    - Limitations of Superpave mix design method



Introduction

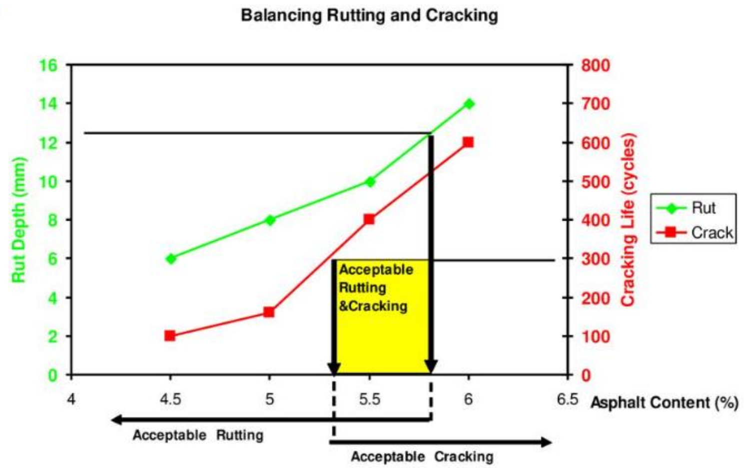
- Volumetrics are important, but volumetrics alone are not enough.
  Limitations of Superpave volumetric design
  - Binder quality: same PG grade but different performance
  - RAP/RAS/rejuvenators
    - Blending virgin/recycled binder
    - Bulk specific gravity
  - Other additives
    - WMA, Plastics, Tire rubber, Fiber



- Ultimate solution: BMD with practical performance tests to characterize the mixes: rutting, cracking, and moisture damage

Elements of BMD

- Although BMD was the goal of many mix design methods (Marshall, Hveem, and Superpave), BMD became a reality in 2007 when TTI designed asphalt mixes with 2 lab tests and associated criteria.
  - Hamburg wheel tracking test
  - Overlay test



AAPT 2007: Zhou, F., Sheng Hu, Tom Scullion, et al. "*A Balanced HMA Mix Design Procedure for Asphalt Overlays*". Vol. 76, San Antonio, Texas.

Elements of BMD

- Practical performance tests
  - Cracking
  - Rutting
  - Moisture damage
- Practical aging protocols
  - Short-term aging
  - Mid-term aging for asphalt overlays
  - Long-term aging for new pavements
- Practical criteria considering traffic, climate, and pavement structure

Elements of BMD-*cracking tests*

Monotonic cracking test

- Disk-shaped compact tension (DCT)
- Semi-circular bend (SCB)-low temperature
- SCB-LTRC
- Illinois flexibility index (IFIT) test
- IDEAL cracking test (IDEAL-CT)

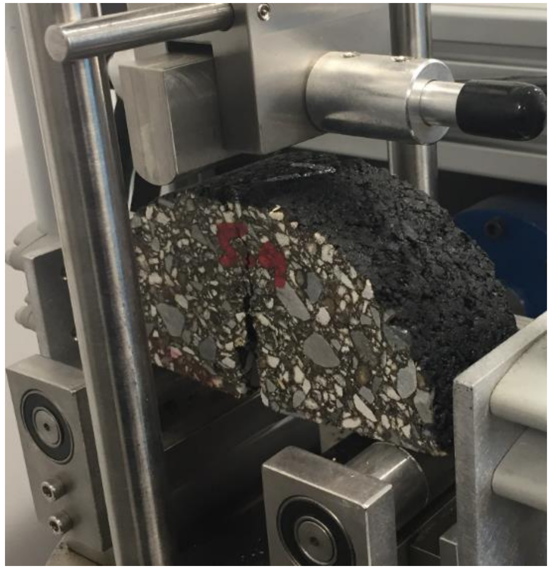
Repeated loading cracking test

- Beam fatigue test
- Overlay test
- AMPT cyclic fatigue test
- IDT-University of Florida

9 videos are available for all the cracking tests on NCHRP 9-57 Website:
apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3644

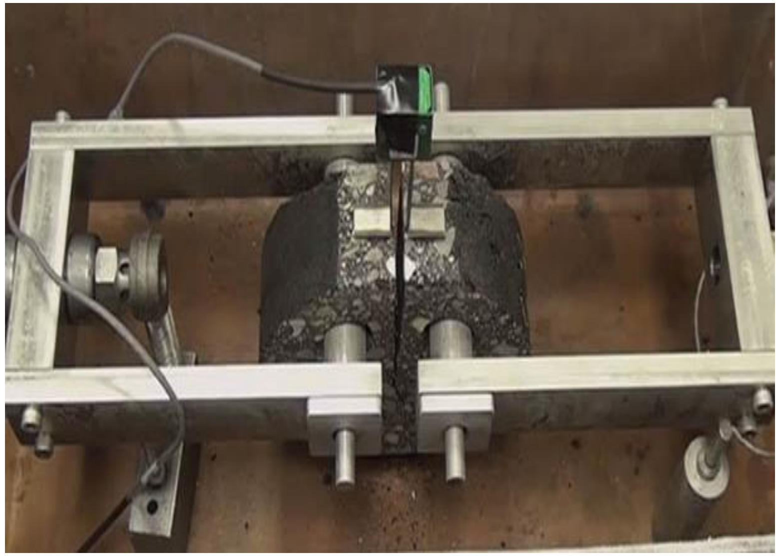
Elements of BMD-*cracking tests*

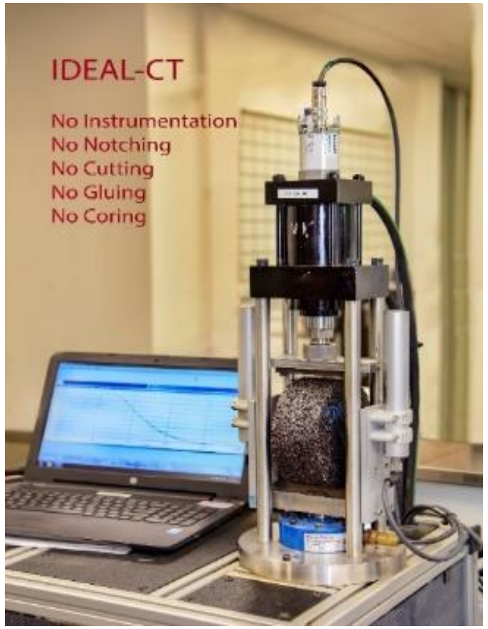
- Cracking tests with monotonic loading: three SCB tests


Elements of BMD-*cracking tests*

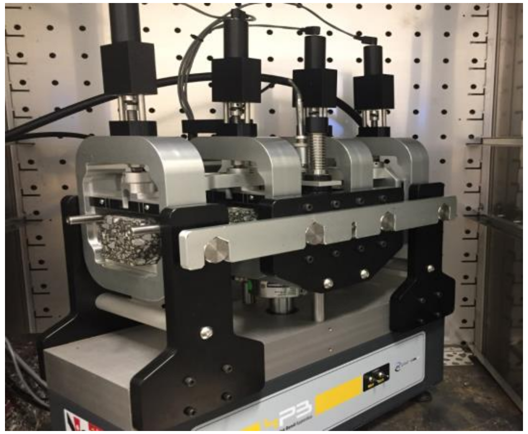
- Cracking tests with monotonic loading

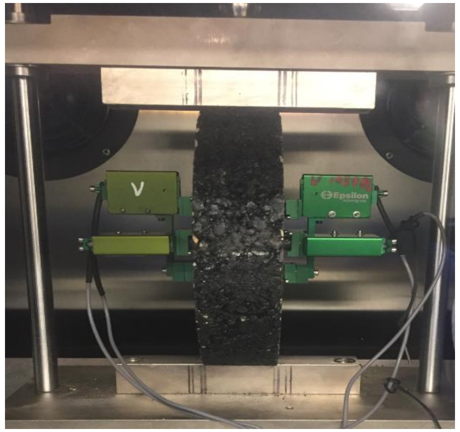


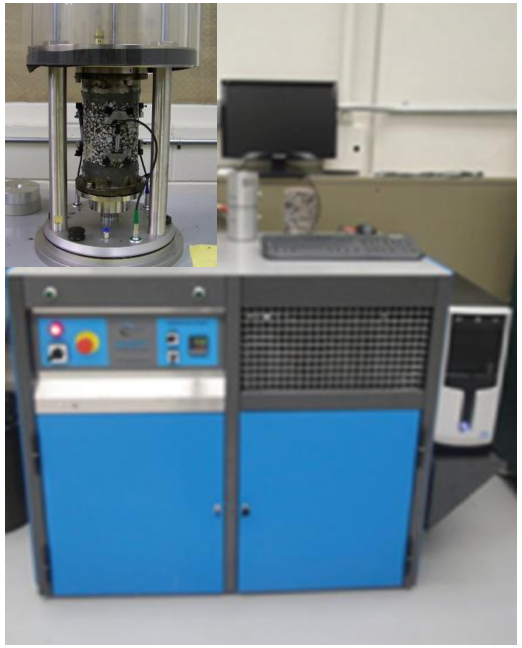


Elements of BMD-*cracking tests*

- Cracking tests with repeated loading







Elements of BMD-*practical cracking test-IDEAL-CT*

Elements of BMD-*rutting tests*

Monotonic rutting test	Repeated loading rutting test
Marshall test	SHRP: Simple shear test (SST)
Hveem test	HWTT
High temperature IDT	Asphalt pavement analyzer (APA)
Ideal rutting test (Ideal-RT)	Flow number (Fn) test
	Stress sweep rutting (SSR) test

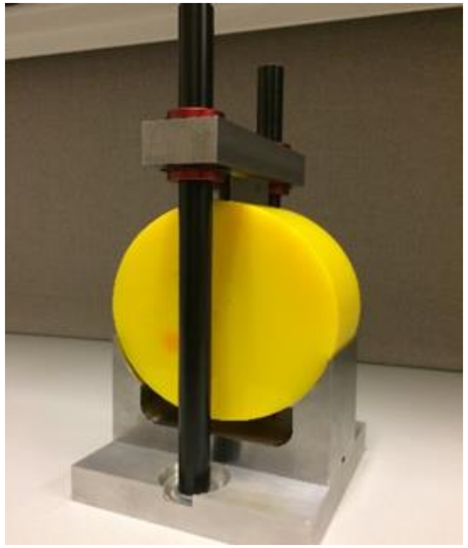
Elements of BMD-*rutting tests*

- Rutting tests with monotonic loading

Marshall

Hveem

IDT-High Temp.



IDEAL-RT

Elements of BMD-*rutting tests*

- Rutting tests with repeated loading


SST


HWTT

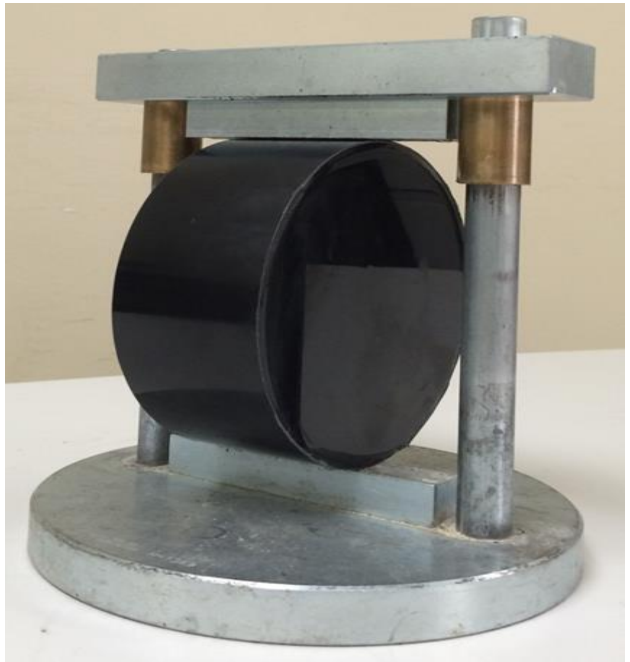

APA


Fn/SSR

Elements of BMD-*moisture damage tests*

- Lab tests for moisture damage

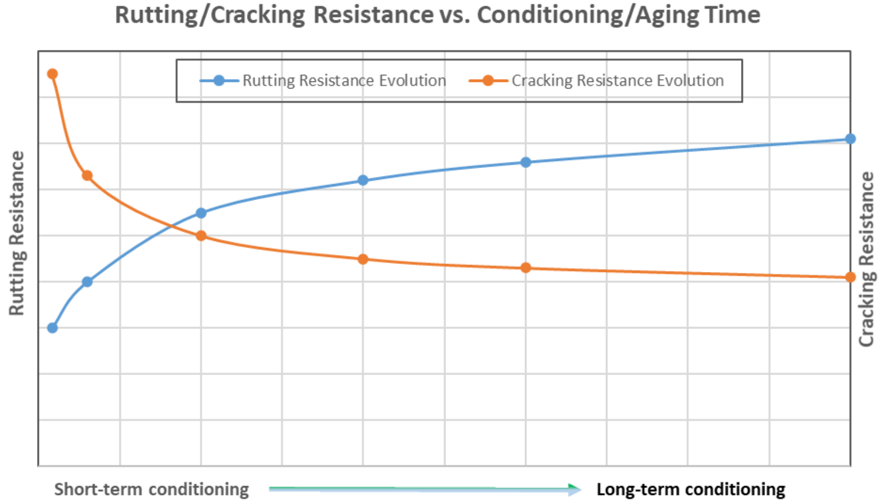
HWTT



TSR

Elements of BMD-*loose mix aging protocols*

- Loose mix aging:
  - Field aging process:
  - Mix rutting/cracking resistances varying with aging in opposite ways
  - Aging protocols: (1) time, (2) temperature, and (3) loose mix thickness



Elements of BMD-*loose mix aging protocols*

- All sorts of aging protocols exist in the literature

Aging protocol		Mix property evaluated	Reference	Note
Short-term aging	2-hr at compaction temperature for loose mixes	Mix design: volumetric properties Mix design: rutting, cracking, and moisture damage QC: compaction density	AASHTO R30 [44] TxDOT specifications 2014 [45] Aschenbrener and Far [47] TxDOT specifications 2014 [43]	Aschenbrener and Far established it based on HWTT data
	2-hr at 116 °C for loose warm mix asphalt (WMA)	Mix design: mix mechanical properties	Epps-Martin et al. [50]	This protocol was developed based mainly on resilient modulus (Mr)
	4-hr at 135 °C for loose hot mix asphalt (HMA)	Mix design: mix mechanical properties	AASHTO R30 [44] Bell et al. [46]	This protocol was developed based mainly on Mr
	2-hr at 135 °C for loose HMA	Mix design: mix mechanical properties	Newcomb et al. [51]	This protocol was developed based mainly on Mr
Long-term aging	120-hr at 85 °C for compacted specimens	Mix design: mix mechanical properties	AASHTO R30 [44] Bell et al. [46]	This protocol was developed based mainly on Mr
	24 to 696-hr at 95 °C for loose mixes	Mix design and structural performance evaluation	Kim et al. [53]	This protocol was developed based on asphalt binder chemistry and rheological property
	8-hr at 135 °C for loose mixes	Mix design: mix mechanical properties	Chen et al. [54]	This protocol was developed based on asphalt binder chemistry and rheological property
	24-hr at 135 °C for loose mixes	Mix fracture property Reinke et al. [52]	Braham et al. [48]	

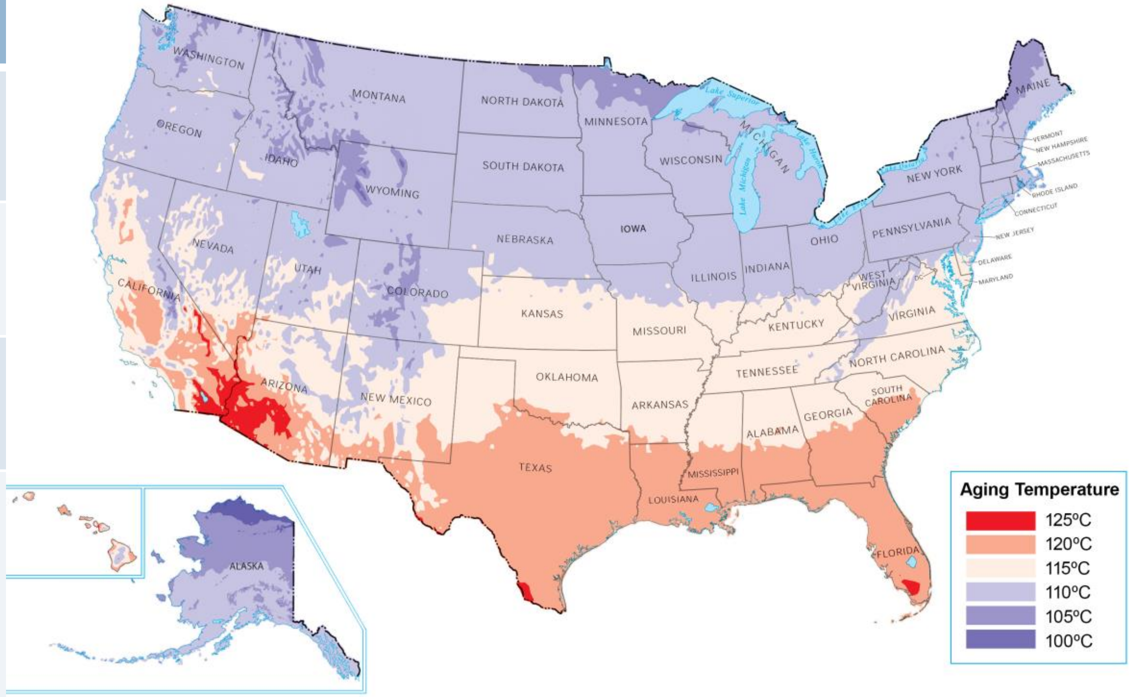
Elements of BMD-*loose mix aging protocols*

Parameters	Short-term aging	Mid-term aging	Long-term aging
Temperature	Compaction temperature	100°C	110°C
Duration (or time)	2 hrs	20 hrs	20 hrs
Loose mix thickness	1.5-2.0 inch	1.5-2.0 inch	1.5-2.0 inch

Reference:

1. AASHTO R 30
2. Zhou, F. et al. AAPT 2021 Mid-term aging protocol for asphalt overlays
3. Zhou, F. et al. AAPT 2022 Practical long-term aging protocol for new pavement construction

Proposed Oven Aging Temperature for a Duration of 20 hours to Match 12 Years of Field Aging at 50mm Below Pavement Surface (ºC)



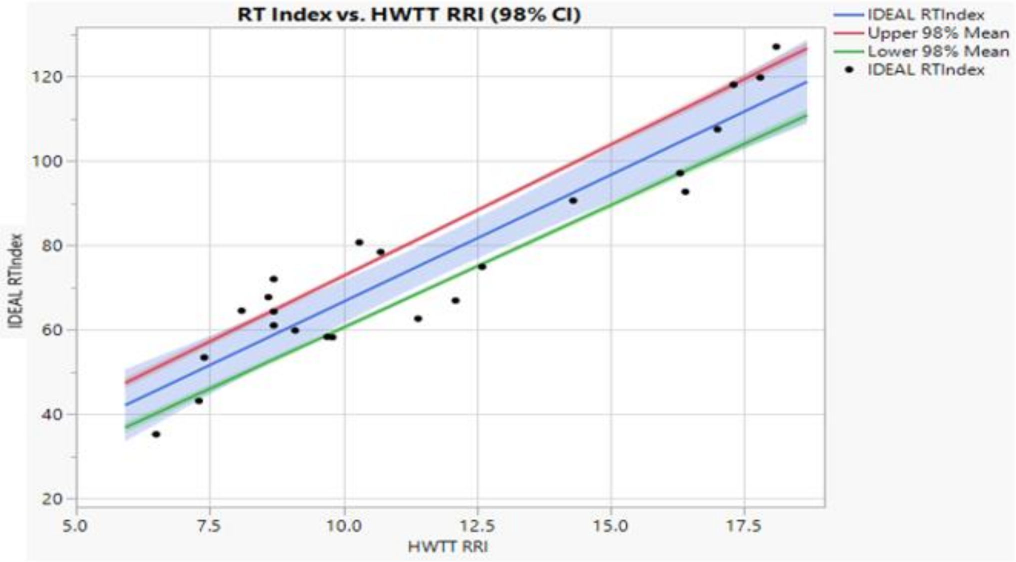
Adopted and modified from an open-access website by GISGeography. Source of Original Map: https://gisgeography.com/us-temperature-map/ (Accessed March 29, 2022)

Elements of BMD-*acceptance criteria*

- Need acceptance criteria for all performance tests
  - Rutting test
  - Cracking test
  - Moisture damage test
- Five methods to establish acceptance criteria
  - Use of neighbor states' criteria
  - Correlation with existing performance tests and criteria
  - Benchmarking test
  - Field test sections
  - Performance simulation

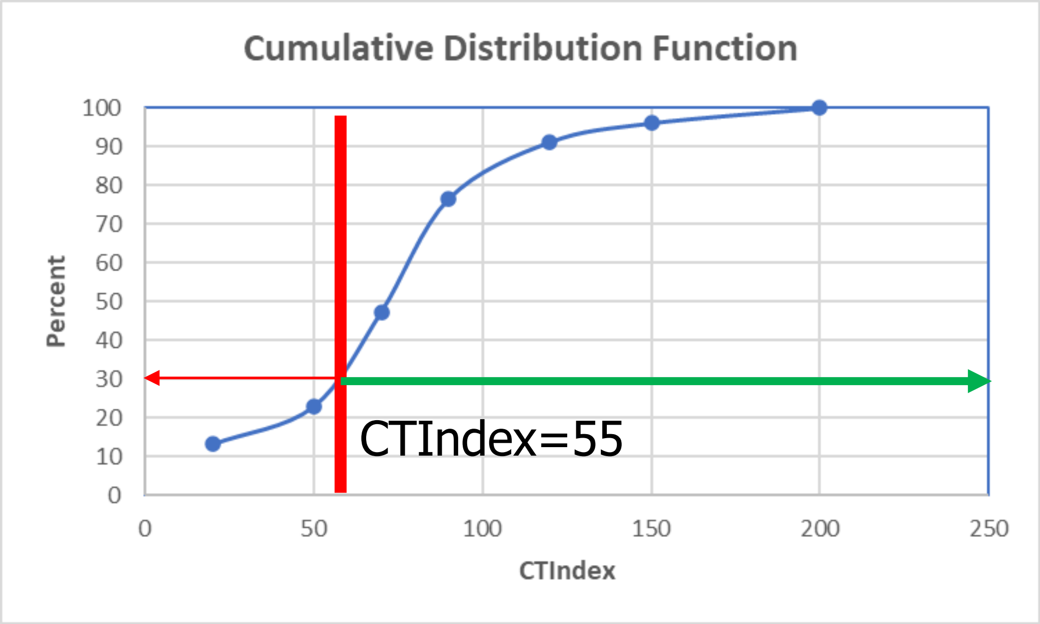
Elements of BMD-*acceptance criteria*

- *Example* of correlation with existing rutting tests and criteria
  - Ideal-RT at 50°C vs. Hamburg wheel tracking test
    - Mixes with PG64-XX (or lower): $RT_{Index} \geq 60$
    - Mixes with PG70-XX: $RT_{Index} \geq 65$
    - Mixes with PG76-XX (or higher): $RT_{Index} \geq 75$



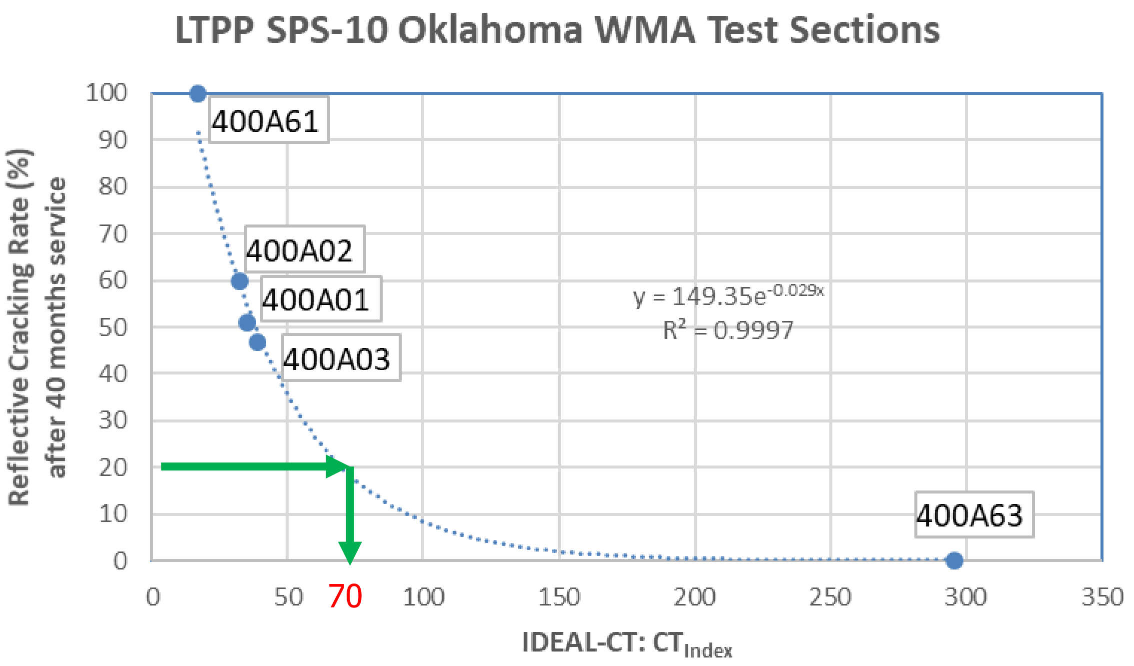
Elements of BMD-*acceptance criteria*

- ***Example*** of benchmarking test with IDEAL-CT
  - Currently TTI is working with ADOT to benchmarking their mixes for cracking criteria
  - Select typical mixes (Superpave III, IV, …) and (practically) plant mixes
  - Perform the test
  - Analyze distribution
  - Determine criteria



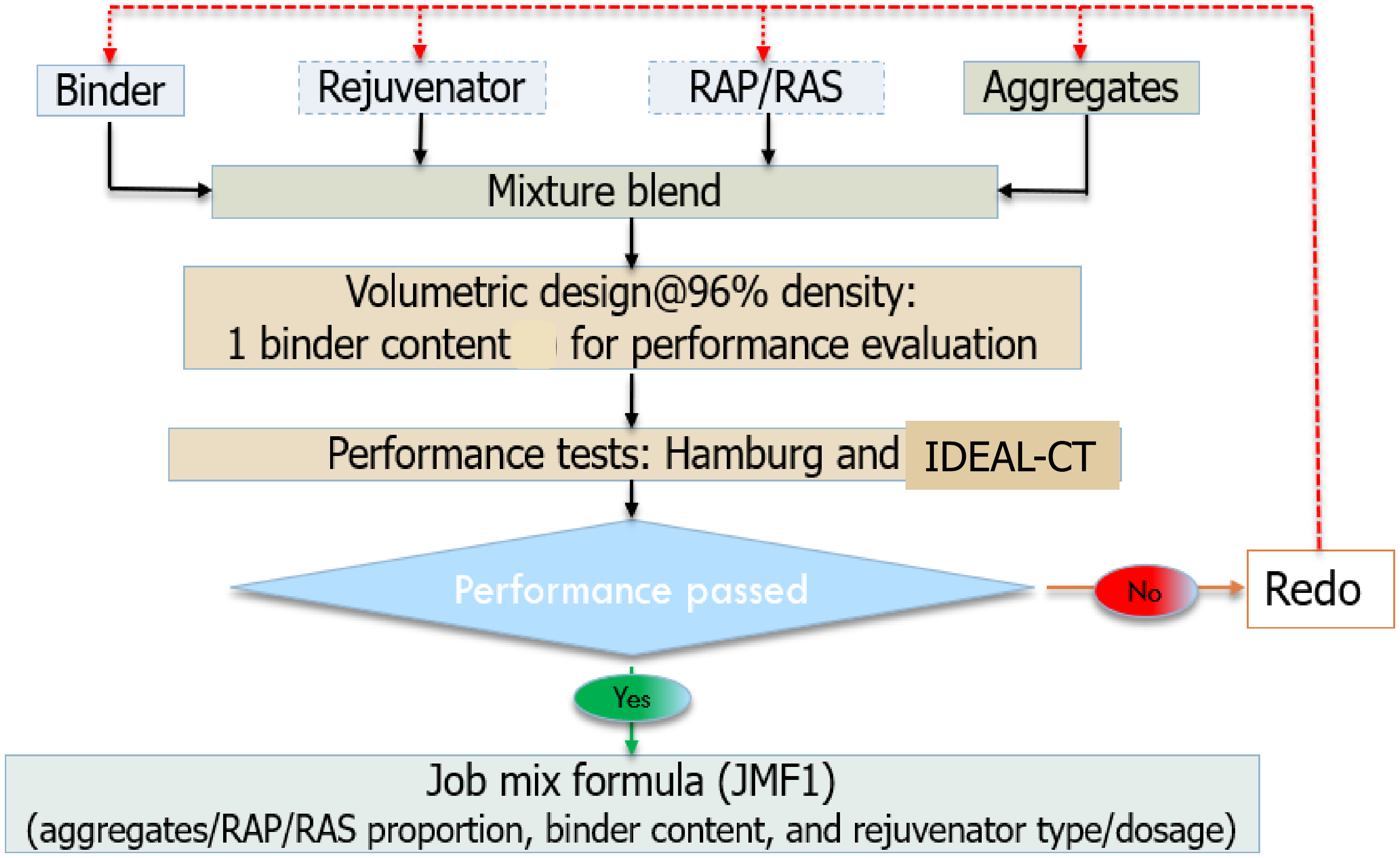
Elements of BMD-*acceptance criteria*

- *<u>Example</u>* of field performance vs. IDEAL-CT
  - Need to construct multiple field test sections



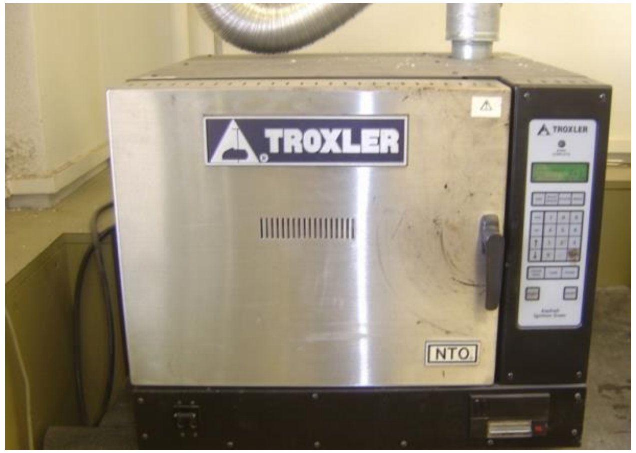
Elements of BMD-*common framework*

- BMD=Superpave + two performance tests with short-term aging
  - Hamburg wheel tracking test
  - IDEAL-CT



Production QC/QA

- QC/QA is a critical step to have a good performance pavement.
- Common QC/QA practices
  - Rice and lab-molded density
  - Asphalt content and gradation from ignition oven test

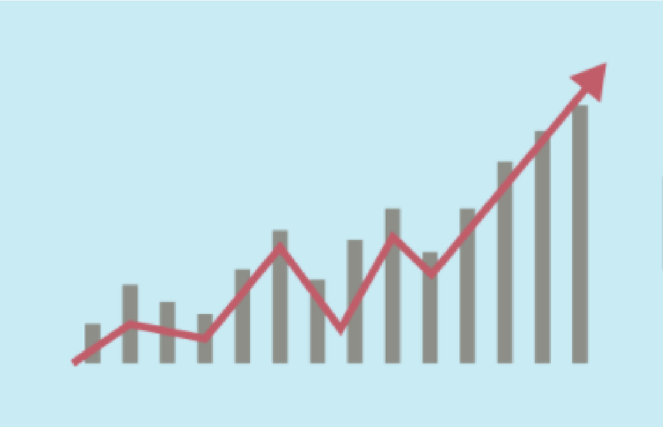


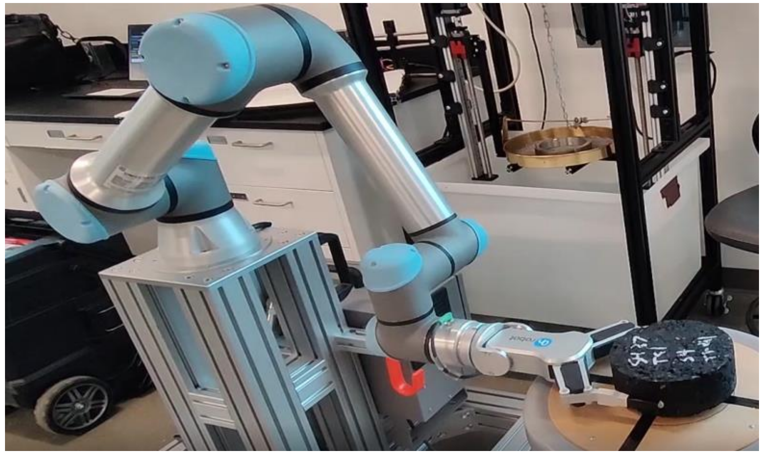
Production QC/QA

- Concerns over QC/QA:
  - Reality: Performance tests in BMD, but none in QC
  - Reason: too much work; short of workforce; running time
  - Consequence:
    - What is produced at plant may be significant different from what was designed in lab
    - Undetected binder source change during production

Production QC/QA-*Automation*

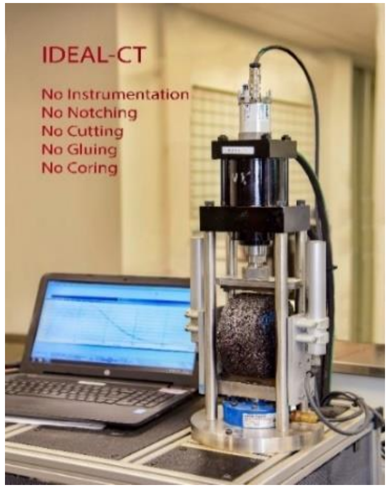
- Automation can help
  - Solve the workforce constrain
  - Increase productivity
  - Improve accuracy by removing human errors

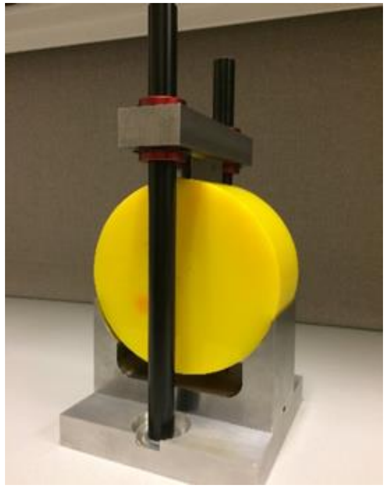




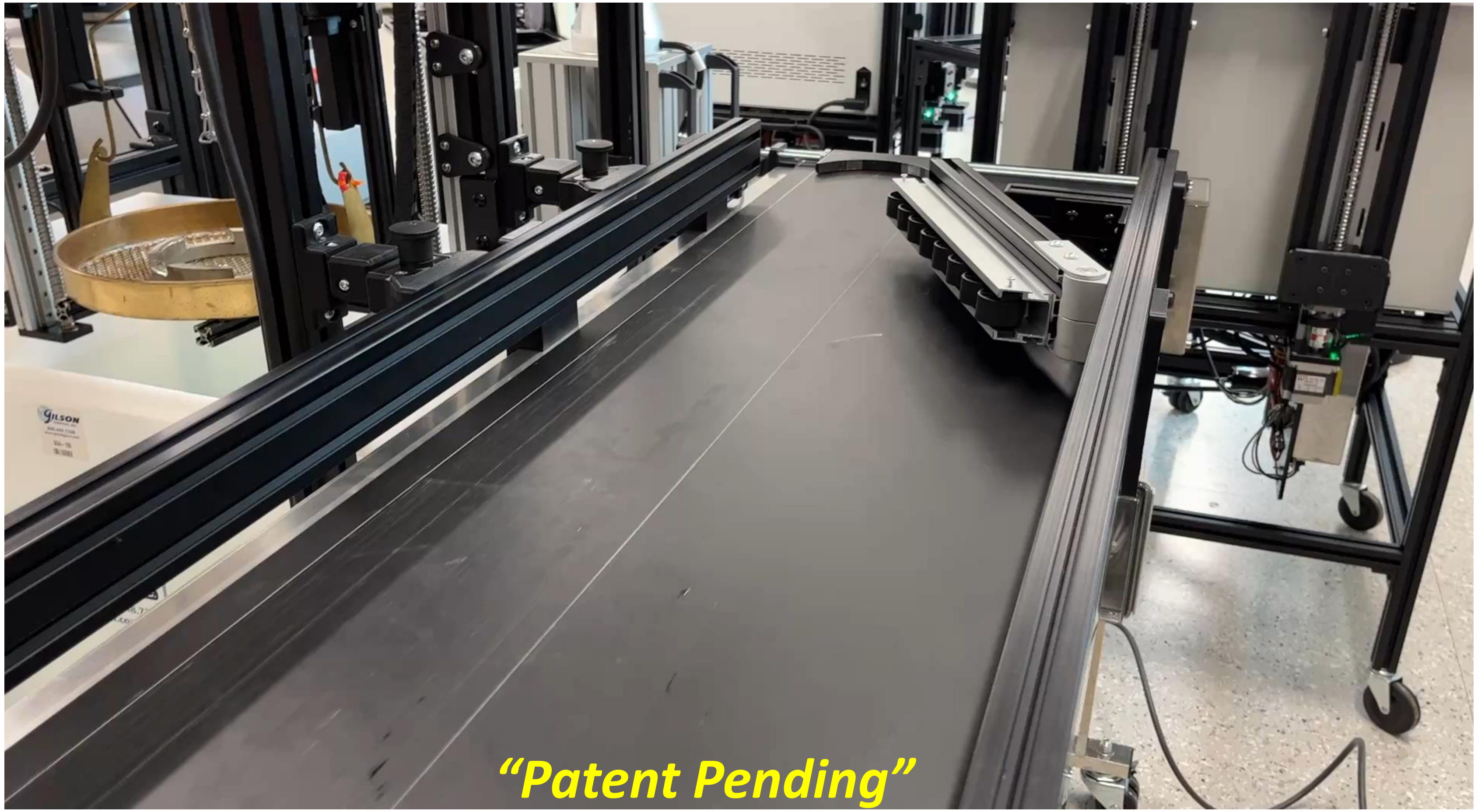
Production QC/QA-*Automation*

- Essential asphalt mixture properties:
  - AASHTO T 166: Bulk specific gravity (air voids)
  - ASTM D6931:
    - Indirect tensile (IDT) strength (or TSR)
    - Hot IDT strength
  - ASTM D8225: IDEAL cracking test (IDEAL-CT)
  - ASTM D8360: Ideal rutting test (Ideal-RT)





Production QC/QA-*Asphalt Mixture Automated Test System with Zero Intervention (AMAZE)*



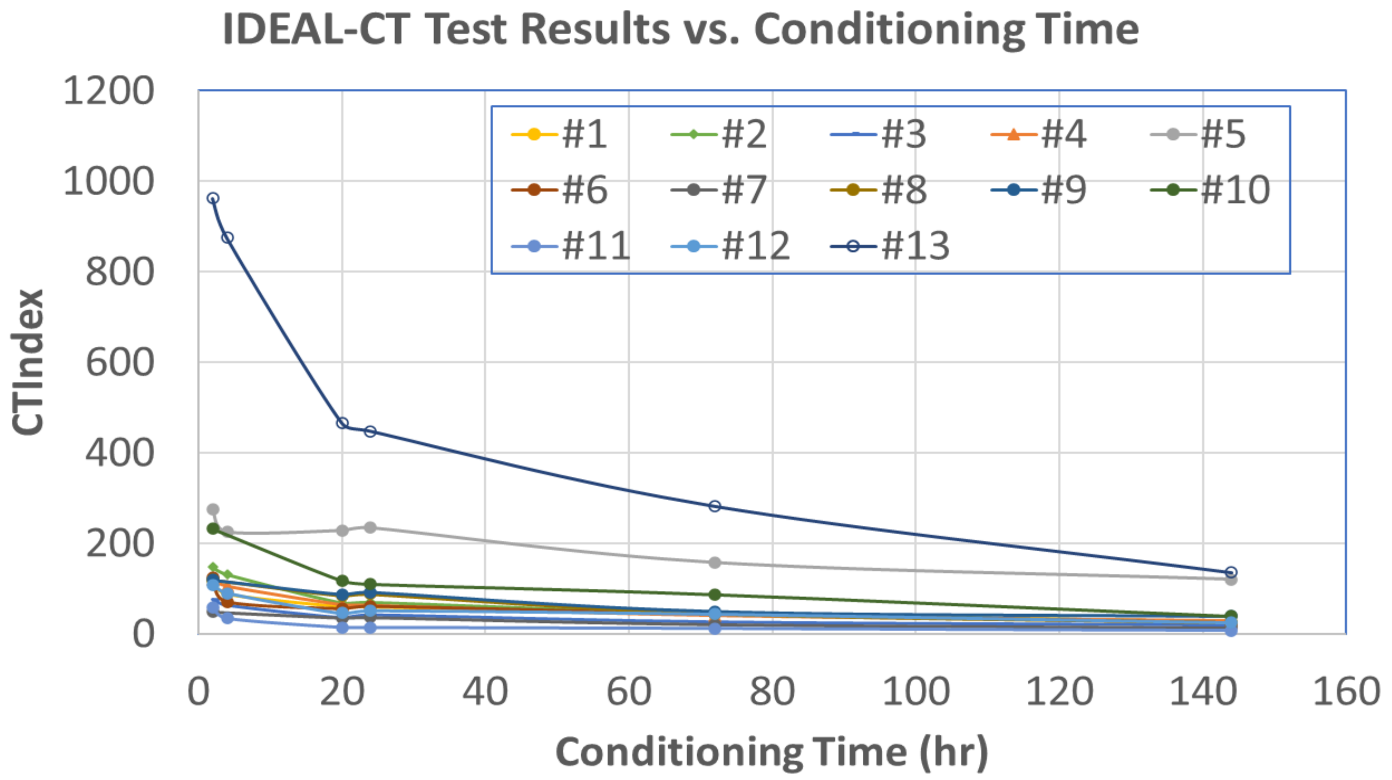
Cracking resistance of asphalt mixes

- Cracking resistance is controlled by asphalt mix components and aging
  - Asphalt mix components
    - Asphalt binder *grade*/*source*/amount
    - Aggregate type/amount
    - Recycled materials/amount
      - RAP, RAS, plastic, etc.
    - Additives/amount
      - Rejuvenator, WMA additive, etc.
  - Aging: short- and (mid-) long-term aging




Cracking resistance of asphalt mixes

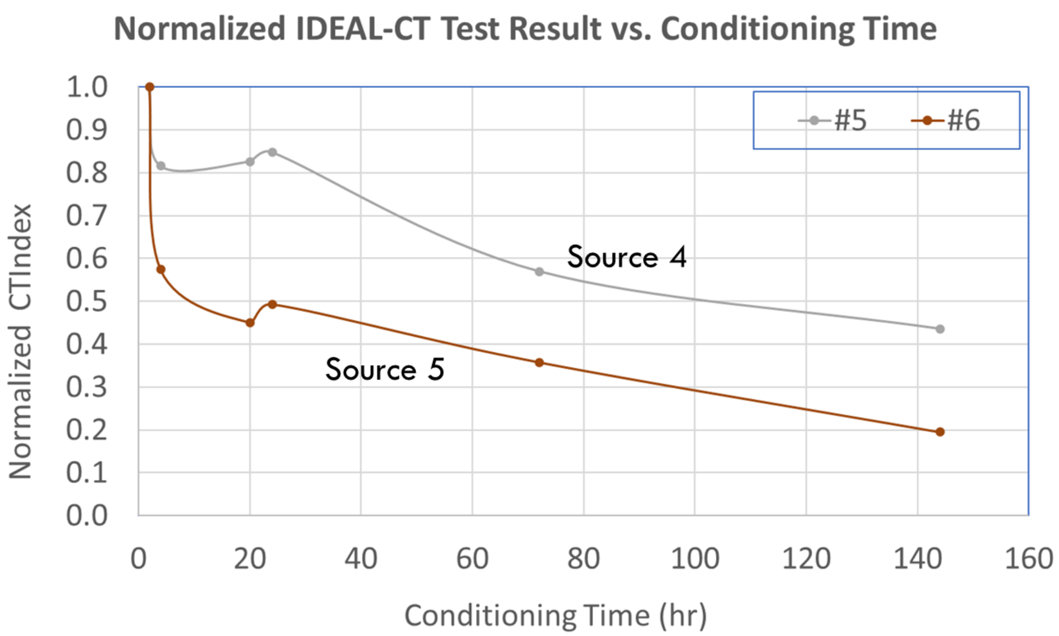
- Aging always reduces cracking resistance, but each ages differently.

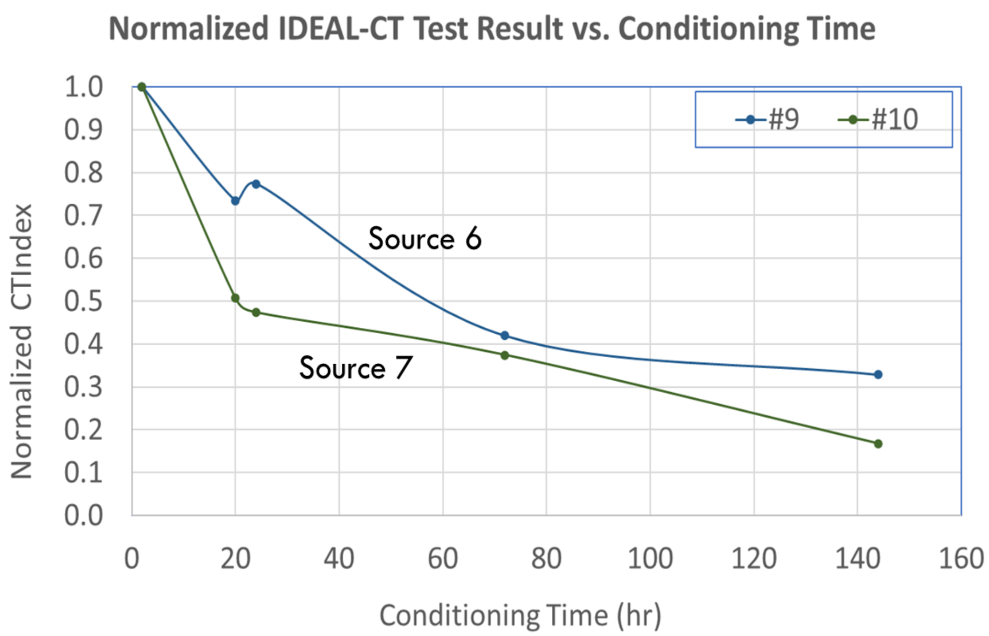


Zhou et al. (2022) Short- and mid-term loose mix conditioning protocols for asphalt overlay BMD and QC/QA, AAPT.

Cracking resistance of asphalt mixes

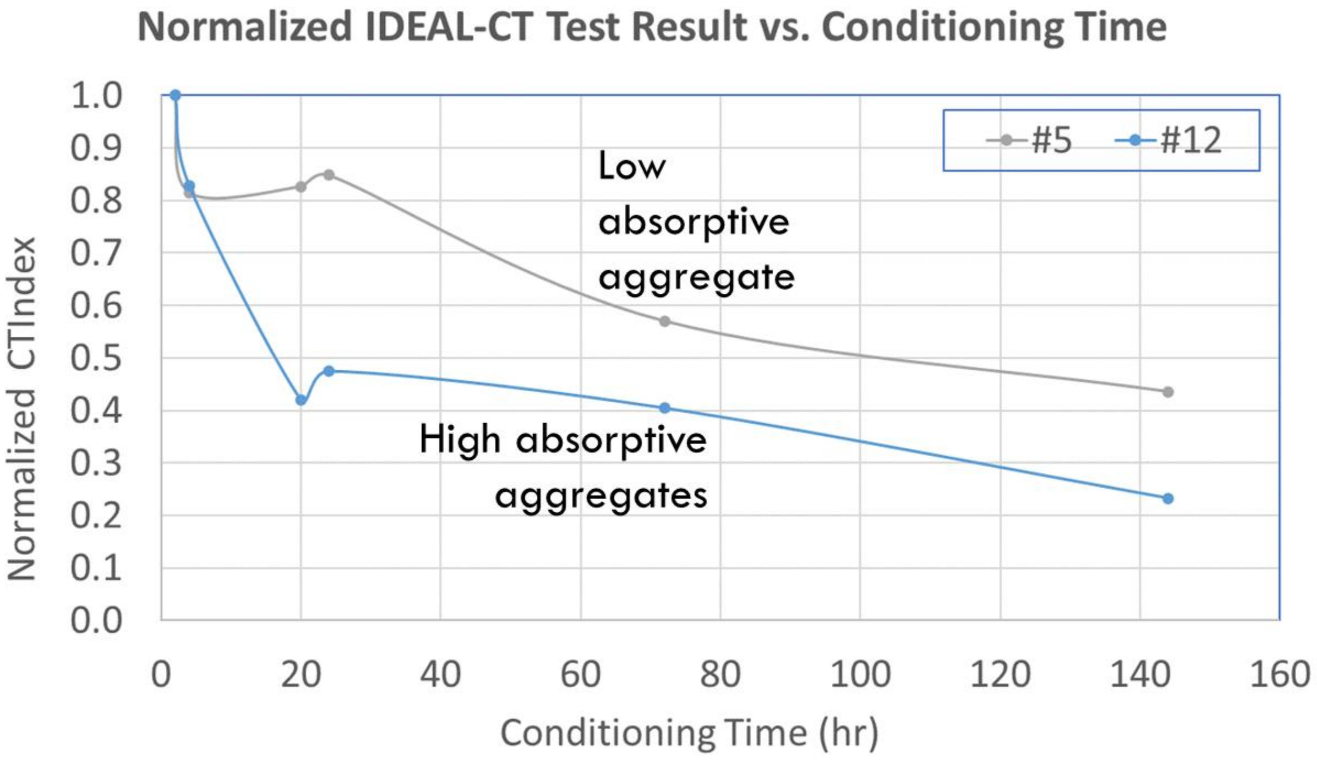
- Binder source: same PG doesn't mean same cracking resistance.





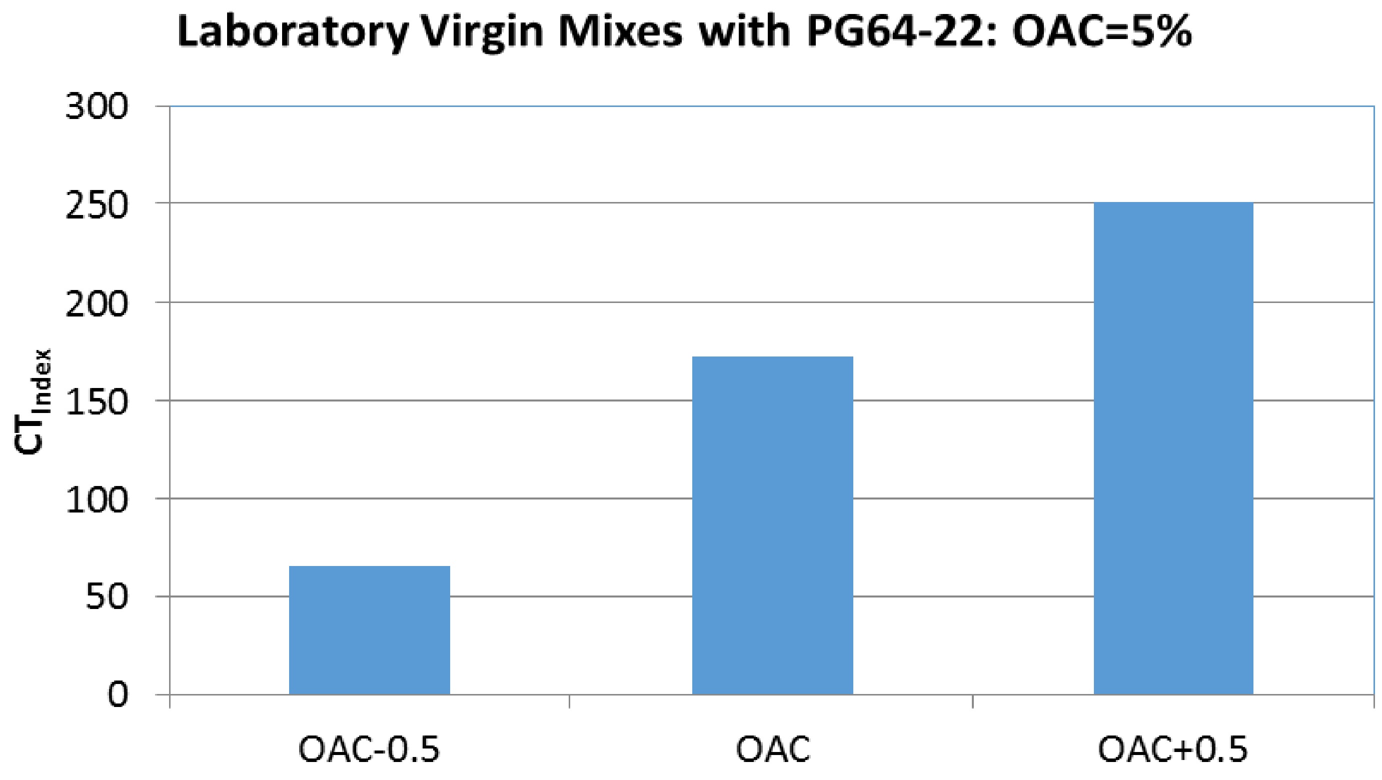
Cracking resistance of asphalt mixes

- Aggregate absorption: high absorption often leads to poor cracking resistance.



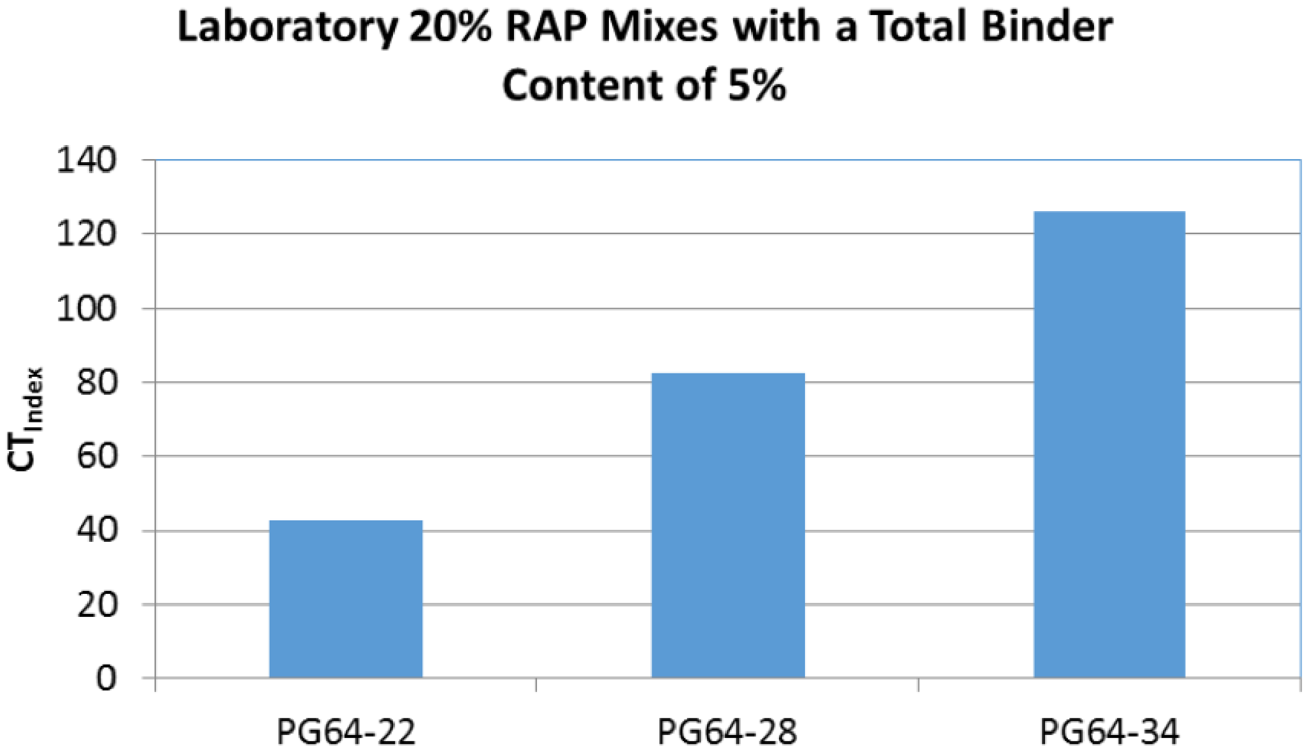
Cracking resistance of asphalt mixes

- Binder content: Maybe the effective way to improve cracking resistance.



Cracking resistance of asphalt mixes

- Binder grade: PG64-28 or PG64-34



Cracking resistance of asphalt mixes

- Binder grade (PG**76**-xx) and polymer modification

  - "Field tests show that all PMAs in general have improved the rutting resistance of asphaltic concrete mix."
  - "However, with respect to cracking, polymers that used 85 to 100 pen base asphalt in these test sections have more cracking than the control sections."

Transportation Research Record Journal of the Transportation Research Board. 1545.
Polymer-Modified Asphalt Pavements in Ontario: Performance and Cost-Effectiveness 151-160.

Casey Nash (2022), Asphalt Mixture Cracking Resistance, TRB Webinar, 12/5/2022

Webinar Details (mytrb.org)

Cracking resistance of asphalt mixes

- Binder grade: PG64-22 vs. PG76-22 NCAT test track

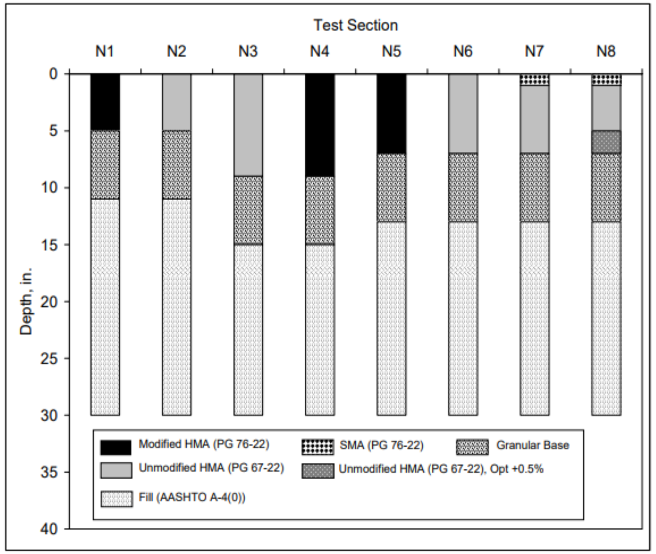


Figure 4.2 Final Design and Section Layout (after Timm et al, 2005).

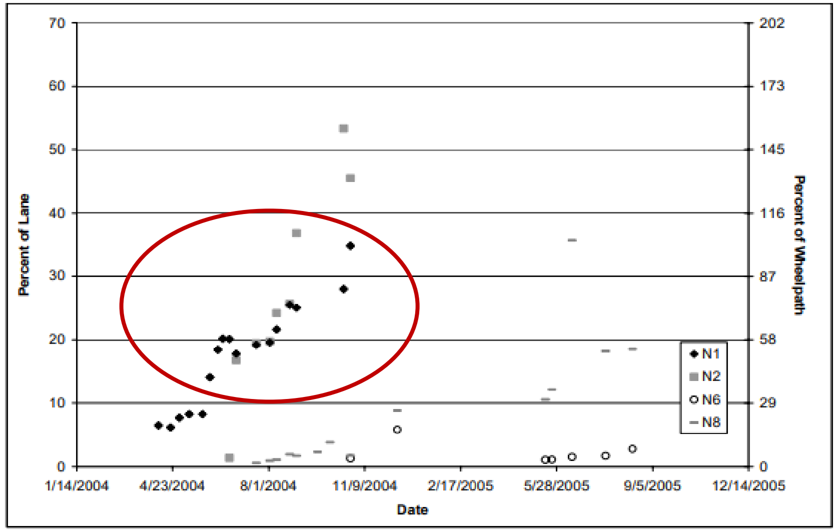


Figure 4.41 Percent Fatigue Cracking by Date.

Table 4.9 Section Failure Data.

Section	Failure Date	Cracking of Lane, %	Cracking of WP, %
N1	6/14/2004	20.2	58.3
N2	7/19/2004	19.5	56.2
N8	8/15/2005	18.5	53.5

David Timm et al. (2006), Phase II NCAT Test Track Results

Microsoft Word - 06-05 with cover.doc (auburn.edu)

Improving cracking resistance of asphalt mixes

- Know your materials and select properly
  - Asphalt binder: *grade*, *source*, *content*
  - Aggregate: absorption
  - Recycled materials
    - RAP, plastic, etc.
  - Additives: Rejuvenator, etc.
- Consider mix aging factor
- Use practical performance tests for BMD and QC/QA
- Remember the contribution of pavement structural thickness: AC layer




Improving cracking resistance of asphalt mixes

- Addressing cracking problem may need more than BMD/QC/QA
  - Know existing pavement structure
  - Evaluate pavement conditions
  - Conduct an asphalt overlay thickness design
    - Traffic
    - Climate
    - Existing pavement structure/condition

[Mechanistic-Empirical Asphalt Overlay Thickness Design and Analysis System (tamu.edu)]

Summary and Conclusions

- BMD is a practical method for ensuring good performance:
  - Practical performance tests: rutting, cracking, moisture damage
  - Practical aging protocols: short- and long-term aging
  - Acceptance criteria related to traffic, climate, and pavement structure
- Many factors impact cracking resistance of asphalt mixes. Asphalt content is critical; pay attention to the materials and aging.
- Not all same PG binders, RAP, etc. perform the same!
- AMAZE-automation helps QC/QA testing.

Thank YOU!

Fujie Zhou, PhD, PE

Senior Research Engineer

Texas A&M Transportation Institute

Phone: (979) 317-2325

Email: f-zhou@tti.tamu.edu

Elements of BMD-*practical cracking test-IDEAL-CT*

- National round robin test:
  - COV=15-20%

Stacey Diefenderfer, VTRC, Dec. 2020

Study	Study Description			Precision Estimates, COV, %	
				Single-operator	Multi-laboratory
Taylor et al. 2019	Phase I: - 1 mixture - 15 participants - Specimens compacted by participating laboratories - Target air voids 7.0% ± 0.5% - Minimum of 5 replicates			19.5%	35.3%
Taylor et al. 2019	Phase II: - 1 mixture (same mixture as in Phase I) - 14 participants - Single lab specimen compaction - Target air voids 7.0% ± 0.5% - Minimum of 5 replicates			18.8%	20.2%
Bennert et al. 2020	- 5 mixtures - 9 participants - Single lab specimen compaction - Target air voids 5.5% ± 0.5% - 3 replicates per mixture			15.2%	23.0%
VDOT	- 2 mixtures - 41 participants - 46 data sets - Single lab specimen compaction - Target air voids 7.0% ± 0.5% - 5 replicates per mixture	Analysis: 16 data sets per mix	Untrimmed data	18.3%	21.3%
			Trimmed data	11.2%	15.9%
		Analysis: 30 data sets per mix	Untrimmed data	20.7%	21.9%
			Trimmed data	12.8%	16.9%

Elements of BMD-*practical cracking test-IDEAL-CT*

- Very simple specimen preparation
- Good correlation with field cracking performance
- Reasonable variability: COV=10-20%
- Sensitivity to asphalt mix components
- Low cost of loading frame (or test machine)
- Short testing time
- Applicable for both lab mix design and field QC/QA