Wisconsin Highway Research Program (WHRP) Updates

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WHRP Flexible Pavements Chair

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The materials included in this presentation are the result of research conducted for WisDOT through the WHRP program

WHRP 20-04 Balanced Mix Design Implementation Support

Close Out Presentation

April 30, 2021

Research Team

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Project Objective

WHRP 20-04 *Balanced Mixture Design Implementation Support*

"The overall objective of this research is to test performance-based methodologies with the intent of developing an implementable BMD specification for WisDOT projects."

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Project Overview

- Task 1 – Literature Review
- Task 2 – Interviews of Mix Designers
- Task 3 – Benchmarking Experiment, Develop Preliminary Criteria, Conduct Workshop
- Task 4 – Modify Existing Wisconsin Mixes
- Task 5 – Economic Analysis of Mix Design Modifications
- Task 6 – Propose Modifications to WisDOT Specs
- Task 7 – Final Report

Project Overview

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Task 1 Literature Review

- Four BMD Approaches described in AASHTO PP 105-20
  A. Volumetric Design with Performance Verification
  B. Volumetric Design with Performance Optimization
  C. Performance-Modified Volumetric Design
  D. Performance Design
- 11 SHAs have a draft, provisional, or standard BMD specification (NCAT, 2020)
  - IL, LA, NJ, TX, and VT: Approach A
  - CA, MO, OK: Approach C
  - AL, TN: Approach D
  - VA: Approach A and D

Task 1 Literature Review

- SHAs most popular performance tests (NCAT, 2020):
  - Rutting: HWTT (14) and APA (10)
  - Cracking: BBF (4), IDEAL-CT (3), I-FIT (3), DCT (3), and OT (2)
  - Moisture: TSR (36), HWTT (7), and immersion compression test (2)
- Potential mix design modifications:
  - Asphalt content, asphalt binder grade and source, polymer modification, aggregate gradation, RAM content, rejuvenators, antistrip agents.

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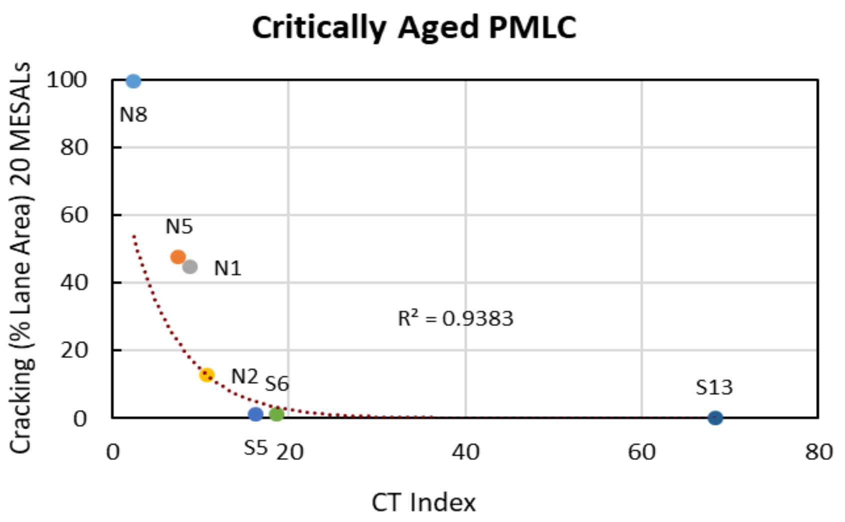
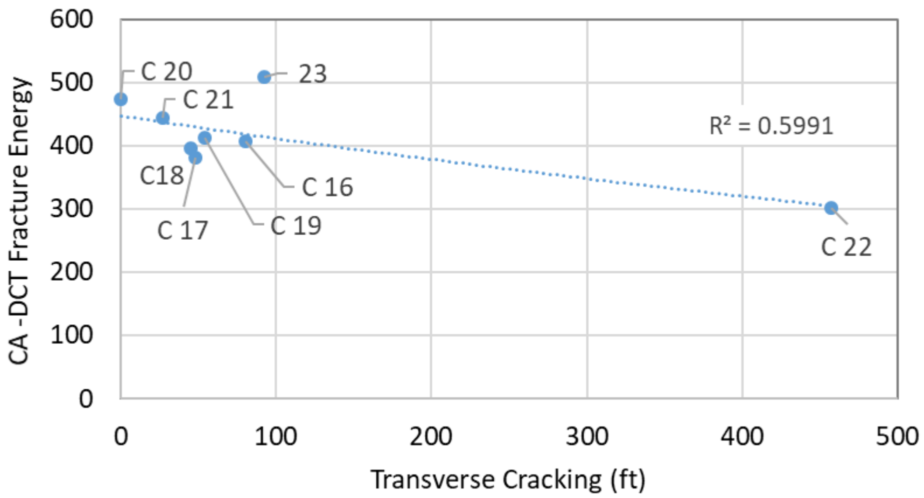
Wisconsin Performance Tests Correlation to Field

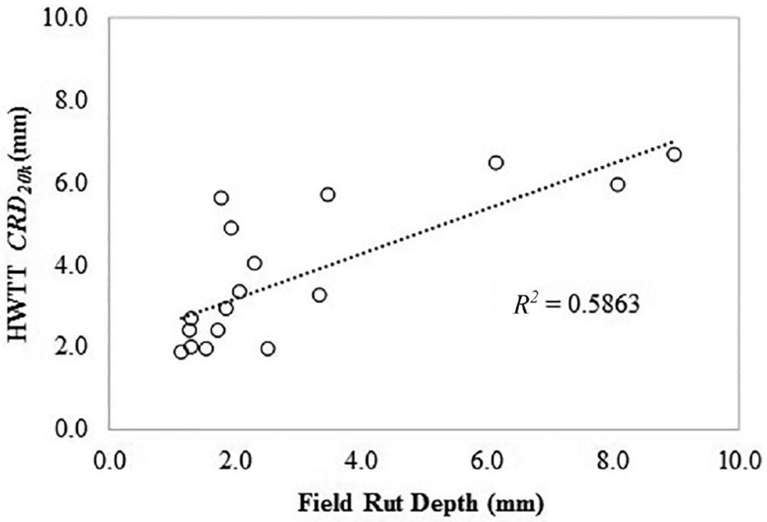
IDEAL-CT – NCAT Cracking Group



DCT – MnROAD Cracking Group



HWTT– NCAT Test Track (Yin et al., 2020)



Limited field validation of most performance tests, but good evidence of lab-field correlation from comprehensive studies for IDEAL-CT, HWTT and DCT

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Task 2 Interviews of Wisconsin Mix Designers

- Seven experienced Wisconsin mix designers were interviewed in March 2020
- Large and medium sized contractors and testing labs that work in multiple states mostly had equipment for popular BMD tests
- Expected mix adjustments for BMD were increased asphalt contents &/or reduce RAP or RAS contents
- Views differed on relaxing current mix design criteria and whether BMD should be used on all projects or certain types of projects such as overlays or other not-traffic factors

Task 3 Benchmarking Experiment

- Benchmark existing mix design to determine the distribution of test results
- 18 mixes with a wide range of aggregate type, gradation, and traffic level
- Mixes designed with 3% regressed air voids approach
- LMLC specimens prepared by contractors, tested at NCAT
- HWTT (46°C), IDEAL-CT (25°C), and DCT (-18°C)

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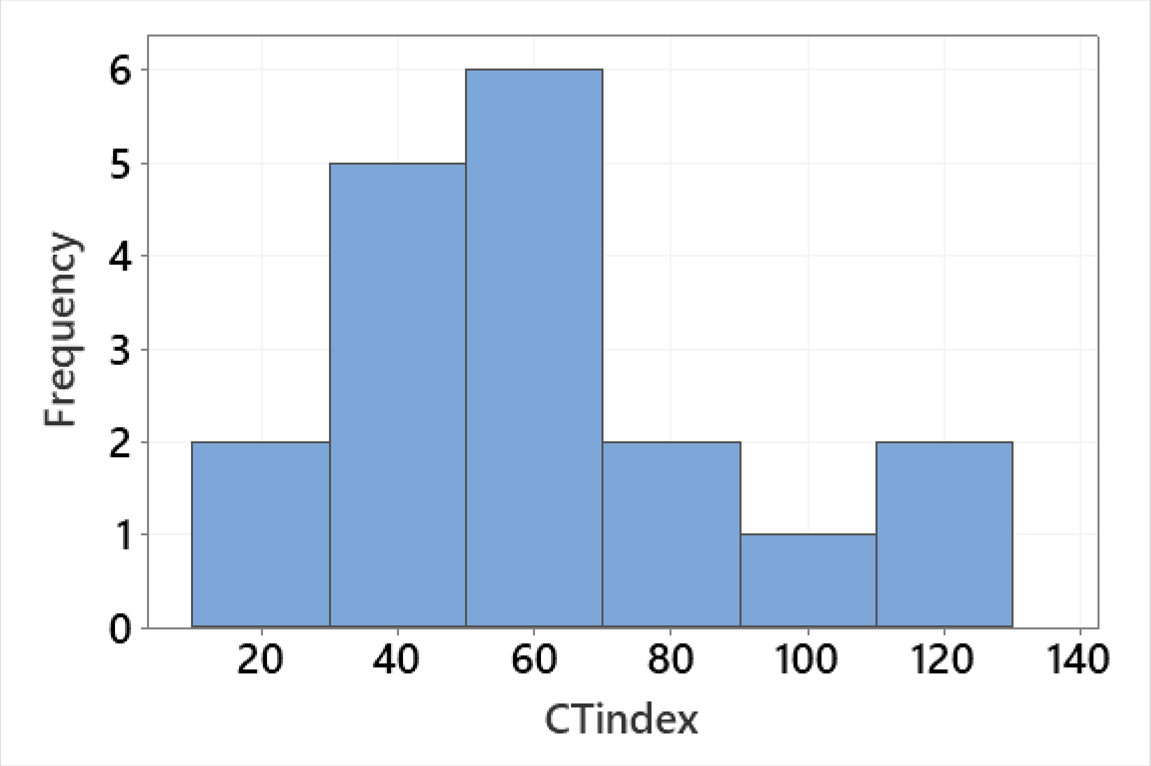
Mix Aging Procedures

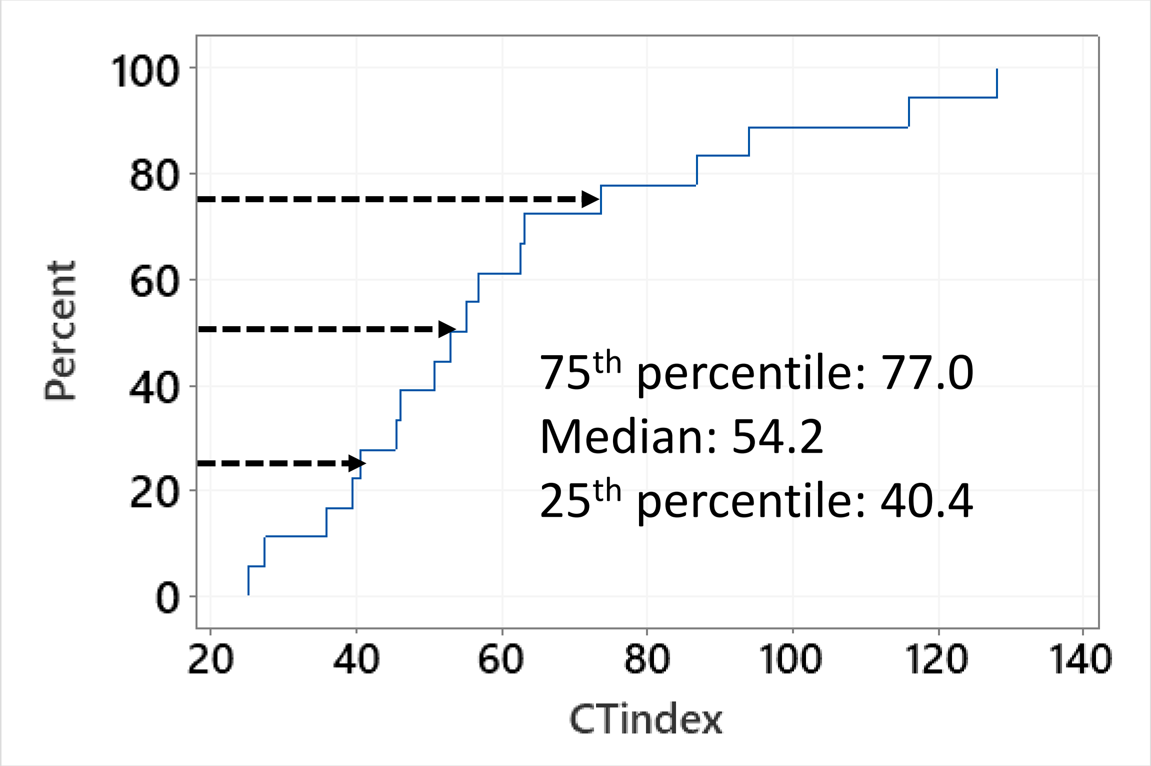
- HWTT: short-term aging for 4 hours at 135°C per AASHTO R30
- IDEAL-CT & DCT: + critical aging for 6 hours at 135°C
  - WHRP field aging and oil modification study (UW-Madison)
  - MnROAD Cracking Group experiment (MnROAD/NCAT)
  - NRRA mix rejuvenator field study (UNH)
  - More severe than aging compacted specimens for <u>5 days at 85°C</u> per AASHTO R30 (1 to 3 years of field aging)
  - More practical than aging loose mix for <u>2 to 3 days at 95°C</u> per NCHRP 09-54 recommendations

IDEAL-CT Benchmarking Analysis

Histogram



Cumulative Distribution Curve



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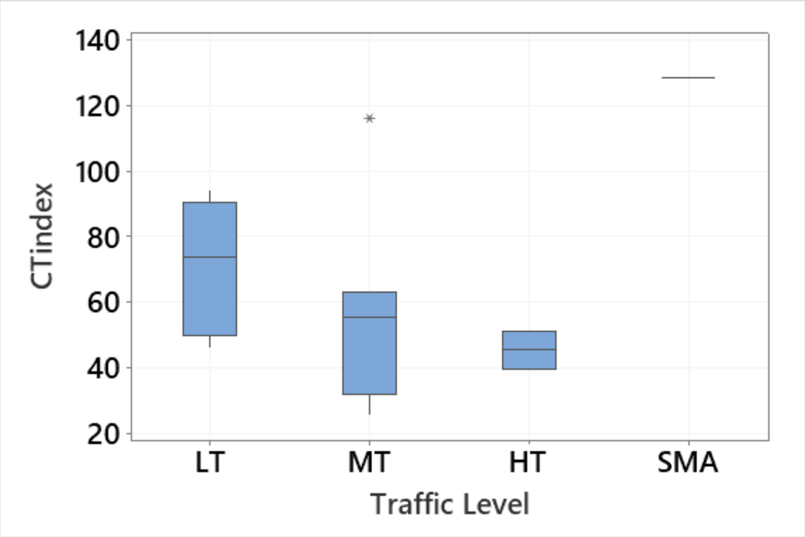
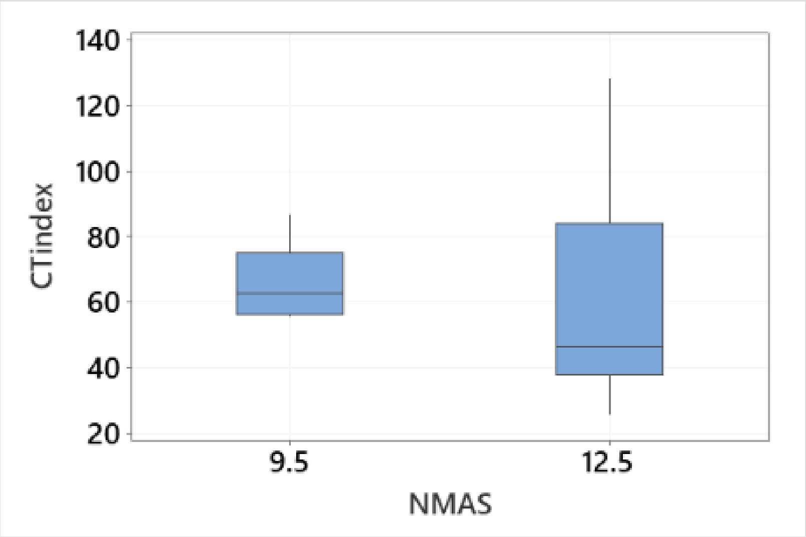
IDEAL-CT Benchmarking Analysis

Boxplot Analysis by Individual Mix Design Variables

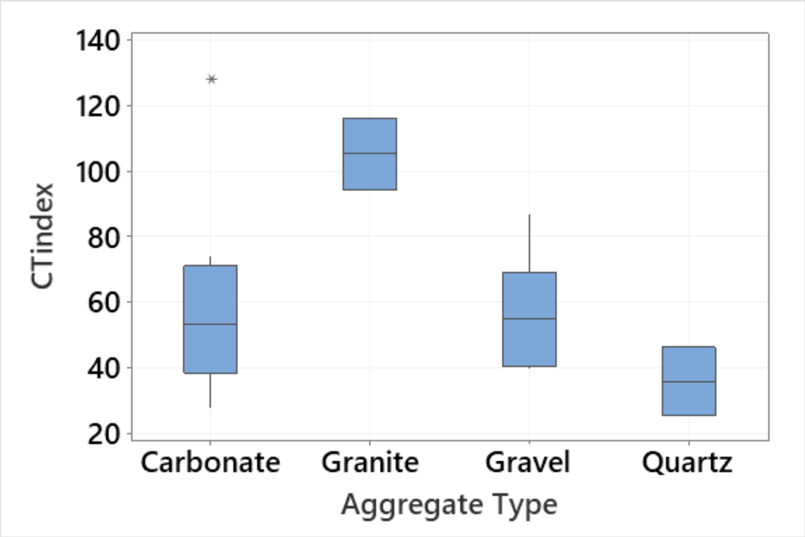
Traffic Level



Aggregate NMAS



Aggregate Type



Same benchmarking analyses conducted for HWTT and DCT results

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Task 3 Preliminary Performance Test Criteria

Traffic Level	IDEAL-CT CT_{Index}	DCT Fracture Energy (J/m^2)	HWTT			
			Min. Passes to 12.5	Min. SIP	CRD_{20k} (mm)	Min. SN
SMA	≥80	≥400	15,000	9,000	6.0	2,000
High	≥40	≥300				
Med					7.0	
Low*			10,000		8.0	

* = Regressed Air Voids sufficient for low traffic in lieu of BMD (AASHTO Provisional BMD Standard)

Recommended Criteria & Pass/Fail Rate

Using WisDOT PMLC Database from early Jan. 2021

<table>
<tr><th rowspan="2">Traffic Level</th><th colspan="2">IDEAL-CT</th><th rowspan="2">DCT Min. Fracture Energy (J/m^2)</th><th colspan="4">Hamburg</th></tr>
<tr><th>Min. CT_{Index}</th><th>No. Fail/ Total No.</th><th>Min. Passes to 12.5 mm</th><th>No. Fail/ Total No.</th><th>Min. SIP</th><th>No. Fail/ Total No.</th></tr>
<tr><td>SMA</td><td>80</td><td>1/1</td><td>400</td><td rowspan="3">15,000</td><td>0/1</td><td rowspan="4">9,000</td><td>0/1</td></tr>
<tr><td>High</td><td rowspan="3">40</td><td>6/13</td><td rowspan="3">300</td><td>0/11</td><td>0/11</td></tr>
<tr><td>Med</td><td>10/32</td><td>12/32</td><td>5/32</td></tr>
<tr><td>Low</td><td>1/15</td><td>10,000</td><td>1/15</td><td>5/15</td></tr>
</table>

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Task 4 Mixes Selected to Modify

Traffic Level	Mix ID	IDEAL-CT CT_{Index}		HWTT CRD_{20k}		HWTT SN		DCT Fracture Energy	
		Criteria	Avg.	Criteria	Avg.	Criteria	Avg.	Criteria	Avg.
High	Mix C	≥ 40	50.9	≤ 6.0 mm	3.7	≥ 2,000	3,579	≥ 300 J/m^2	292
Med	Mix K		27.5	≤ 7.0 mm	4.1		2,253		310
	Mix L		36.0		2.9		6,076		349
	Mix M		25.4		3.4		20,000		433
	Mix F		63.1		7.1		1,573		240 (337)*

* = Tested at -24°C (-18°C)

Task 4 Mixes Modified

Mix ID	NMAS (mm)	Traffic Level	Ndes	Base Binder	Primary Aggregate	RAP (%)	RAS (%)
Mix M	12.5	Medium	75	PG 58S-28	Quartz	18	3
Mix L	12.5	Medium	75	PG 58S-28	Carbonate	10.1	3.4
Mix K	12.5	Medium	75	PG 58S-28	Carbonate	26	0
Mix C	12.5	High	100	PG 58S-28	Carbonate	16	0
Mix F	9.5	Medium	75	PG 52S-34	Gravel	35	0

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Task 4 Testing Plan

- Critical Test – The performance test for a particular mix that fell below the preliminary criteria
  - IDEAL-CT : Mixes M, L, and K
  - HWTT : Mix F
  - DCT : Mix C
- Raw materials provided to NCAT by the contractors
- Lab-mixed, lab-compacted specimens
- Mix design verification
  - G_{mm} and G_{mb} within AASHTO d2s of JMF Values
- Optimize mix with regard to critical test, then verify other two tests and report volumetrics

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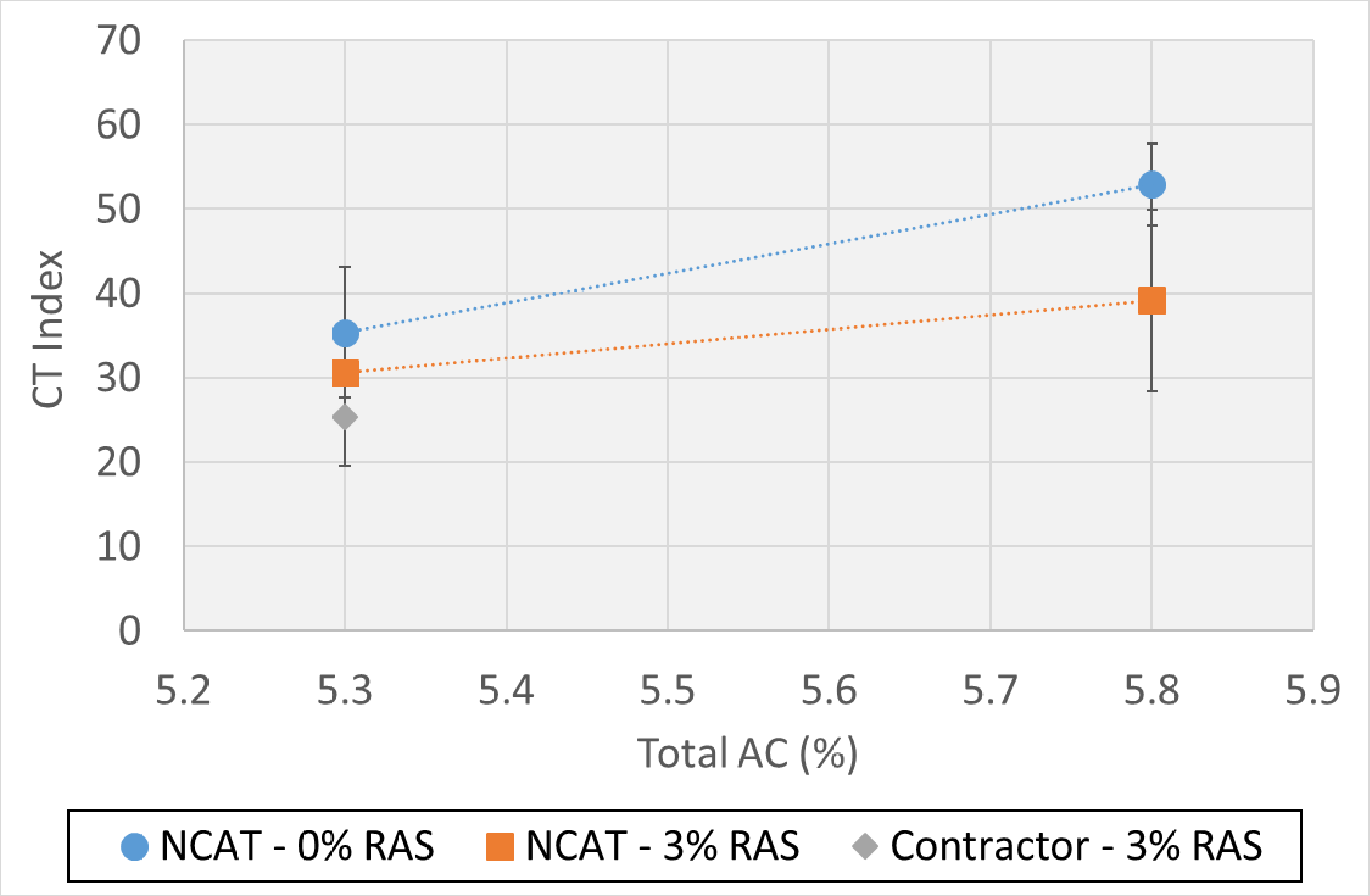
Attempted Optimization Strategies

- Add additional asphalt (cracking)
- Remove RAS (cracking)
- Add rejuvenator (cracking)
- Lower low PG grade (cracking)
- Higher MSCR grade (rutting)
- Liquid anti-strip (stripping)

Mix M – IDEAL-CT Optimization

- Critical Test: IDEAL-CT
  - Redesign without RAS
  - Add AC (%)
- BMD OAC
  - $CT_{Index} > 40$
  - With RAS; OAC = 5.9%
  - No RAS; OAC = 5.5%
- Modified design met DCT and HWTT criteria



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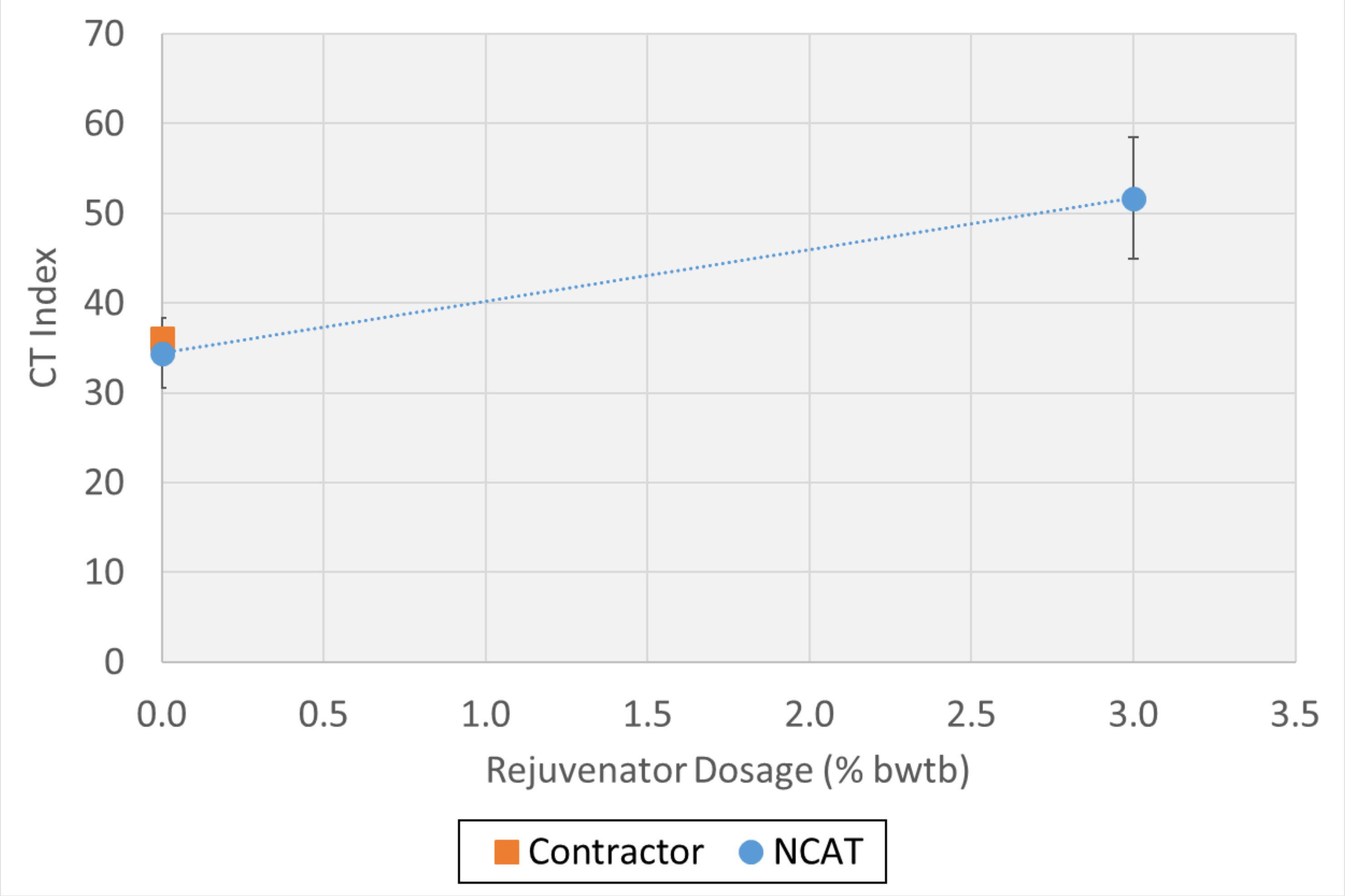
Mix L – IDEAL-CT Optimization

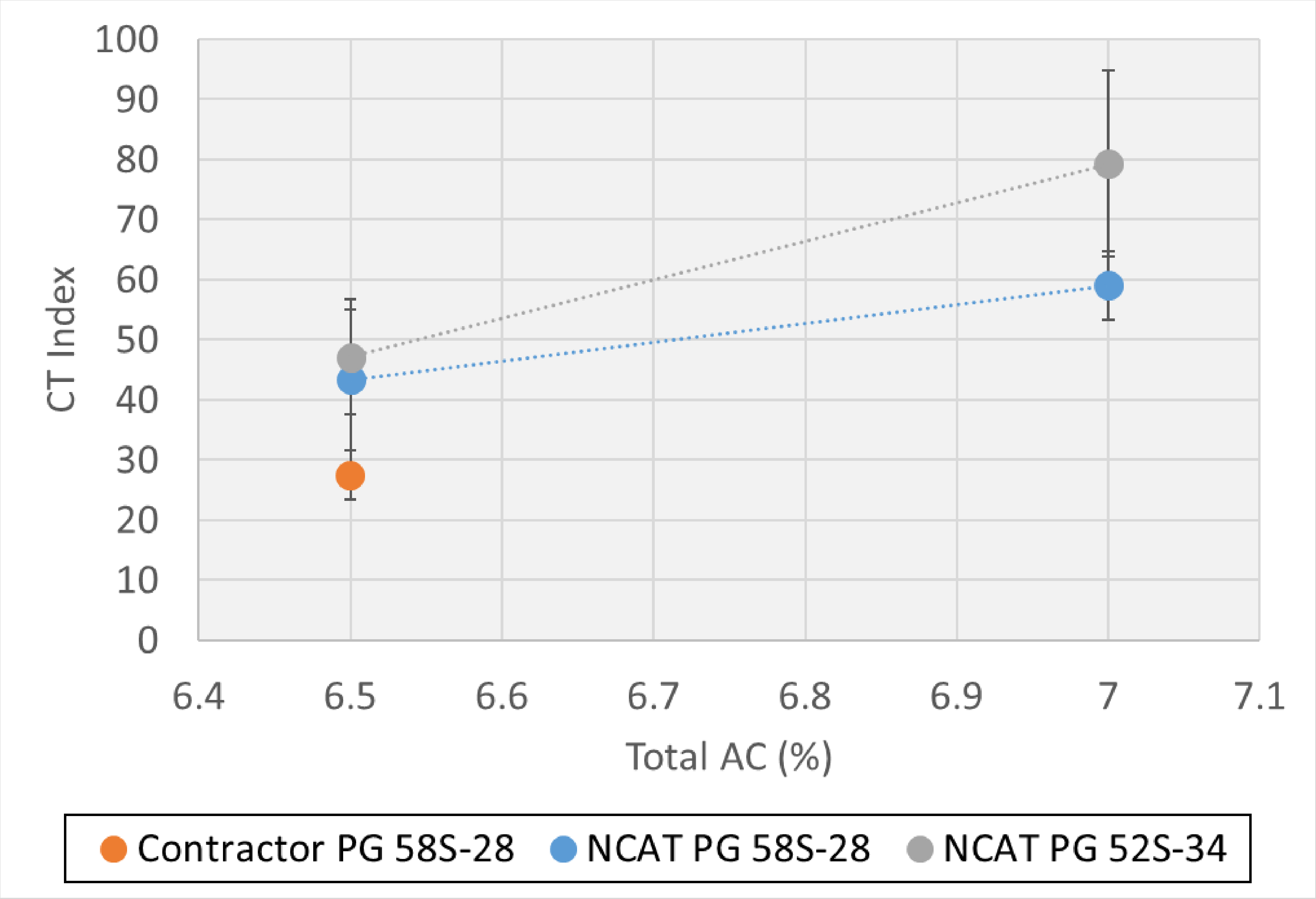
- Critical Test: IDEAL-CT
  - BMD Opt. Rejuvenator Dosage

    $CT_{Index} > 40$
- 1.5% Rejuvenator meets IDEAL-CT criteria
- Modified design met DCT and HWTT criteria



Mix K – IDEAL-CT Optimization

- Critical Test: IDEAL-CT
  - Softer Asphalt
  - More Asphalt
- Regressed Air Voids OAC = 6.5%
- Disconnect with benchmarking result
- Increased OAC for each binder to improve CT_{Index} above baseline
- PG 58S-28 (OAC = 6.8%)
- PG 52S-34 (OAC = 6.6%)



Mix K – HWTT

- PG 58H-34 passed at 6.5% AC (regressed air voids OAC)
  - Higher MSCR grade
  - Met all performance criteria
- PG 52S-34 failed quickly at 6.6% AC
- PG 58S-28 barely failed CRD criteria at 6.8% AC

AC %	Binder Grade	Specimen Origin	HWTT CRD 20k (mm)	HWTT SN (passes)	CT Index	DCT FE (J/m²)
			Max 7.0	Min 2,000	Min. 40	Min. 300
6.5	PG 58S-28	Contractor	4.1	2,253	27.5	310
6.5	PG 58H-34	NCAT	5.1	2,319	43.6	449
6.6	PG 52S-34	NCAT	10.7	1,061	53.4	n/a
6.8	PG 58S-28	NCAT	7.3	2,405	52.9	n/a

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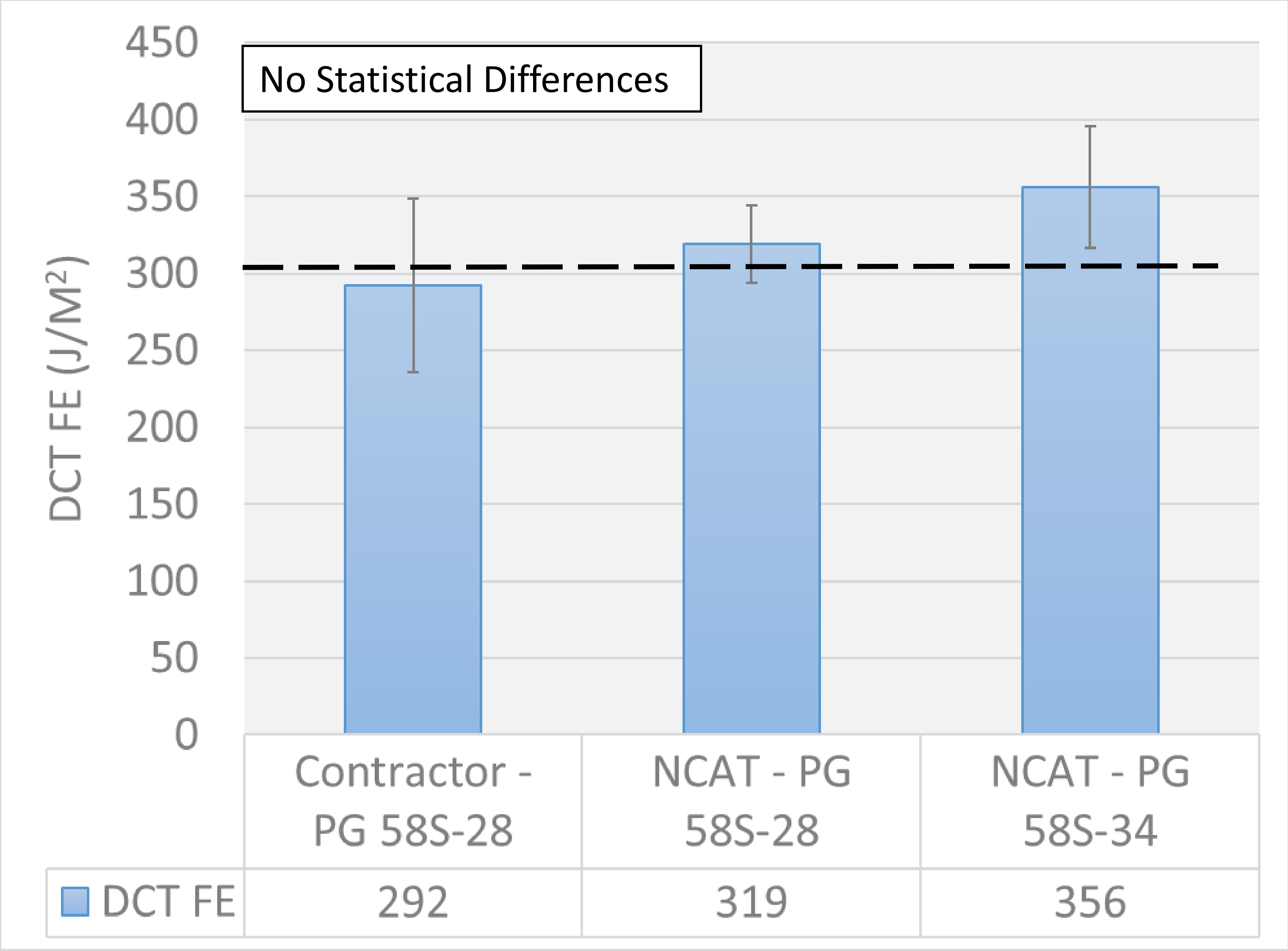
Mix C – DCT Optimization

- Critical Test: DCT
- Optimization strategies
  - Use softer asphalt (low grade)
    - PG 58S-34



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Mix C – HWTT and IDEAL-CT

- HWTT with PG 58S-34 did not pass CRD SN criteria
  - Added 0.5% anti-strip (LAS) by weight of total binder to get a passing result
- Unexpectedly, mix with PG 58S-34 and LAS did not pass recommended CT_{Index} criteria

AC %	Binder Grade	Specimen Origin	Liquid Anti-Strip (% tbw)	HWTT CRD 20k (mm)	HWTT SN (passes)	CT_{Index}
				Max 6.0	Min. 2,000	Min. 40
5.5	PG 58S-28	Contractor	0	3.7	3,579	50.9
5.5	PG 58S-34	NCAT	0	4.2	1,665	n/a
5.5	PG 58S-34	NCAT	0.5	3.9	2,405	32.2

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Mix F - HWTT and IDEAL-CT

- Critical Test: HWTT
- LAS alone was insufficient to improve HB results
- PG 58H-34 did provide passing results
  - LAS gives a small improvement to SN
- CT_{Index} and DCT passed for modified mix

AC %	Binder Grade	Specimen Origin	Liquid Anti-Strip (% tbw)	HWTT CRD 20k (mm)	HWTT SN (passes)	CT_{Index}	DCT FE (J/m^2)
				Max 7.0	*Min. 2,000*	*Min. 40*	*Min. 300*
6.4	PG 52S-34	Contractor	0	7.1	1,573	60.6	337
6.4	PG 52S-34	NCAT	0	10.5	1,317	n/a	n/a
6.4	PG 52S-34	NCAT	0.5	8.5	1,661	n/a	n/a
6.4	PG 58H-34	NCAT	0	6.1	2,189	n/a	n/a
6.4	PG 58H-34	NCAT	0.5	6.5	2,557	63.6	416

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Findings from Task 4

- With respect to performance testing results, different mixes may respond differently to changes to same variables
    - e.g. Different rates of CT_{Index} improvement when AC% is increased the same amount with different binders
- Fixing one problem may create another problem
    - The steps taken to fix a cracking problem may create a rutting problem
    - Hence the ‘Balance’ in BMD
- Be cognizant of between-lab variation in performance testing
    - Particularly specimen fabrication

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Thank you!

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Recommended BMD Criteria

Traffic Level	IDEAL-CT CT_{Index} [1]	DCT Fracture Energy (J/m²)	HWTT	
			CRD_{20k} (mm)	Min. SN
SMA	≥80	≥400	6.0	2,000
High	≥40	≥300		
Med			7.0	

[1] CT_{index} criteria are for specimens compacted after aging loose mixture for 6 hours at 135°C

LT mixtures should be designed by the regressed air voids approach. No BMD criteria.

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