ARC
Asphalt Research Consortium

University of Nevada Reno

Presented by: Elie Y. Hajj, Ph.D.

Updates on ARC Work Element E2d:
Thermal Cracking Testing of Asphalt Mixtures

Asphalt Mixture & Construction Expert Task Group

Wisconsin – Madison

September 20-21, 2010

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ARC Work Element E2d

A. Environmental conditions within intermountain region
B. TSRST – SGC cylindrical specimens
C. TSRST – Cooling Rates Experiment

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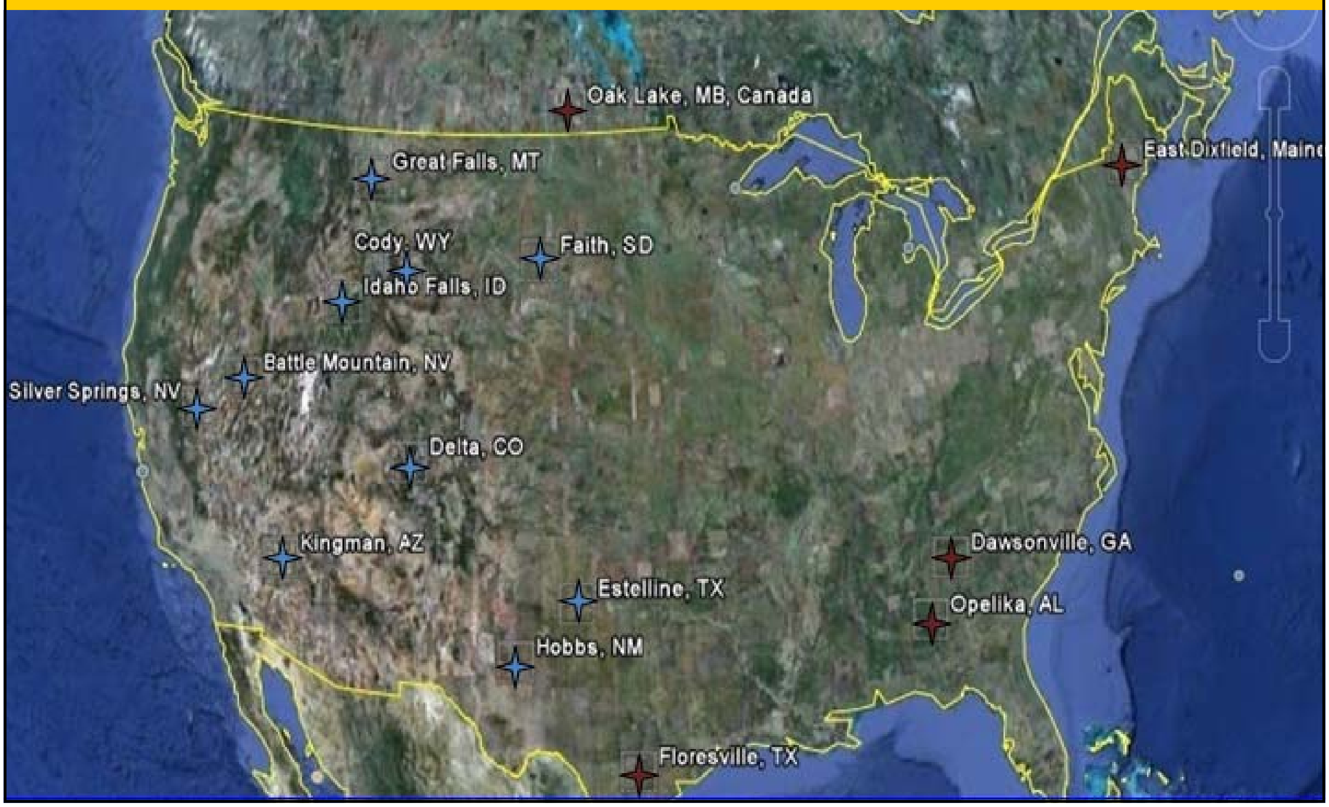
A. Environmental Conditions

- Collect & report actual pavement temperature history & profile throughout the depth of HMA pavements within & outside intermountain region.
  - Identified HMA pavements:
    - LTPP SMP sites in the intermountain region: 10 sections
    - LTPP SMP sites outside the intermountain region: 5 sections
    - WesTrack project (NATC): 3 sections

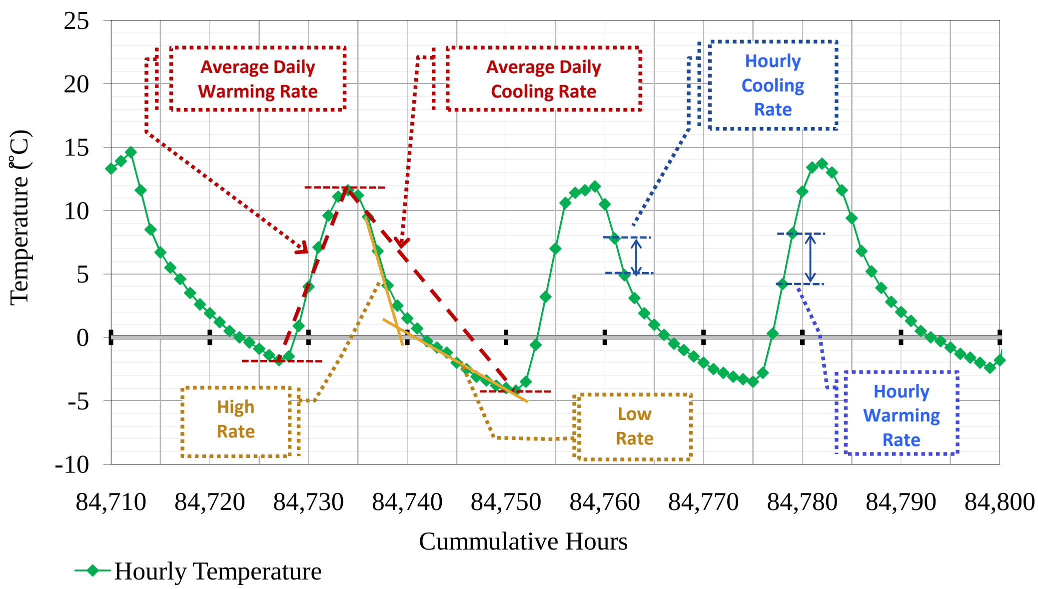
A. Environmental Conditions

Sites Locations



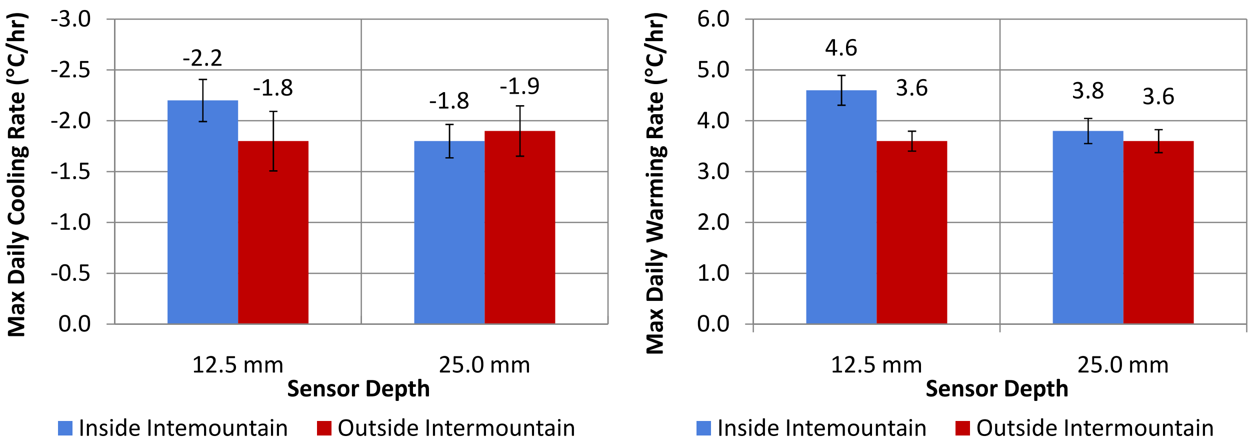
A. Environmental Conditions

Temp. Rates Definitions



A. Environmental Conditions

Summary of Daily Cooling and Warming Rates



(Whiskers represent 95% confidence interval)

A. Environmental Conditions

Hourly Cooling/Warming Rate – Sensor depth = 12.5 mm

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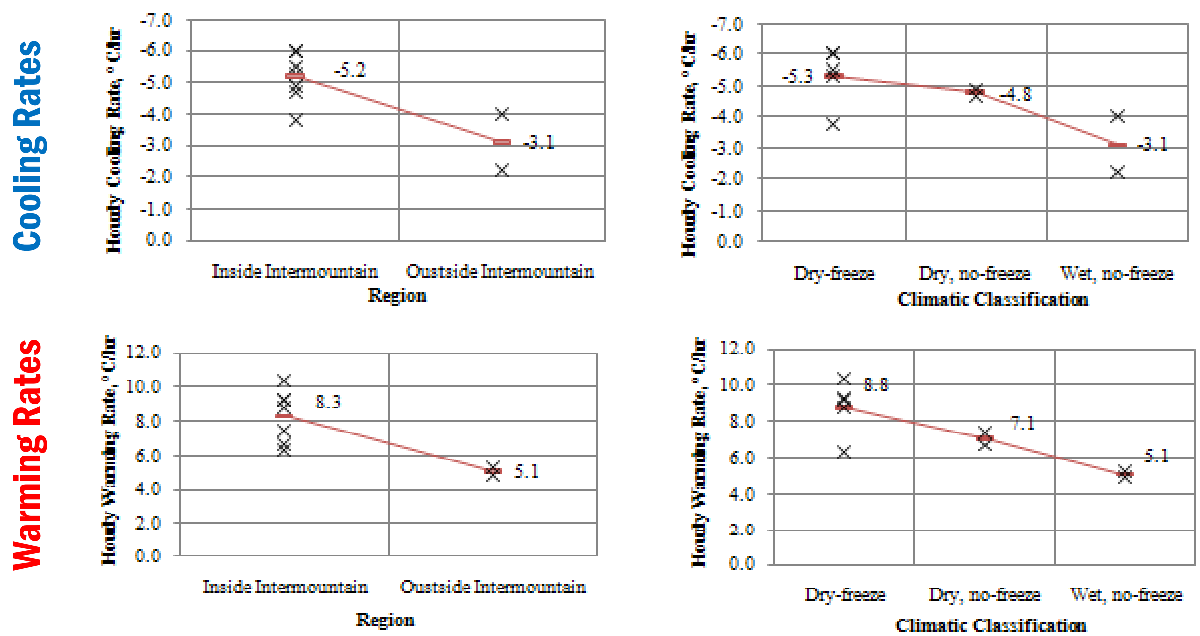

Intermountain: dry-no freeze (2), dry-freeze (5)
Outside: wet-no freeze (2)

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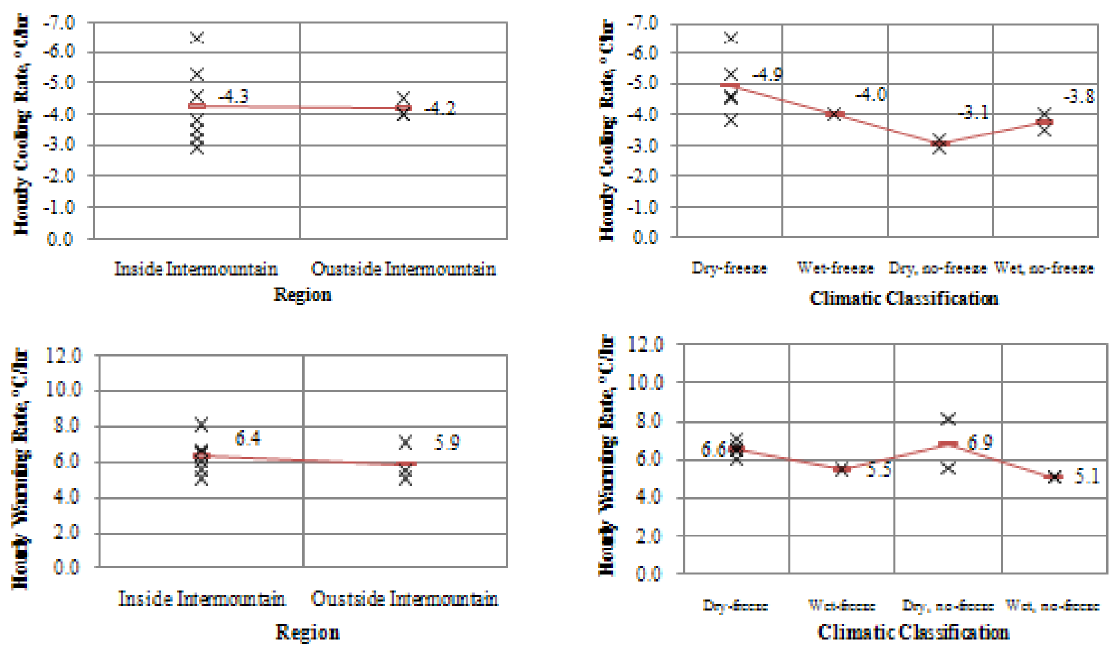
A. Environmental Conditions

Hourly Cooling/Warming Rate – Sensor depth = 25 mm

Cooling Rates

Warming Rates



Intermountain : dry-no freeze (4), dry-freeze (2) wet-no freeze (1)
Outside: wet-no freeze (1), wet-freeze (1), dry-freeze (1)

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A. Environmental Conditions

Binary Cooling Rate

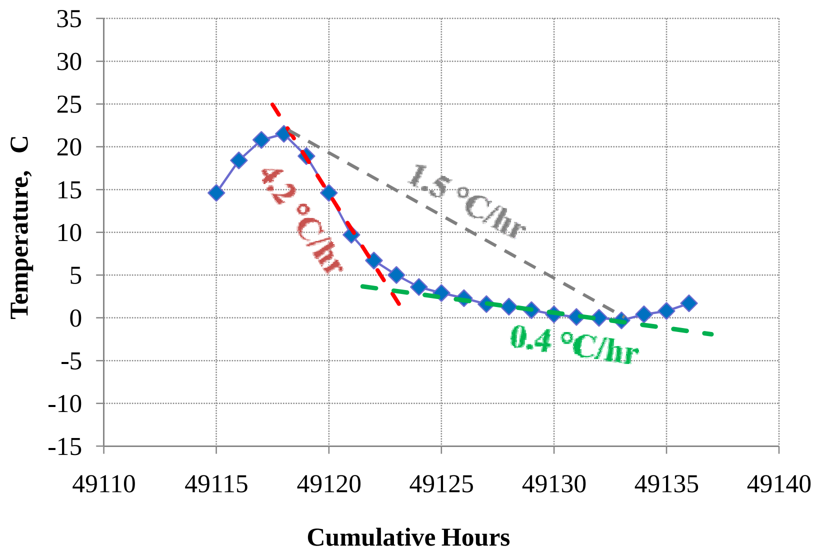
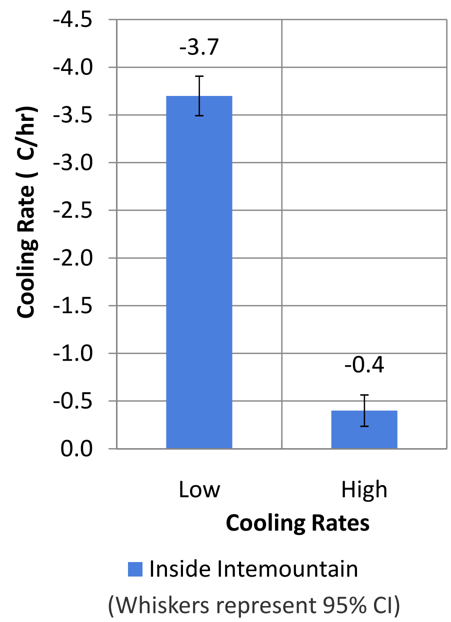


FIGURE. High rate and low rate calculation of the maximum hourly cooling rate for section 040113 (Kingman, AZ) of 4.9°C/hour of pavements temperatures 10°C and colder at a sensor depth of 12.5 mm



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A. Environmental Conditions

Summary of Findings

- Pavement Temp histories:
  - Lower temp. rates at deeper pavement depths (i.e. 12.5 vs. 25.0 mm).
  - At 12.5 mm depth: higher average hourly cooling/warming rates for sections within intermountain region.
  - At 25.0 mm depth: similar cooling/warming rates for sections within & outside intermountain region.

A. Environmental Conditions

Summary of Findings

- Within Intermountain Region:
  - Maximum *DAILY*:
    - cooling rates: 2-3°C/hr range
    - warming rates: 4-5°C/hr range
  - Maximum *HOURLY*:
    - cooling rates: 4-6°C/hr.
    - warming rates: 6-10°C/hr.

A. Environmental Conditions

Summary of Findings

- Pavement Temp histories:
  - Daily cooling periods can typically be divided into two phases:
    - initial period of high cooling rate: ~ 4°C/hr
    - followed by a much lower cooling rate ~ 0.5°C/hr.

B. TSRST – Cylinders vs. Beams

Objective

- **Effect of: Geometry (cylinder vs beam) & Compaction method (SGC vs kneading compactor) on TSRST results**

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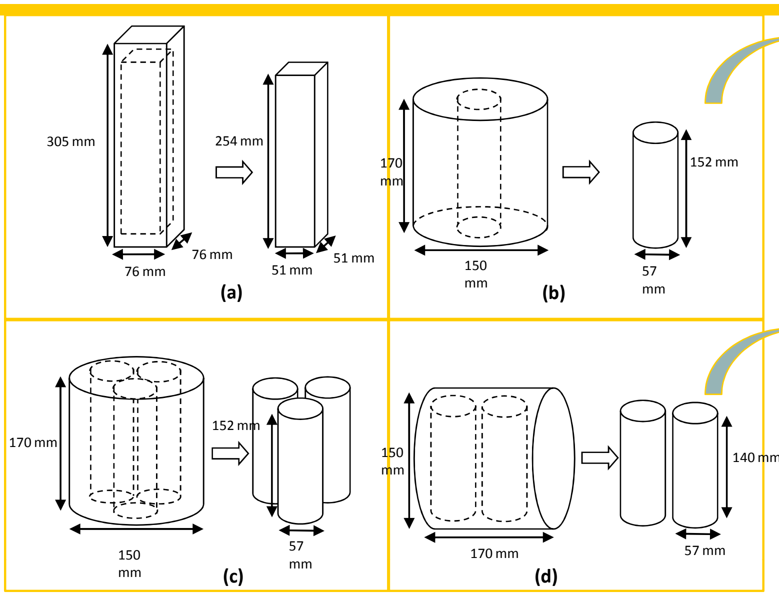
B. TSRST – Cylinders vs. Beams

Specimen Geometries



Different TSRST specimen geometries (a) Beam, (b) 1-in-1 Cylinder (c) 3-in-1 Cylinder, (d) Side Cylinder

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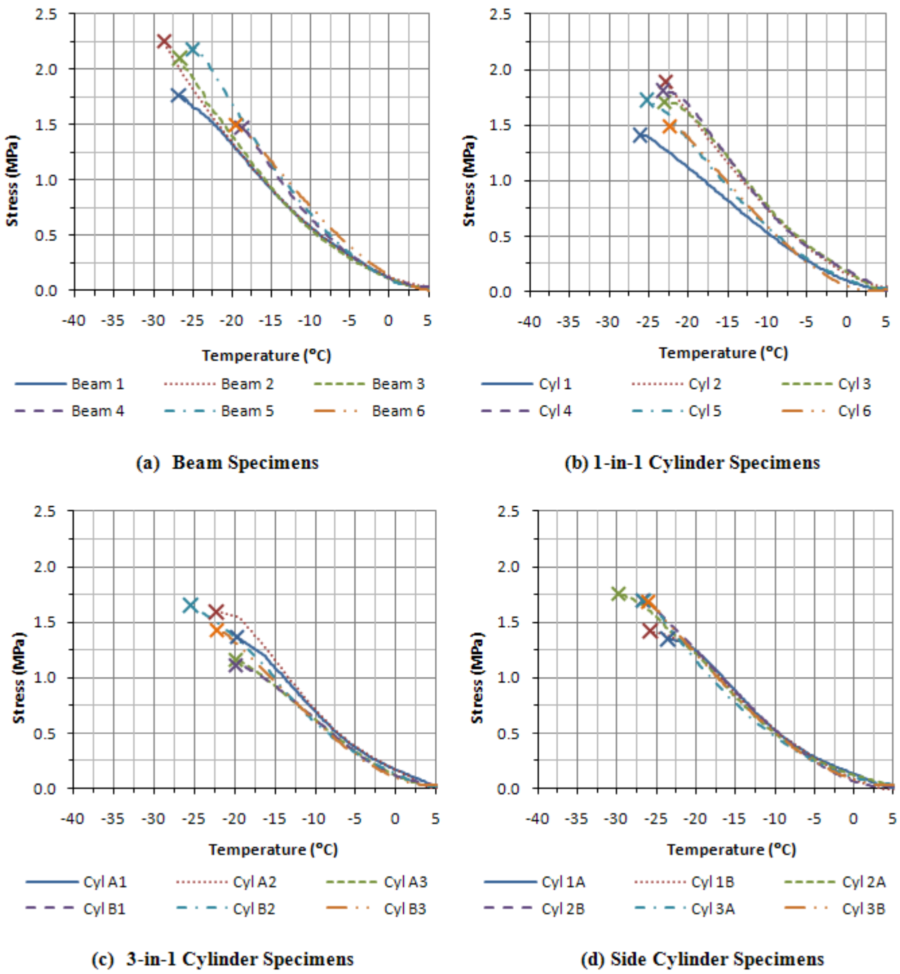
B. TSRST – Cylinders vs. Beams

PG64-22 Mix



(a) Beam Specimens

(b) 1-in-1 Cylinder Specimens

(c) 3-in-1 Cylinder Specimens

(d) Side Cylinder Specimens

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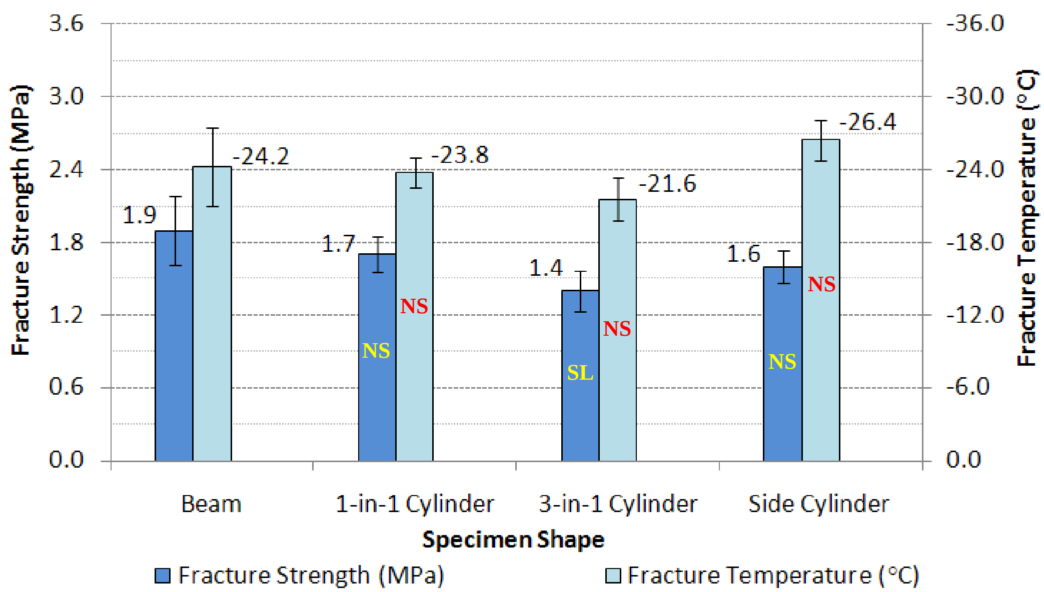
B. TSRST – Cylinders vs. Beams

Results – PG64-22 Mix



(Whiskers represent 95% confidence interval)

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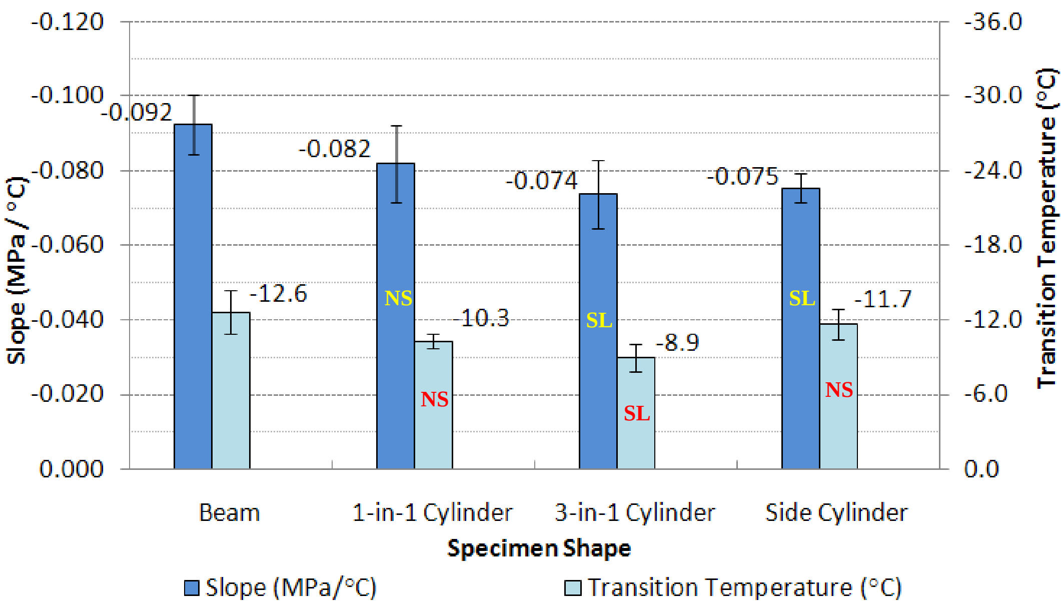
B. TSRST – Cylinders vs. Beams

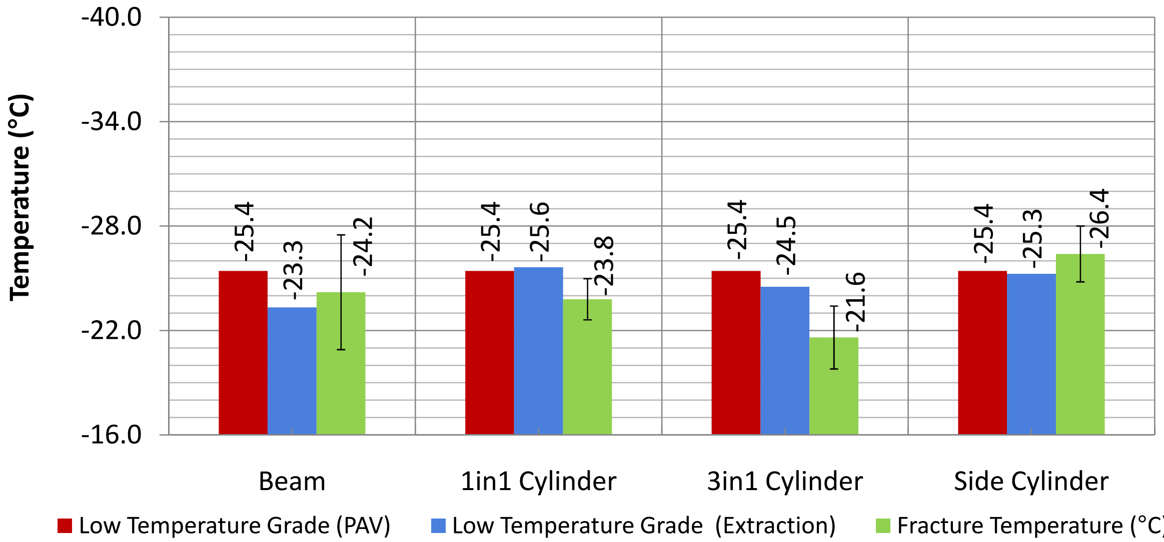
Results – PG64-22 Mix



(Whiskers represent 95% confidence interval)

B. TSRST – Cylinders vs. Beams

Results – Low temp. grade comparison PG64-22 mix



Comparison of TSRST fracture temperatures to asphalt binder low temperature grades for 64-22 mixture (whiskers represent 95% confidence interval)

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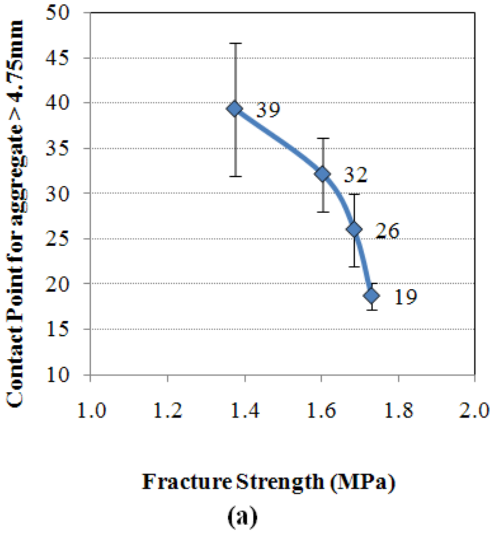
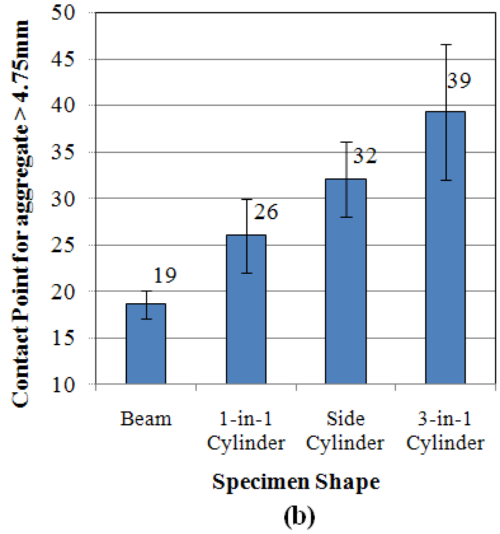
B. TSRST – Cylinders vs. Beams

2D Image Analysis (PG64-22 mix)





2D image analysis (a) fracture strength versus aggregate contact points and (b) aggregate contact points versus specimen type (numbers represent mean values and whiskers represent 95% confidence interval).

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B. TSRST – Cylinders vs. Beams

Summary

- TSRST side cylinders:
  - Cored sideways from SGC samples (perpendicular to compaction direction).
  - Improved repeatability of test results.
  - Can be cored out of field core samples from different lifts within asphalt layer parallel to traffic direction
    - Preserve specimens' orientation to simulate actual thermal loading conditions in the lab by subjecting tensile stresses parallel to traffic direction.

C. TSRST Cooling Rate Experiment

Experimental Plan

- **Effect of Monotonic Cooling Rate:**
  - Standard Cooling Rate: 10°C/hr
  - Average Daily Cooling Rate: 2.5°C/hr
- **Effect of starting test temperature**
  - 5°C vs. 20°C starting temperature
- **Effect of Binary Cooling Rate:** 3.7°C/hr to 0.4°C/hr
- **Effect of Temperature Cycling** *(soon to start)*

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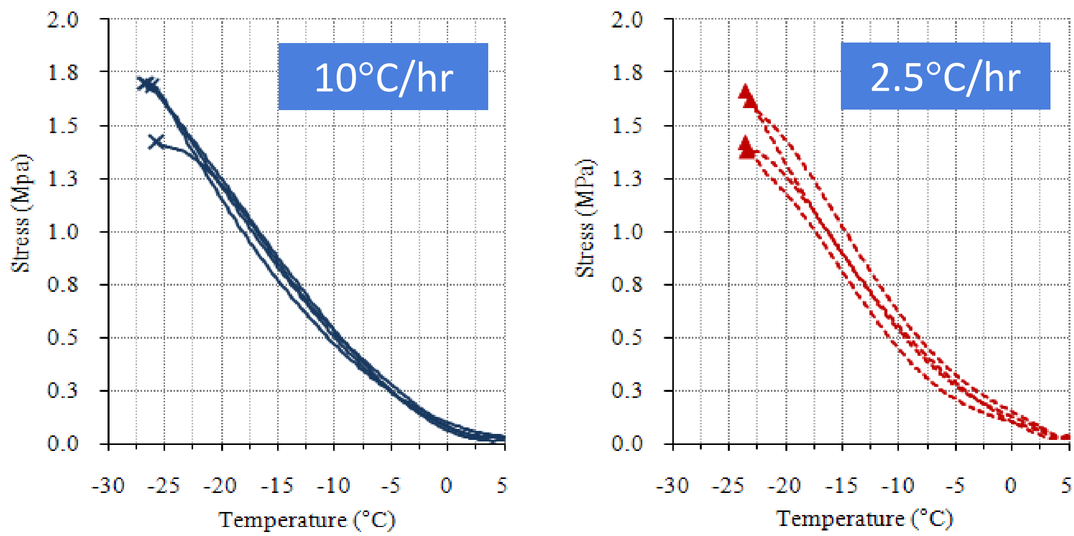
C. TSRST Cooling Rate Experiment

Effect of Monotonic Cooling Rate (Starting Test Temp. = 5° C)



(a) (b)

Only fracture temp. was affected by cooling rate

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C. TSRST Cooling Rate Experiment

Effect of Monotonic Cooling Rate (Starting Test Temp. = 5° C)

TSRST Property		Cooling Rate	
		10°C/hr	2.5°C/hr
Fracture strength (MPa)	Mean	1.627	1.584
	STD*	0.135	0.245
	CV#	8.3	15.4
	95% CI!	0.133	0.240
Fracture temperature (°C)	Mean	-26.3	-23.5
	STD*	0.475	0.360
	CV#	1.8	1.5
	95% CI!	0.466	0.352
Transition temperature (°C)	Mean	-12.0	-11.0
	STD*	1.274	0.866
	CV#	10.6	7.9
	95% CI!	1.248	0.848
Slope of non relaxation period (MPa/°C)	Mean	-0.076	-0.080
	STD*	0.006	0.004
	CV#	7.9	4.6
	95% CI!	0.006	0.004

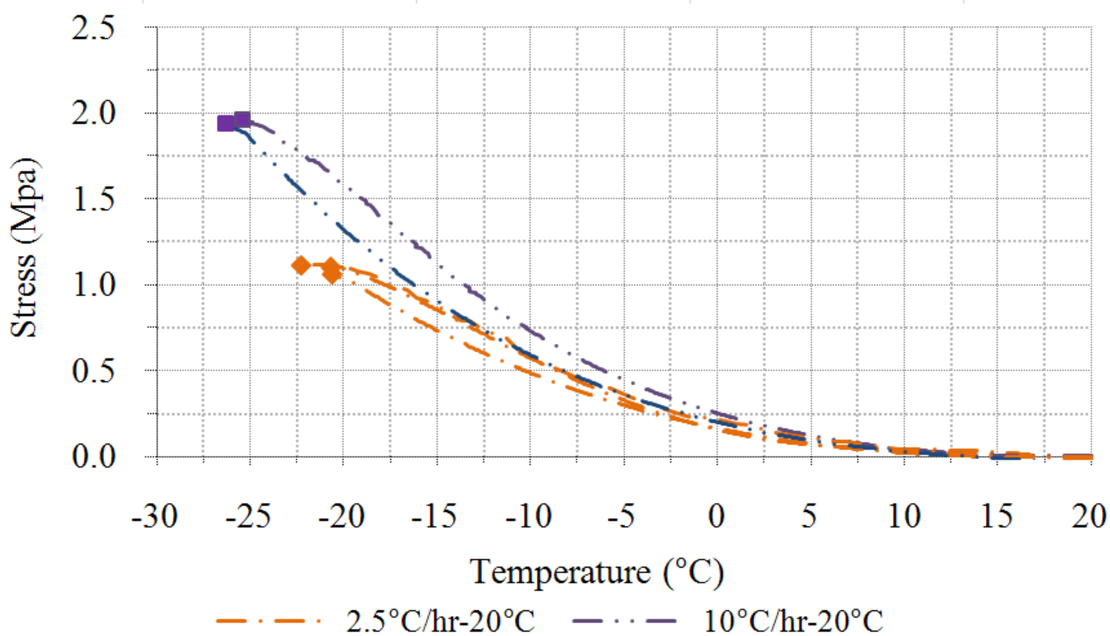
* STD denotes "Standard Deviation"

\# CV denotes "Coefficient of Variation"

! 95% confidence interval

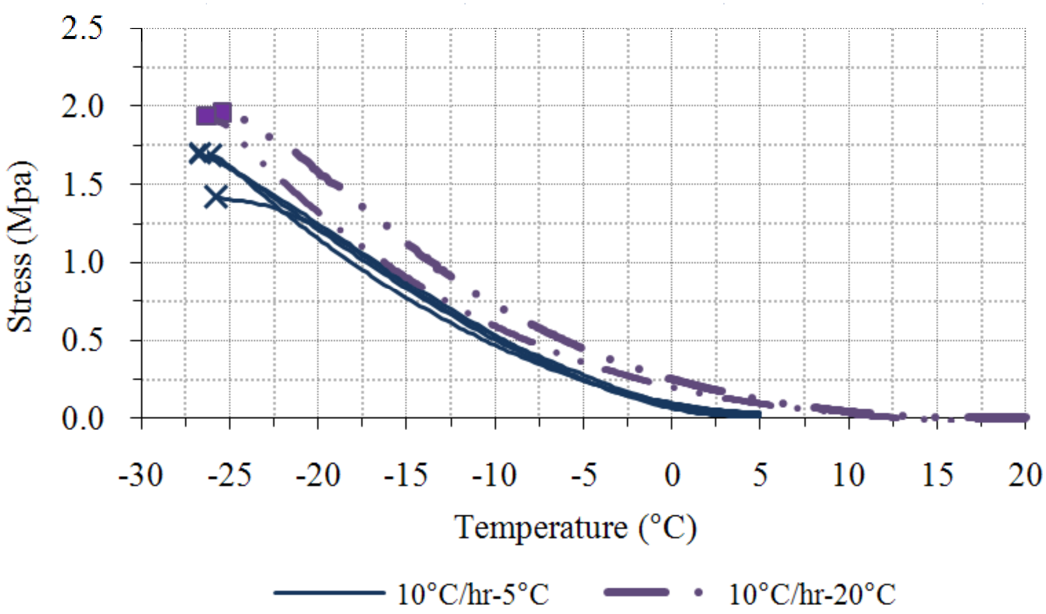
C. TSRST Cooling Rate Experiment

Effect of Starting Test Temperature



C. TSRST Cooling Rate Experiment

Effect of Starting Test Temperature



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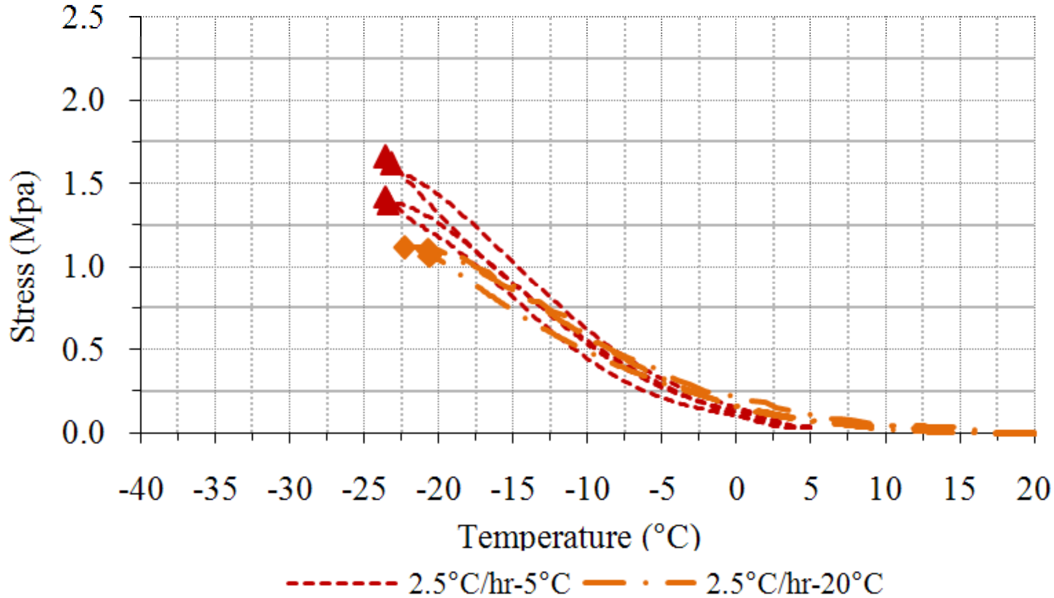
C. TSRST Cooling Rate Experiment

Effect of Starting Test Temperature



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C. TSRST Cooling Rate Experiment

Effect of Starting Test Temperature

Starting Test Temp., °C	Cooling Rate, °C/hr	Fracture Strength, Mpa	Fracture Temperature, °C
5.0	2.5	1.58	-23.5
	10	1.63	-26.3
20.0	2.5	1.10	-20.9
	10	1.94	-25.8

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C. TSRST Cooling Rate Experiment

Effect of Binary Cooling Rate

- Binary Cooling Rate: 3.7°C/hr to 0.4°C/hr
- Field: average cooling period approx. 14 hrs
  - initial high rate avg. approx. 3 hrs
  - secondary low rate approx. 11 hrs
- Test duration approx. 25 hours
  - 6 hours at 3.7°C/hr
  - Remainder at 0.4°C/hr

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C. TSRST Cooling Rate Experiment

Effect of Binary Cooling Rate

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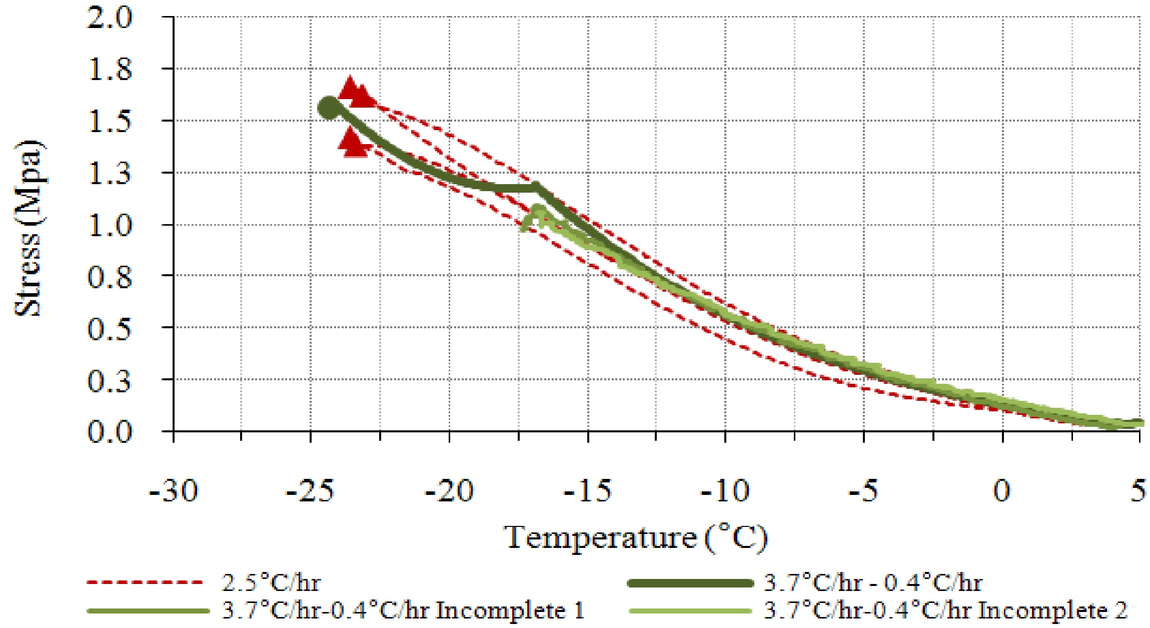

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C. TSRST Cooling Rate Experiment

Preliminary Findings

- TSRST testing: For monotonic cooling rates at a starting test temp of 5°C:
  - Warmer fracture temperature was observed but similar build-up of thermally induced stresses.

- Binary cooling rate showed similar thermally induced stress accumulation behavior for initial rate (at a start temp of 5°C).

C. TSRST Cooling Rate Experiment

Preliminary Findings

- A starting test temp of 5°C was not warm enough to see any difference in the *thermally induced stress-temperature plots* for the various rates.

- Warmer starting test temperature allowed additional thermal stresses to accumulate in specimens subjected to a higher cooling rate.
  - longer relaxation period for specimen during test

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Acknowledgment

– This work is part of the overall effort in the Asphalt Research Consortium (ARC) work element E2d. (www.arc.unr.edu)

– Authors gratefully acknowledge the FHWA support.

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