POOLED FUND STUDY: LOW TEMPERATURE CRACKING

Statistical Analysis Results

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Experimental Plan

Test Device	Temp	Mix Conditioning	MN/Road Test Section				SMA		Mixture	
			33, 34, 35, 37		20, 21, 22		WI		NYS	
			Air Voids, %							
			4	7	4	7	4	7	4	7
SCB	PG	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG+10ºC	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG	5 days@85ºC		xxx		xxx		xxx		xxx
	PG	cores		xxx		xxx		xxx		xxx
DC(T)	PG	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG+10ºC	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG	5 days@85ºC		xxx		xxx		xxx		xxx
	PG	cores		xxx		xxx		xxx		xxx
IDT	PG	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG+10ºC	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PG	5 days@85ºC		xxx		xxx		xxx		xxx
	PG	cores		xxx		xxx		xxx		xxx

Mixes used for the study

Location	Construction date	Binder Grade	Asphalt modifiers	RAP
MnRoad 33	September 2007	PG 58-34	PPA	-
MnRoad 34	September 2007	PG 58-34	SBS+PPA	-
MnRoad 35	September 2007	PG 58-34	SBS	-
MnRoad 77	September 2007	PG 58-34	Elvaloy+PPA	-
MnRoad 20	August 2008	PG 58-28	-	30% Non-Fractioned
MnRoad 21	August 2008	PG 58-28	-	30% Fractioned
MnRoad 22	August 2008	PG 58-34	-	30% Fractioned
Wisconsin 9.5 mm SMA	2008	-	-	-
New York "Typical Mix"	2008	PG 64-22	-	-

Experimental Plan and Analysis

- Methodology
  - Blocked by mix
  - Split plot experimental design
- DCT, SCB and IDT results are compared
- Cores vs. Laboratory vs. Conditioned Samples
- RAP vs. FRAP for PG -28
- No RAP vs. FRAP for PG-34
- Comparison of all mixes and tests via *Wilcoxon Rank Sum Test*

DCT Fracture Energy-
Cores vs. Laboratory vs. Conditioned Samples

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	20	284507.43	14225.4	1.9804
Error	45	323237.63	7183.1	Prob > F
C. Total	65	607745.06		0.0289*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	6	6	66099.01	1.5337	0.1891
Condition	2	2	120919.43	8.4170	0.0008*
Mix*Condition	12	12	89108.64	1.0338	0.4360

LSMeans Differences Tukey HSD

α= 0.050 Q= 2.42362

Level		Least Sq Mean
NONE	A	426.57976
YES	B	357.13119
FIELD	B	323.42857

Levels not connected by same letter are significantly different.

For the DCT test, conditioning plays a roll in the response variable. The “mix” is a blocking factor and the conditioning is the factor of interest. The test temperature was the low performance grade and air voids for these samples were 7%.

Not conditioned, laboratory compacted samples have a higher fracture energy than the field cores and the conditioned samples. There was not a statistical difference between the cores and the lab conditioning.

SCB Stress Intensity Factor-
Cores vs. Laboratory vs. Conditioned Samples

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	6	6	0.06655370	1.7755	0.1289
Conditioning	2	2	0.05811385	4.6510	0.0153*
Mix*Conditioning	12	12	0.16914499	2.2562	0.0270*

LSMeans Differences Student's t

α= 0.050 t= 2.02108

Level		Least Sq Mean
YES	A	0.85452381
Field	B	0.79523810
NONE	B	0.78261905

Level		Least Sq Mean
SCB-35	A	0.86000000
SCB-22	A B	0.84333333
SCB-77	A B C	0.81444444
SCB-21	A B C	0.81166667
SCB-34	A B C	0.81055556
SCB-20	B C	0.77777778
SCB-33	C	0.75777778

Levels not connected by same letter are significantly different.

- Conditioning plays a roll in the Stress intensity factor.
- The “mix” is a blocking factor and the conditioning is the factor of interest. The test temperature was the low performance grade and air voids for these samples were 7%.
- Conditioned, laboratory compacted samples have a higher stress intensity factor than the field cores and the conditioned samples.
- No statistical difference between the cores and the no conditioning.

SCB Fracture Energy-
Cores vs. Laboratory vs. Conditioned Samples

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	6	6	89442.4	1.8764	0.1089
Conditioning	2	2	1188324.6	74.7901	<.0001*
Mix*Conditioning	12	12	212075.7	2.2246	0.0292*

LSMeans Differences Student's t

α= 0.050 t= 2.02108

Level		Least Sq Mean
YES	A	604.66095
NONE	B	539.31214
Field	C	282.43381

Levels not connected by same letter are significantly different.

LSMeans Differences Student's t

α= 0.050 t= 2.02108

Level			Least Sq Mean
SCB-35	A		533.66778
SCB-20	A		507.71778
SCB-77	A		494.39333
SCB-34	A	B	465.41556
SCB-21	A	B	462.97833
SCB-22	A	B	456.18444
SCB-33		B	407.92556

Levels not connected by same letter are significantly different.

- Conditioning plays a roll in the SCB fracture energy.
- The “mix” is a blocking factor and the conditioning is the factor of interest. The test temperature was the low performance grade and air voids for these samples were 7%.
- Conditioned, laboratory compacted samples have a higher stress intensity factor than the field cores and the conditioned samples.
- Conditioned, Field cores and Not Conditioned Samples are statistically different.

IDT Stiffness @60-
Cores vs. Laboratory vs. Conditioned Samples

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	6	6	244.64214	2.1878	0.0632
Conditioning	2	2	185.57591	4.9787	0.0115*
Mix*Conditioning	12	12	142.03834	0.6351	0.8002

LSMeans Differences Student's t

α= 0.050 t= 2.01808

Level		Least Sq Mean
FIELD	A	23.228810
YES	A	22.061905
NONE	B	19.147619

Level				Least Sq Mean
IDT-22	A			23.543667
IDT-77	A			23.385667
IDT-34	A	B		22.948889
IDT-33	A	B	C	22.658444
IDT-35	A	B	C	20.067111
IDT-20		B	C	19.184111
IDT-21			C	18.568222

Levels not connected by same letter are significantly different.

- Conditioning plays a roll in the IDT Stiffness @ 60.
- The “mix” is a blocking factor and the conditioning is the factor of interest. The test temperature was the low performance grade and air voids for these samples were 7%.
- Field Cores and Laboratory conditioned samples have the highest stiffness
- Conditioned and Field cores are statistically different from the not conditioned samples.

IDT Stiffness @ 500

Cores vs. Laboratory vs. Conditioned Samples

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	6	6	348.80138	7.1115	<.0001*
Conditioning	2	2	25.87854	1.5829	0.2174
Mix*Conditioning	12	12	116.58673	1.1885	0.3224

LSMeans Differences Student's t

α= 0.050 t= 2.01808

Level		Least Sq Mean
FIELD	A	18.353333
YES	A	17.100476
NONE	A	16.907619

Levels not connected by same letter are significantly different.

Level				Least Sq Mean
IDT-22	A			21.454778
IDT-34	A	B		19.166556
IDT-77	A	B		18.922111
IDT-33		B	C	17.158444
IDT-35			C D	15.999111
IDT-20			C D	15.330333
IDT-21			D	14.145333

Levels not connected by same letter are significantly different.

- There are no statistical differences for any of the conditioning levels.
- The “mix” is a blocking factor and the conditioning is the factor of interest. The test temperature was the low performance grade and air voids for these samples were 7%.
- None of the mixes are statistically different from all the others.

IDT Strength

Cores vs. Laboratory vs. Conditioned

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Mix	6	6	5.0650285	11.4976	<.0001*
Conditioning	2	2	0.8194401	5.5804	0.0073*
Mix*Conditioning	12	12	4.6616026	5.2909	<.0001*

LSMeans Differences Student's t

α= 0.050 t= 2.02108

Level		Least Sq Mean
YES	A	4.0102381
NONE	A	3.9978571
FIELD	B	3.7594762

Level				Least Sq Mean
IDT-35	A			4.3686667
IDT-22	A	B		4.1346667
IDT-21		B		4.0580000
IDT-20		B	C	3.9757778
IDT-34			C	3.7555556
IDT-77			C	3.7288889
IDT-33			D	3.4361111

Levels not connected by same letter are significantly different.

- Laboratory conditioned samples and not conditioned samples are statistically similar and field cores are statistically different.
- The “mix” is a blocking factor and the conditioning is the factor of interest. The test temperature was the low performance grade and air voids for these samples were 7%.
- Only mix MN Road 33 (PPA modified) was statistically different from all other mixes.

Split Plot Design and Analysis

- Response: Test data from the following tests- DCT, SCB and IDT
- Conditions:
  - Factor 1: Air Voids, 4% and 7% (Whole plot/between Mixes)
  - Factor 2: Test Temperature, PG and PG+10 (Sub plot/within mixes)

Each Mix has these variables:

4% Air Voids	7% Air Voids
Tested at PG and PG+10	Tested at PG and PG+10

Location	Construction date	Binder Grade	Asphalt modifiers	RAP
MnRoad 33	September 2007	PG 58-34	PPA	-
MnRoad 34	September 2007	PG 58-34	SBS+PPA	-
MnRoad 35	September 2007	PG 58-34	SBS	-
MnRoad 77	September 2007	PG 58-34	Elvaloy+PPA	-
MnRoad 20	August 2008	PG 58-28	-	30% Non-Fractioned
MnRoad 21	August 2008	PG 58-28	-	30% Fractioned
MnRoad 22	August 2008	PG 58-34	-	30% Fractioned

DCT Fracture Energy:
Analysis for Air Voids and Temperature

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	3473.45	3473.45	1	0.2056	0.6577
Mix[Air Voids]&Random	210011	17500.9	12	2.0056	0.0335*
Relative Temp	504560	504560	1	57.8220	<.0001*
Relative Temp*Air Voids	1208.39	1208.39	1	0.1385	0.7107

"Mix[Air Voids] & Random" represents differences among mixes that are treated the same.

LSMeans Differences Student's t

α 0.050 1.98861

Level		Least Sq Mean
PG+10,4	A	588.75814
PG+10,7	A	569.42921
PG,4	B	439.17045
PG,7	B	433.79951

Levels not connected by same letter are significantly

Multiple comparison tests showed that the air voids for these mixes were not statistically different in the DCT test results. The temperature made the greatest difference. No mix was statistically different from all other mixes.

SCB- Stress Intensity Factor:
Analysis for Air Voids and Temperature

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	0.52525	0.52525	1	30.4497	<.0001*
Mix[Air Voids]&Random	0.23207	0.01934	12	2.0050	0.0300*
Relative Temp	0.08174	0.08174	1	8.4738	0.0043*
Relative Temp*Air Voids	0.01325	0.01325	1	1.3732	0.2437

LSMeans Differences Student's t

α= 0.050 t= 2.12567

Level		Least Sq Mean
4	A	0.93349994
7	B	0.78843776

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG	A	0.88935533
PG+10	B	0.83258237

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
PG,4	A		0.97331384
PG+10,4		B	0.89368605
PG,7		C	0.80539683
PG+10,7		C	0.77147870

Levels not connected by same letter are significantly different.

- 4% Air Voids and PG have higher Stress Intensity Factors.
- The 4% air voids are statistically different at PG and PG+10
- 7% air voids are not statistically different at PG and PG+10, in this instance.

SCB Fracture Energy:
Analysis for Air voids and Temperature

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	650939	650939	1	14.1314	0.0014*
Mix[Air Voids]&Random	555727	46310.5	12	1.0266	0.4299
Relative Temp	1305190	1305190	1	28.9334	<.0001*
Relative Temp*Air Voids	162065	162065	1	3.5927	0.0607

LSMeans Differences Student's t

α= 0.050 t= 1.98177

Level				Least Sq Mean
PG+10,4	A			859.54639
PG+10,7	A	B		777.79582
PG,4		B		712.40354
PG,7			C	470.52929

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
4	A		785.97497
7		B	624.16256

Level			Least Sq Mean
PG+10	A		818.67111
PG		B	591.46642

- Air voids and Temperature show statistical differences in the SCB fracture energy.
- The combination of the temperature PG and 7% air voids is statistically different than all other tests.

IDT Stiffness @60

Analysis for Air Voids and Temperature

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	39.9421	39.9421	1	1.2692	0.2773
Mix[Air Voids]&Random	426.42	35.535	12	2.1368	0.0201*
Relative Temp	1808.47	1808.47	1	108.7457	<.0001*
Relative Temp*Air Voids	0.0228	0.0228	1	0.0014	0.9705

LSMeans Differences Student's t

α= 0.050 t= 1.98217

Level		Least Sq Mean
PG	A	22.104960
PG+10	B	13.480902

Level		Least Sq Mean
4	A	18.433759
7	A	17.152103

Level		Least Sq Mean
PG,4	A	22.730476
PG,7	A	21.479444
PG+10,4	B	14.137042
PG+10,7	B	12.824762

Levels not connected by same letter are significantly different.

- Air voids and Temperature show statistical differences in the IDT Stiffness @60.
- The Student's t-test of the temperature-air void combinations show that temperature has more of an impact, in this case.

IDT Stiffness @500

Analysis for Air Voids and Temperature

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	39.9421	39.9421	1	1.2692	0.2773
Mix[Air Voids]&Random	426.42	35.535	12	2.1368	0.0201*
Relative Temp	1808.47	1808.47	1	108.7457	<.0001*
Relative Temp*Air Voids	0.0228	0.0228	1	0.0014	0.9705

LSMeans Differences Student's t

α= 0.050 t= 2.12845

Level		Least Sq Mean
4	A	18.433759
7	A	17.152103

Level		Sq Mean
PG	A	22.104960
PG+10	B	13.480902

Level		Least Sq Mean
PG,4	A	22.730476
PG,7	A	21.479444
PG+10,4	B	14.137042
PG+10,7	B	12.824762

Levels not connected by same letter are significantly different.

- Only Temperature shows a statistical difference in the IDT Stiffness @500.
- The Student's t-test of the temperature-air void combinations show that temperature has more of an impact, in this case.

IDT Strength [MPa]:
Analysis for Air Voids and Temperature

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	22.2946	22.2946	1	25.8918	0.0002*
Mix[Air Voids]&Random	12.0443	1.00369	12	6.9013	<.0001*
Relative Temp	2.18063	2.18063	1	14.9938	0.0002*
Relative Temp*Air Voids	0.00115	0.00115	1	0.0079	0.9294

LSMeans Differences Student's t

α= 0.050 t= 1.98304

Level				Least Sq Mean
PG+10,4	A			5.1834821
PG,4		B		4.8761905
PG+10,7			C	4.2279262
PG,7			D	3.9344129

Level			Least Sq Mean
4	A		5.0298363
7		B	4.0811696

Level			Least Sq Mean
PG+10	A		4.7057042
PG		B	4.4053017

- Air Voids and Temperature show a statistical difference in the IDT Strength Values.
- The Student's t-test of the temperature-air void combinations show that temperature has more of an impact in this case.

DCT Fracture Energy: RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	779.138	779.138	1	0.0460	0.8500
RAP[Air Voids]&Random	33850.4	16925.2	2	1.8836	0.1696
Relative Temp	123705	123705	1	13.7674	0.0008*
Relative Temp*Air Voids	83.1136	83.1136	1	0.0092	0.9240

- Temperature shows a statistical difference in the DCT Fracture, air voids do not.
- The Student's t-test of the FRAP/RAP-air void combinations show that the fractionated and non fractionated RAP are not statistically different.

LSMeans Differences Student's t

α= 0.050 t= 2.04227

Level		Least Sq Mean
PG+10,7	A	535.29750
PG+10,4	A	528.46764
PG,7	B	421.09750
PG,4	B	408.18986

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG+10	A	531.88257
PG	B	414.64368

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
7	A	478.19750
4	A	468.32875

Levels not connected by same letter are significantly different.

Level		Sq Mean
[4]30% Fractioned	A	513.25917
[7]30% Non-Fractioned	A	488.04167
[7]30% Fractioned	A	468.35333
[4]30% Non-Fractioned	A	423.39833

Levels not connected by same letter are significantly different.

SCB- Stress Intensity Factor: RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	0.17203	0.17203	1	12.6858	0.0703
RAP[Air Voids]&Random	0.02718	0.01359	2	2.4037	0.1243
Relative Temp	0.03067	0.03067	1	5.4248	0.0342*
Relative Temp*Air Voids	0.0009	0.0009	1	0.1588	0.6959

- Temperature shows a statistical difference in the SCB K_{ic}, air voids do not.
- The Student's t-test of the FRAP/RAP-air void combinations show that the fractionated and non fractionated RAP are not statistically different in their respective air void category.

LSMeans Differences Student's t

α= 0.050 t= 2.13145

Level		Least Sq Mean
PG	A	0.88560185
PG+10	B	0.80875000

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
4	A	0.93916667
7	A	0.75518519

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
[4]30% Non-Fractioned	A		0.99000000
[4]30% Fractioned	A		0.88833333
[7]30% Non-Fractioned		B	0.77000000
[7]30% Fractioned		B	0.74037037

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
PG,4	A		0.98416667
PG+10,4	A		0.89416667
PG,7		B	0.78703704
PG+10,7		B	0.72333333

Levels not connected by same letter are significantly different.

SCB Fracture Energy: RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	35813.1	35813.1	1	1.3701	0.3617
RAP[Air Voids]&Random	52271.2	26135.6	2	0.9712	0.4012
Relative Temp	81464.6	81464.6	1	3.0271	0.1024
Relative Temp*Air Voids	932.934	932.934	1	0.0347	0.8548

- Fracture energy does not indicate any statistical differences in this instance.

LSMeans Differences Student's t

α= 0.050 t= 4.27347

Level		Least Sq Mean
4	A	777.52208
7	A	693.57833

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG+10	A	798.17904
PG	A	672.92138

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
[4]30% Non-Fractioned	A	847.35750
[7]30% Fractioned	A	716.04667
[4]30% Fractioned	A	707.68667
[7]30% Non-Fractioned	A	671.11000

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG+10,4	A	846.85308
PG+10,7	A	749.50500
PG,4	A	708.19108
PG,7	A	637.65167

Levels not connected by same letter are significantly different.

IDT Stiffness@60: RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	30.8051	30.8051	1	204.4146	0.0016*
RAP[Air Voids]&Random	0.2656	0.1328	2	0.0201	0.9801
Relative Temp	255.192	255.192	1	38.6968	<.0001*
Relative Temp*Air Voids	2.11766	2.11766	1	0.3211	0.5783

- Fractionated and non-fractionated rap show no statistical difference.
- Air voids are statistically different but temperature has the greatest impact.

LSMeans Differences Student's t

α= 0.050 t= 3.49284

Level		Least Sq Mean
4	A	16.829630
7	B	14.501667

Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error	Mean
PG	19.015833	0.74131976	19.0158
PG+10	12.315463	0.78141964	12.2491

Level		Least Sq Mean
[4]30% Fractioned	A	16.958333
[4]30% Non-Fractioned	A	16.700926
[7]30% Non-Fractioned	A	14.586667
[7]30% Fractioned	A	14.416667

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG,4	A	20.485000
PG,7	A	17.546667
PG+10,4	B	13.174259
PG+10,7	B	11.456667

Levels not connected by same letter are significantly different.

IDT Stiffness@500: RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	52.3522	52.3522	1	11.2909	0.0773
RAP[Air Voids]&Random	9.25637	4.62819	2	0.6021	0.5589
Relative Temp	251.888	251.888	1	32.7688	<.0001*
Relative Temp*Air Voids	1.05192	1.05192	1	0.1368	0.7160

- Fractionated and non-fractionated rap show no statistical difference.
- Air voids are statistically different at the PG test temperature but temperature has the greatest impact.

LSMeans Differences Student's t

α= 0.050 t= 2.10982

Level		Least Sq Mean
[4]30% Fractioned	A	14.151667
[4]30% Non-Fractioned	A B	12.971296
[7]30% Non-Fractioned	A B	11.203333
[7]30% Fractioned	B	9.850000

Levels not connected by same letter are significantly different.

Level		Sq Mean
PG	A	15.372500
PG+10	B	8.715648

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG,4	A	17.105000
PG,7	B	13.640000
PG+10,4	C	10.017963
PG+10,7	C	7.413333

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
4	A	13.561481
7	A	10.526667

Levels not connected by same letter are significantly different.

IDT Strength [MPa]: RAP vs. FRAP

Compares mixes MN 20 and 21 Each are PG-28

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	2.95419	2.95419	1	31.0402	0.0294*
RAP[Air Voids]&Random	0.19282	0.09641	2	2.3090	0.1336
Relative Temp	0.66751	0.66751	1	15.9870	0.0012*
Relative Temp*Air Voids	0.08274	0.08274	1	1.9816	0.1796

- Fractionated and non-fractionated rap show no statistical difference within the air void categories.
- Air voids and temperature are statistically different.

LSMeans Differences Student's t

α= 0.050 t= 2.13145

Level		Least Sq Mean
PG+10	A	4.9400000
PG	B	4.5775926

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
4	A	5.1400000
7	B	4.3775926

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
[4]30% Non-Fractioned	A		5.2030000
[4]30% Fractioned	A		5.0770000
[7]30% Fractioned		B	4.4966667
[7]30% Non-Fractioned		B	4.2585185

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
PG+10,4	A		5.3850000
PG,4		B	4.8950000
PG+10,7		C	4.4950000
PG,7		C	4.2601852

Levels not connected by same letter are significantly different.

DCT Fracture Energy: No RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	6730.6	6730.6	1	0.3868	0.5507
Asphalt Modifiers & FRAP[Air Voids]&Random	141756	17719.5	8	2.0295	0.0608
Relative Temp	389968	389968	1	44.6647	<.0001*
Relative Temp*Air Voids	1769.35	1769.35	1	0.2027	0.6545

- No mix is statistically different from all other mixes. The trend shows SBS mixes having the highest average DCT fracture energy.
- The test temperatures are statistically different.

LSMeans Differences Student's t

α= 0.050 t= 2.00665

Level			Least Sq Mean
PG+10,4	A		615.80533
PG+10,7	A		584.11643
PG,4		B	447.89894
PG,7		B	437.40241

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
4	A	531.85214
7	A	510.75942

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG+10	A	599.96088
PG	B	442.65068

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
[4]SBS PPA	A		593.70833
[4]SBS	A		589.08333
[7]SBS PPA	A	B	573.54833
[7]SBS	A	B	560.18833
[4]Elvaloy PPA	A	B	506.40500
[4]PPA	A	B	499.53736
[7]30% Fractioned		B	479.94750
[7]Elvaloy PPA		B	472.51460
[4]30% Fractioned		B	470.52667
[7]PPA		B	467.59833

Levels not connected by same letter are significantly different.

SCB Fracture Energy: No RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	309786	309786	1	5.0657	0.0534
Asphalt Modifiers[Air Voids]&Random	490102	61262.8	8	1.1042	0.3757
Relative Temp	772823	772823	1	13.9299	0.0005*
Relative Temp*Air Voids	82699.7	82699.7	1	1.4906	0.2276

- No mix is statistically different from all other mixes.
- The test temperatures are statistically different.

LSMeans Differences Student's t

α= 0.050 t= 2.29245

Level		Least Sq Mean
4	A	789.23017
7	A	647.85625

Level		Least Sq Mean
PG+10	A	829.96179
PG	B	607.12463

Levels not connected by same letter are significantly different.

Level				Least Sq Mean
[4]SBS PPA	A			959.45833
[4]Elvaloy PPA	A	B		902.13982
[4]PPA	A	B	C	718.67500
[7]Elvaloy PPA	A	B	C	712.58000
[7]SBS PPA		B	C	683.72500
[4]30% Fractioned		B	C	683.70167
[4]SBS		B	C	682.17602
[7]30% Fractioned		B	C	643.86167
[7]SBS			C	619.51125
[7]PPA			C	579.60333

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
PG+10,4	A		864.20108
PG+10,7	A		795.72250
PG,4	A		714.25926
PG,7		B	499.99000

Levels not connected by same letter are significantly different.

SCB Stress Intensity Factor: No RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	0.33844	0.33844	1	18.5618	0.0025*
Asphalt Modifiers[Air Voids]&Random	0.14721	0.0184	8	1.9394	0.0735
Relative Temp	0.02031	0.02031	1	2.1404	0.1495
Relative Temp*Air Voids	0.025	0.025	1	2.6351	0.1106

- No mix is statistically different from all other mixes. The trend shows SBS mixes having the highest average stress intensity factor.
- The air voids are statistically different. Temperature has the most influence at 4% air voids.

LSMeans Differences Student's t

α= 0.050 t= 2.00665

Level					Least Sq Mean
[4]SBS	A				0.98577558
[4]SBS PPA	A				0.98333333
[4]30% Fractioned	A	B			0.92666667
[4]PPA	A	B	C		0.88000000
[4]Elvaloy PPA	A	B	C		0.87962046
[7]SBS		B	C		0.86156250
[7]SBS PPA			C	D	0.80000000
[7]30% Fractioned			C	D	0.77666667
[7]Elvaloy PPA				D	0.75000000
[7]PPA				D	0.72833333

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
4	A		0.93107921
7		B	0.78331250

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
PG	A		0.87525743
PG+10	A		0.83913428

Levels not connected by same letter are significantly different.

Level				Least Sq Mean
PG,4	A			0.96918152
PG+10,4		B		0.89297690
PG+10,7			C	0.78529167
PG,7			C	0.78133333

Levels not connected by same letter are significantly different.

IDT Stiffness @60: No RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	92.6795	92.6795	1	5.1380	0.0529
Asphalt Modifiers[Air Voids]&Random	144.159	18.0198	8	0.7189	0.6738
Relative Temp	881.463	881.463	1	35.1641	<.0001*
Relative Temp*Air Voids	25.9616	25.9616	1	1.0357	0.3140

- No mix is statistically different from all other mixes. The trend shows fractionated RAP having the highest stiffness.
- The test temperatures are statistically different.
- Temperature/air void combinations show that at low temperatures, the air voids play a larger role in stiffness values

LSMeans Differences Student's t

α= 0.050 t= 2.30312

Level		Least Sq Mean
4	A	19.091444
7	A	16.580000

Level		Least Sq Mean
PG	A	21.708333
PG+10	B	13.963111

Levels not connected by same letter are significantly different.

Level			Least Sq Mean
[4]30% Fractioned	A		21.440556
[4]SBS	A	B	20.793333
[7]30% Fractioned	A	B	18.943333
[4]SBS PPA	A	B	18.358333
[4]PPA	A	B	17.565000
[7]SBS PPA	A	B	17.548333
[4]Elvaloy PPA	A	B	17.300000
[7]Elvaloy PPA	A	B	15.895000
[7]SBS	A	B	15.370000
[7]PPA		B	15.143333

Levels not connected by same letter are significantly different.

Level				Least Sq Mean
PG,4	A			23.628667
PG,7		B		19.788000
PG+10,4			C	14.554222
PG+10,7			C	13.372000

Levels not connected by same letter are significantly different.

IDT Stiffness @500: No RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	37.1612	37.1612	1	1.3578	0.2774
Asphalt Modifiers[Air Voids]&Random	219.322	27.4153	8	2.9175	0.0100*
Relative Temp	1364.28	1364.28	1	145.1874	<.0001*
Relative Temp*Air Voids	1.20505	1.20505	1	0.1282	0.7219

- No mix is statistically different from all other mixes. The trend shows 30% Fractionated RAP having the highest stiffness.
- The test temperatures are statistically different. In the temperature/air void combinations, the two temperatures are statistically different regardless of air voids.

LSMeans Differences Student's t

α= 0.050 t= 2.30529

Level		Least Sq Mean
4	A	15.130292
7	A	13.540000

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG	A	19.153000
PG+10	B	9.517292

Levels not connected by same letter are significantly different.

Level				Least Sq Mean
[7]30% Fractioned	A			18.225000
[4]30% Fractioned	A	B		16.319792
[4]SBS	A	B		15.856667
[4]Elvaloy PPA	A	B	C	15.256667
[4]SBS PPA	A	B	C	14.936667
[7]SBS PPA		B	C D	13.381667
[4]PPA		B	C D	13.281667
[7]Elvaloy PPA		B	C D	13.158333
[7]SBS			C D	12.051667
[7]PPA			D	10.883333

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG,4	A	20.091333
PG,7	A	18.214667
PG+10,4	B	10.169250
PG+10,7	B	8.865333

Levels not connected by same letter are significantly different.

IDT Strength [MPa]: No RAP vs. FRAP

Tests wrt Random Effects

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Air Voids	11.3653	11.3653	1	8.5302	0.0193*
Asphalt Modifiers[Air Voids]&Random	10.702	1.33775	8	10.8367	<.0001*
Relative Temp	1.71051	1.71051	1	13.8563	0.0005*
Relative Temp*Air Voids	0.13904	0.13904	1	1.1263	0.2941

- 7% PPA, 7% Elvaloy, PPA and 7% SBS PPA are statistically different from all other mixes. SBS and Fractionated RAP at 4% air voids have the highest strength values.
- The test temperatures and air voids are statistically different. In the temperature/air void combinations, 7% air voids is more sensitive to the test temperature.

LSMeans Differences Student's t

α= 0.050 t= 2.30567

Level		Least Sq Mean
4	A	4.9918611
7	B	4.1034583

Levels not connected by same letter are significantly different.

Level		Least Sq Mean
PG+10	A	4.7199861
PG	B	4.3753333

Levels not connected by same letter are significantly different.

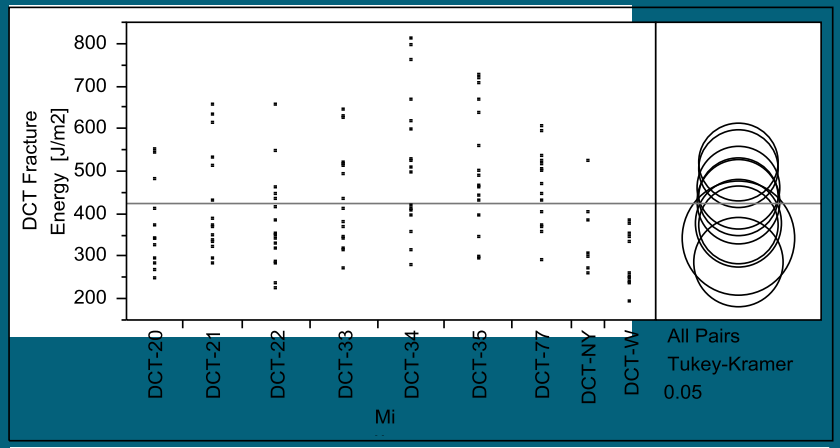
Level			Least Sq Mean
PG+10,4	A		5.1150556
PG,4	A		4.8686667
PG+10,7		B	4.3249167
PG,7		C	3.8820000

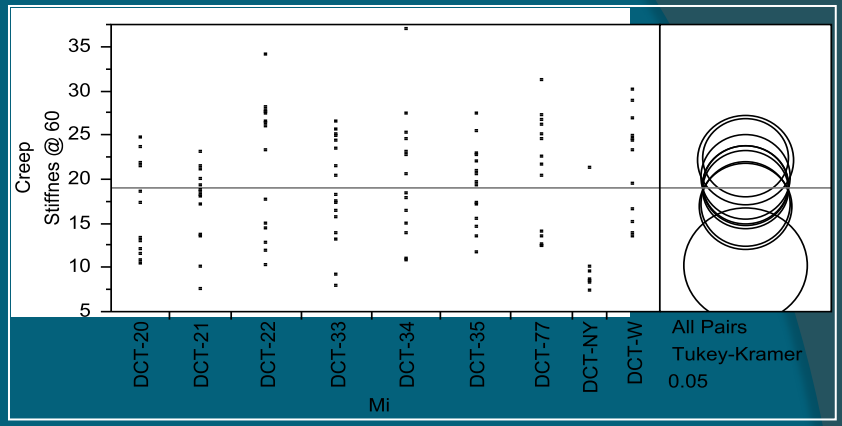
Levels not connected by same letter are significantly different.

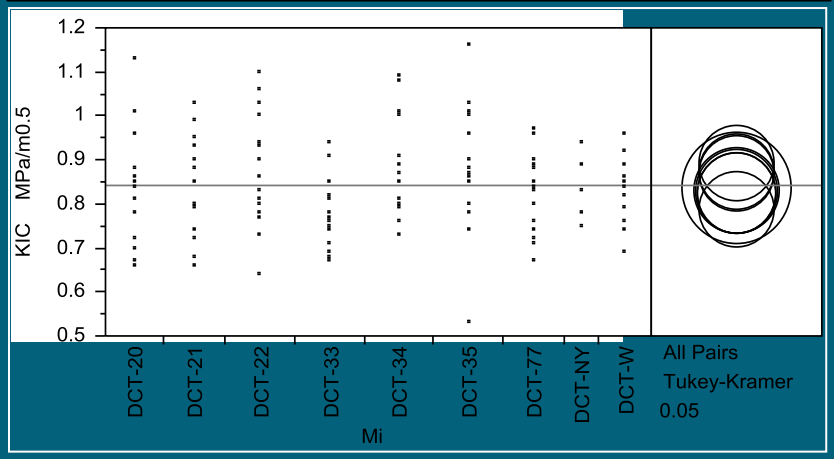
Level					Least Sq Mean
[4]SBS	A				5.5450000
[4]30% Fractioned	A	B			5.2626389
[4]SBS PPA		B	C		5.0733333
[7]30% Fractioned			C	D	4.6816667
[4]PPA				D	4.5550000
[7]SBS				D	4.5233333
[4]Elvaloy PPA				D	4.5233333
[7]SBS PPA				E	4.0616667
[7]Elvaloy PPA				E	F 3.7822917
[7]PPA					F 3.4683333

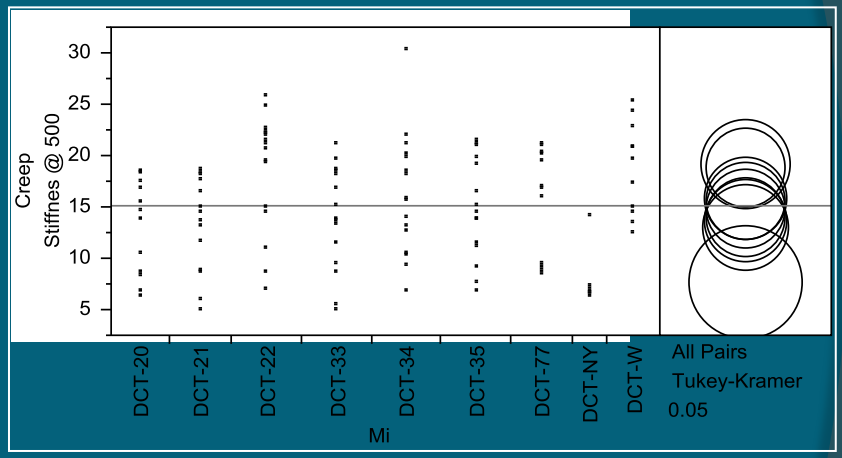
Levels not connected by same letter are significantly different.

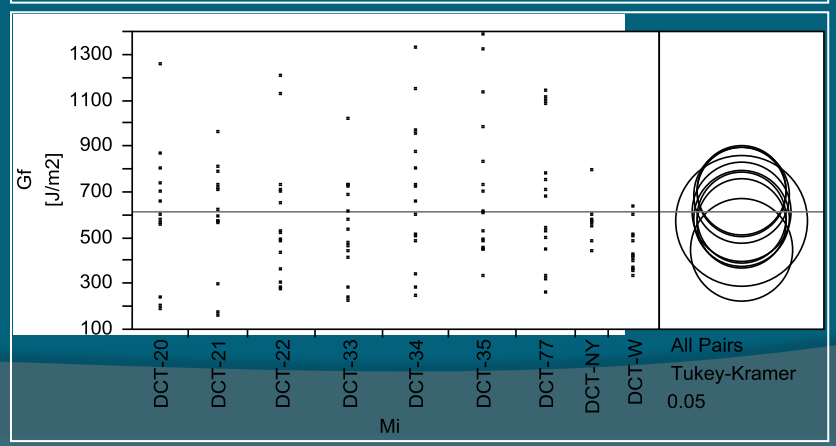
Comparing all of the Tests and Mixes

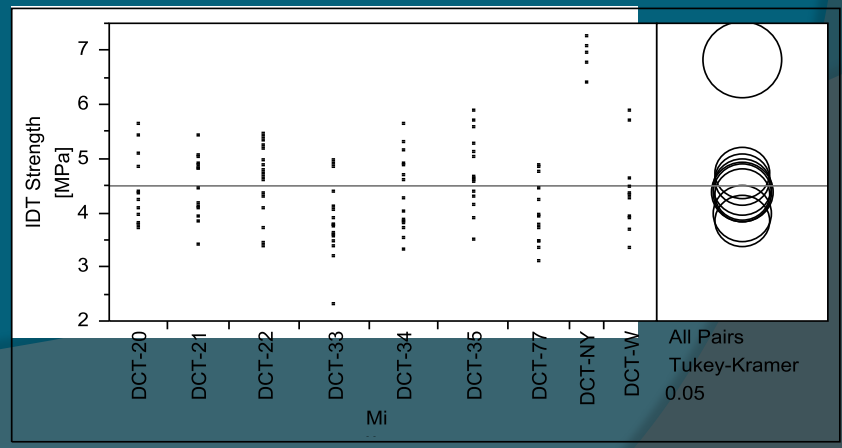






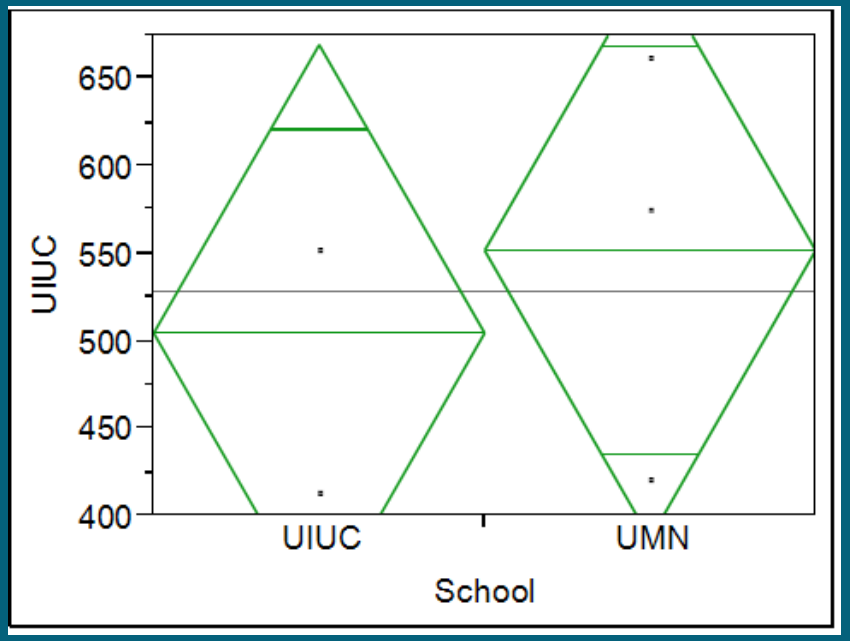






DCT Laboratory Comparison

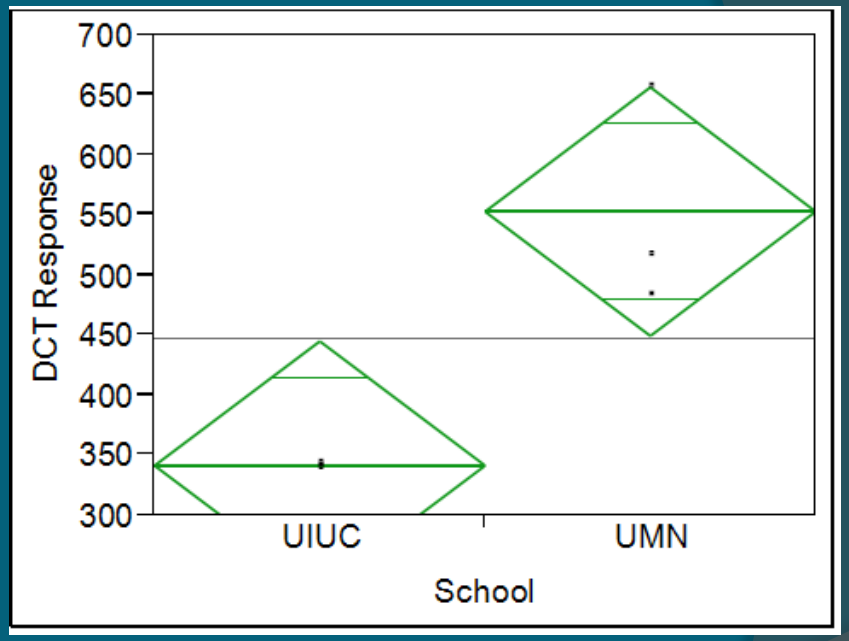
Mix	Test Temp		Air Voids	Recycled Asphalt	Binder
DCT-20	-18	PG+10	7	30% Non-Fractioned	58-28



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
School	1	3353.098	3353.1	0.3164	0.6038
Error	4	42384.145	10596.0		
C. Total	5	45737.243			

Mix	Test Temp		Air Voids	Recycled Asphalt	Binder
DCT-20	-28	PG	7	30% Non-Fractioned	58-28

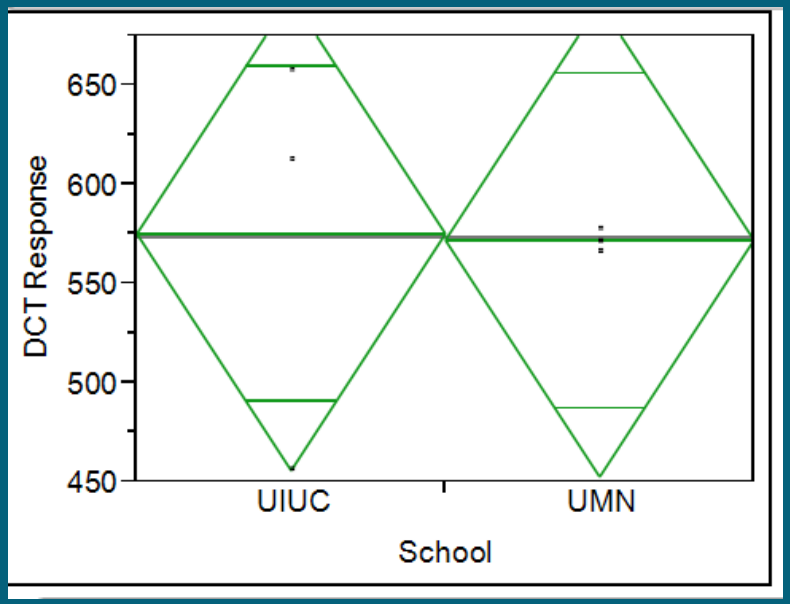


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
School	1	67077.227	67077.2	16.0779	0.0160*
Error	4	16688.094	4172.0		
C. Total	5	83765.321			

DCT Laboratory Comparison

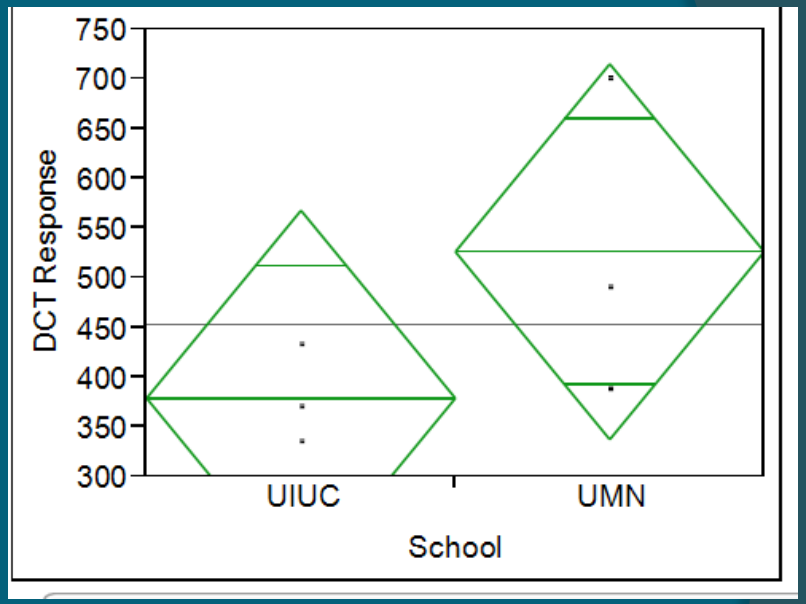
Mix	Test Temp		Air Voids	Recycled Asphalt	Binder
DCT-21	-18	PG+10	4	30% Fractioned	58-28



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
School	1	15.714	15.71	0.0028	0.9601
Error	4	22192.957	5548.24		
C. Total	5	22208.671			

Mix	Test Temp		Air Voids	Recycled Asphalt	Binder
DCT-21	-28	PG	4	30% Fractioned	58-28

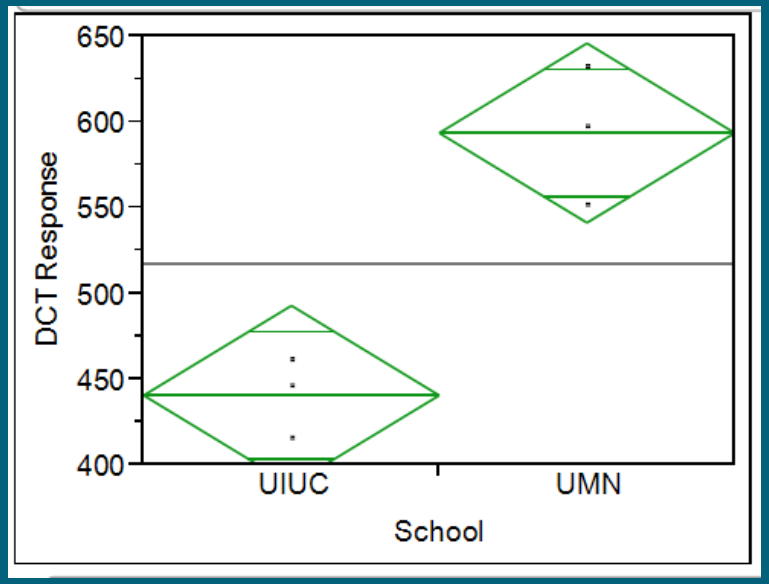


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
School	1	32584.244	32584.2	2.3467	0.2003
Error	4	55541.368	13885.3		
C. Total	5	88125.612			

DCT Laboratory Comparison

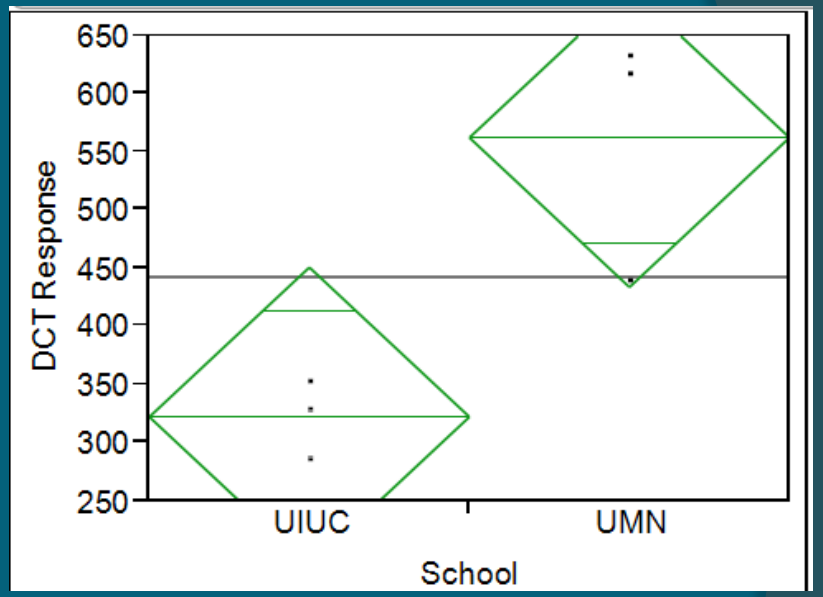
Mix	Test Temp		Air Voids	Recycled Asphalt	Binder
DCT-22	-24	PG+10	7	30% Fractioned	58-34



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
School	1	35154.822	35154.8	32.9556	0.0046*
Error	4	4266.934	1066.7		
C. Total	5	39421.756			

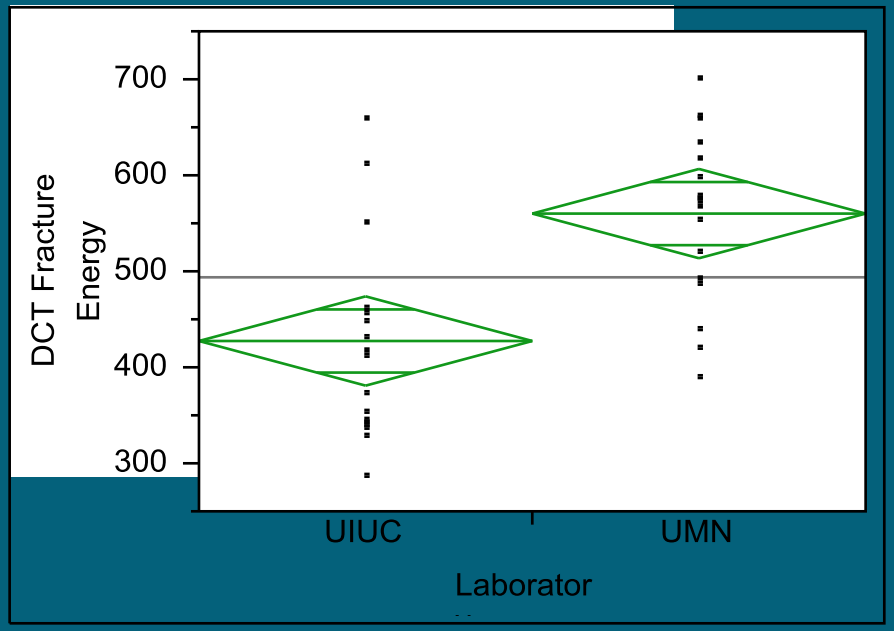
Mix	Test Temp		Air Voids	Recycled Asphalt	Binder
DCT-22	-34	PG	7	30% Fractioned	58-34



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
School	1	86572.89	86572.9	13.4370	0.0215*
Error	4	25771.58	6442.9		
C. Total	5	112344.47			

DCT Laboratory Comparison: Comparison of all collected data from two laboratories



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Laboratory	1	158494.23	158494	16.8242	0.0002 *
Error	34	320300.08	9421		
C. Total	35	478794.31			

Statistical differences are observed for the two different laboratories at 95% confidence.

For this set of data, there may be confounding effects; however half of the previous comparisons show statistical difference.

Further investigations on multi-lab variability may useful.

Ranking of mixes based on all test data

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
DCT-20	14	886.500	938.000	63.321	-0.374
DCT-21	15	1082.50	1005.00	72.167	0.548
DCT-22	17	1323.00	1139.00	77.824	1.237
DCT-33	17	656.000	1139.00	38.588	-3.252
DCT-34	17	1055.50	1139.00	62.088	-0.559
DCT-35	17	1398.50	1139.00	82.265	1.745
DCT-77	15	660.500	1005.00	44.033	-2.447
DCT-NY	8	1036.00	536.000	129.500	4.727
DCT-W	13	812.500	871.000	62.500	-0.439

The DCT, SCB, IDT all ranked the mixes in the order shown above; however, no mix was statistically different from all of the other mixes.

Summary Tables

- Tables show that all the tests are good indicators of overall trends.
- Asphalt Modifiers and FRAP were not shown in a table because all mixes were statistically similar except for a few cases in IDT Strength test.
- Mixed results between tests when ranking field cores, laboratory compacted and lab conditioned samples.

Ranking Air Void and Temperature Combinations				
	1st	2nd	3rd	4th
DCT FE	PG+10, 4	PG+10, 7	PG, 4	PG, 7
SCB SIF	PG, 4	PG+10, 4	PG, 7	PG+10, 7
SCB FE	PG+10, 4	PG+10, 7	PG, 4	PG, 7
IDT Stiffness @60	PG, 4	PG, 7	PG+10,4	PG+10, 7
IDT Stiffness @500	PG, 4	PG, 7	PG+10,4	PG+10, 7
IDT Strength	PG+10, 4	PG, 4	PG+10,7	PG,7

RAP vs. FRAP (Air void %, 30% RAP/ 30%FRAP)				
	1st	2nd	3rd	4th
DCT FE	4%, FRAP	7%, RAP	7%, FRAP	4% RAP
SCB SIF	4%, RAP	4%, FRAP	7%, RAP	7%, FRAP
SCB FE	4%, RAP	7%, FRAP	4%, FRAP	7%, RAP
IDT Stiffness @60	4%, FRAP	4%, RAP	7%, RAP	7%, FRAP
IDT Stiffness @500	4%, FRAP	4%, RAP	7%, RAP	7%, FRAP
IDT Strength	4%, RAP	4%, FRAP	7%, FRAP	7%, RAP

Field Cores vs. Laboratory vs. Lab Conditioned			
	Rank (If shaded, no statistical difference)		
	1st	2nd	3rd
DCT FE	NONE	YES	Field
SCB SIF	YES	Field	None
SCB FE	Yes	None	Field
IDT Stiffness @60	Field	Yes	None
IDT Stiffness @500	Field	Yes	None
IDT Strength	Yes	None	Field