Investigation of Low Temperature Cracking in Asphalt Pavements National Pooled Fund Study – Phase II

Task 2 Report
Mechanical Testing and Analysis

November 2010

Introduction

Materials

Location	Construction date	Binder Grade	Asphalt modifiers	RAP (30%)
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	-	Non-Fractioned
MnRoad 21	August 2008	PG 58-28	-	Fractioned
MnRoad 22	August 2008	PG 58-34	-	Fractioned
Wisconsin 9.5 mm SMA	2008	PG 64-22	-	-
NYS Typical Mix	2008	PG 64-22	-	-

Test samples

- Loose mix laboratory compacted (SGC) specimens
- Field cored specimens

Introduction

Participating test laboratories

University of Minnesota (UMN)
University of Illinois Urbana Champagne (UIUC)
University of Wisconsin (UWM)
Iowa State University (ISU)

Fracture Test Methods

Indirect Tensile (IDT)
Semi-Circular Bend (SCB)
Disc-Shaped Compact Tension (DCT)

Introduction

Primary experimental variables

Test Temperature

- PGLT [(1)]
- PGLT+10°C

Air void content

- For laboratory specimens: 4% and 7%
- For field specimens: assumed to be 7%

Asphalt mixture conditioning

- Non conditioned
- Conditioned for 5 days @ 85°C (long term aging)
- Field cores (2 to 3 years old)

Secondary experimental variables

Asphalt modification: PPA, SBS, SBS+PPA, Elvaloy+PPA

RAP fractioning: Non-fractioned vs. Fractioned

PG low limit: PG 58-28 vs. PG 58-34

(1) PG low temperature limit

Introduction

Laboratory experimental layout

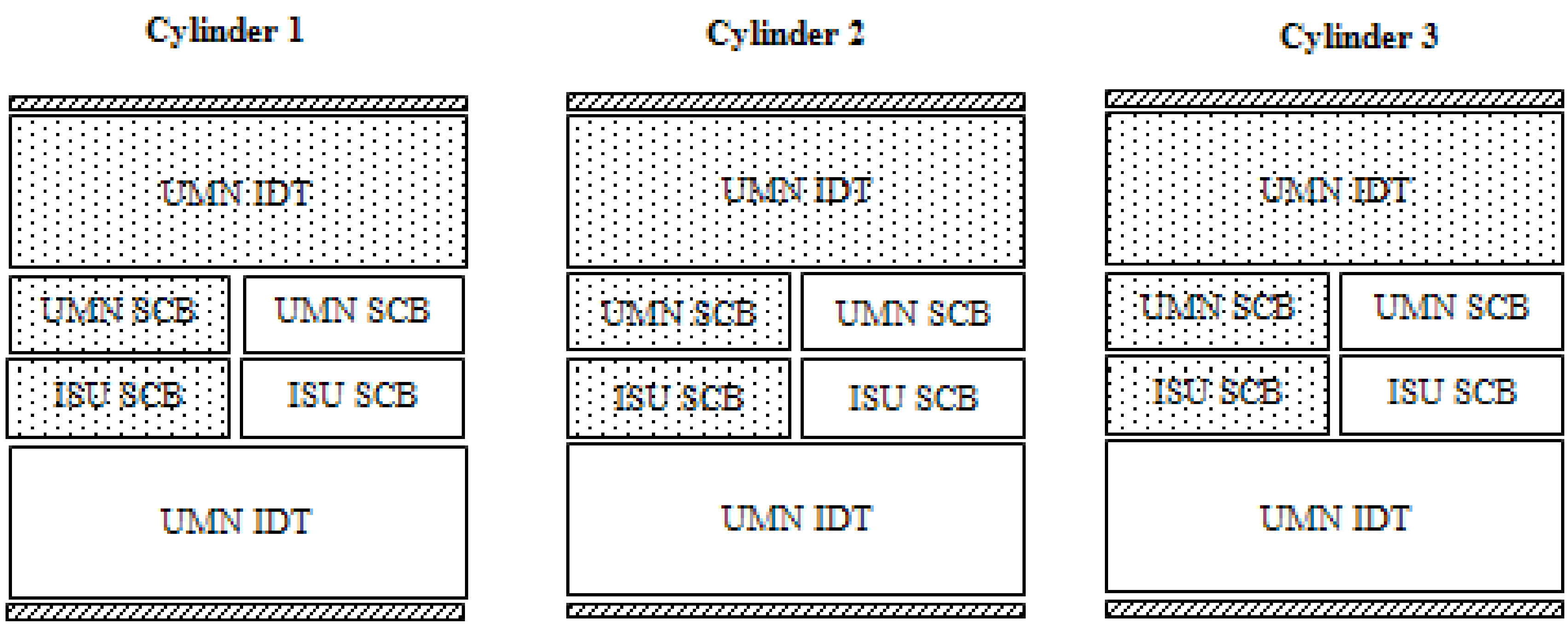
Test Device	Temp	Mix Conditioning	MN/Road Test Section				WI		NYS	
			33, 34, 35, 77		20, 21, 22					
			Air Voids, %							
			4	7	4	7	4	7	4	7
SCB	PGLT	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PGLT+10ºC	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PGLT	5 days@85ºC		xxx		xxx		xxx		xxx
	PGLT	Field cores		xxx		xxx		xxx		xxx
DC(T)	PGLT	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PGLT+10ºC	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PGLT	5 days@85ºC		xxx		xxx		xxx		xxx
	PGLT	Field cores		xxx		xxx		xxx		xxx
IDT	PGLT	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PGLT+10ºC	None	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	PGLT	5 days@85ºC		xxx		xxx		xxx		xxx
	PGLT	Field cores		xxx		xxx		xxx		xxx

* Shadowed cells indicate the data missing from the experimental layout

Experimental work

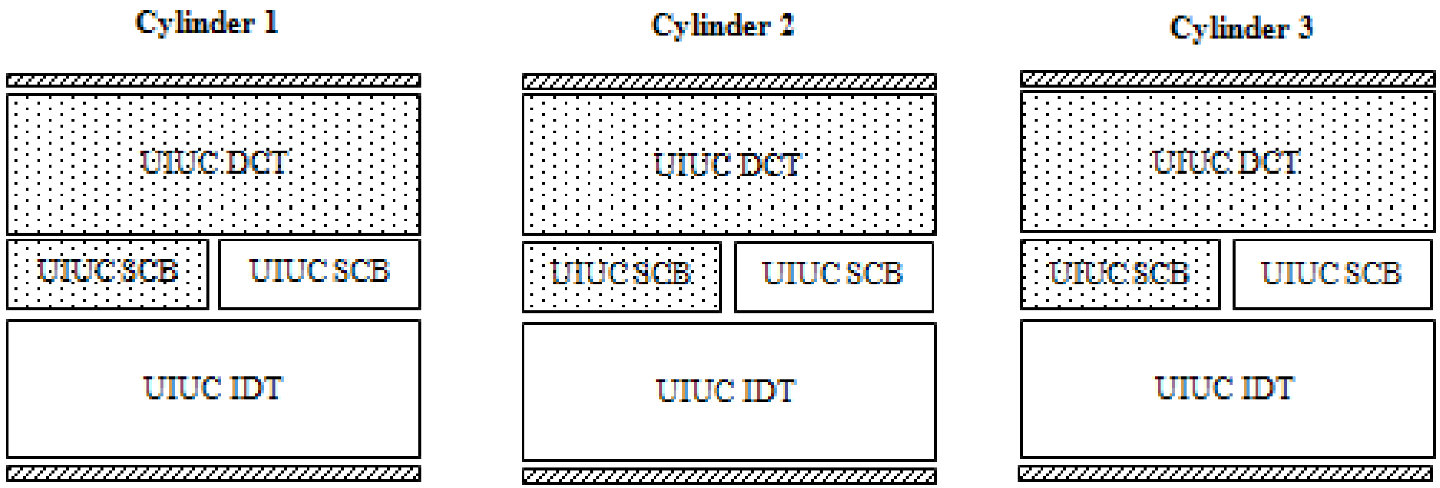
Preparation of laboratory test specimens

- All SGC compaction at UMN
- Half of the 7% air voids cylinders were long termed aged
- IDT, SCB, and DCT test samples cut
- Cylinders and samples distributed to UIUC and UWM

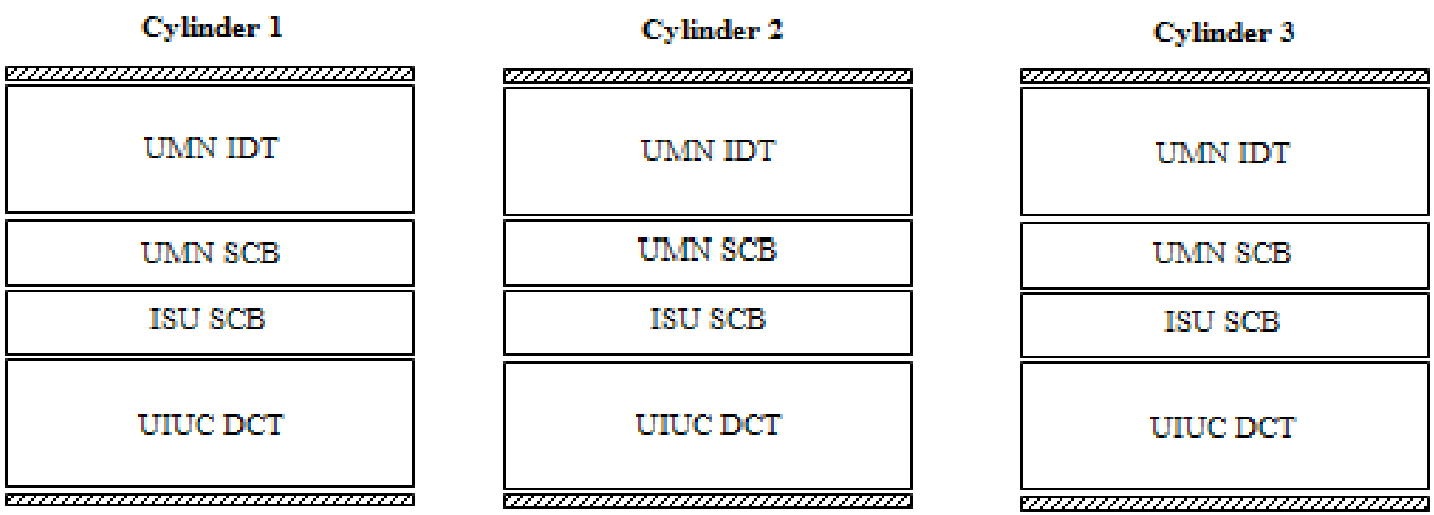


Non-conditioned specimens used at UMN

Experimental work



Non-conditioned specimens used at UIUC

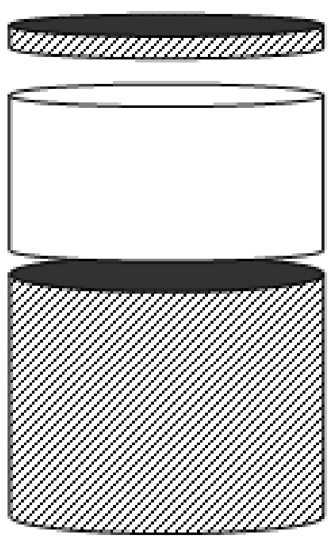


Conditioned specimens

Experimental work

Preparation of field test specimens

- Cylindrical field cores obtained from MnROAD
- Top and bottom discarded
- IDT, SCB, and DCT test samples were cut
- Air void content determined in different study



Sample preparation scheme for field cores

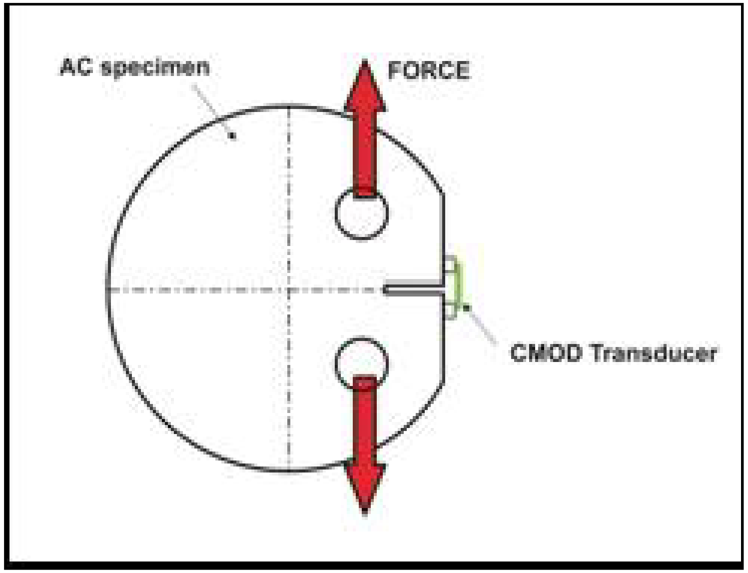
Field cores air void content		
Cell	Mean	CV
20	6.0	0%
21	5.1	2%
22	5.7	2%
33	5.3	1%
34	5.9	2%
35	6.4	2%
77	5.1	13%

Air void content for field cores

Experimental work – Test methods

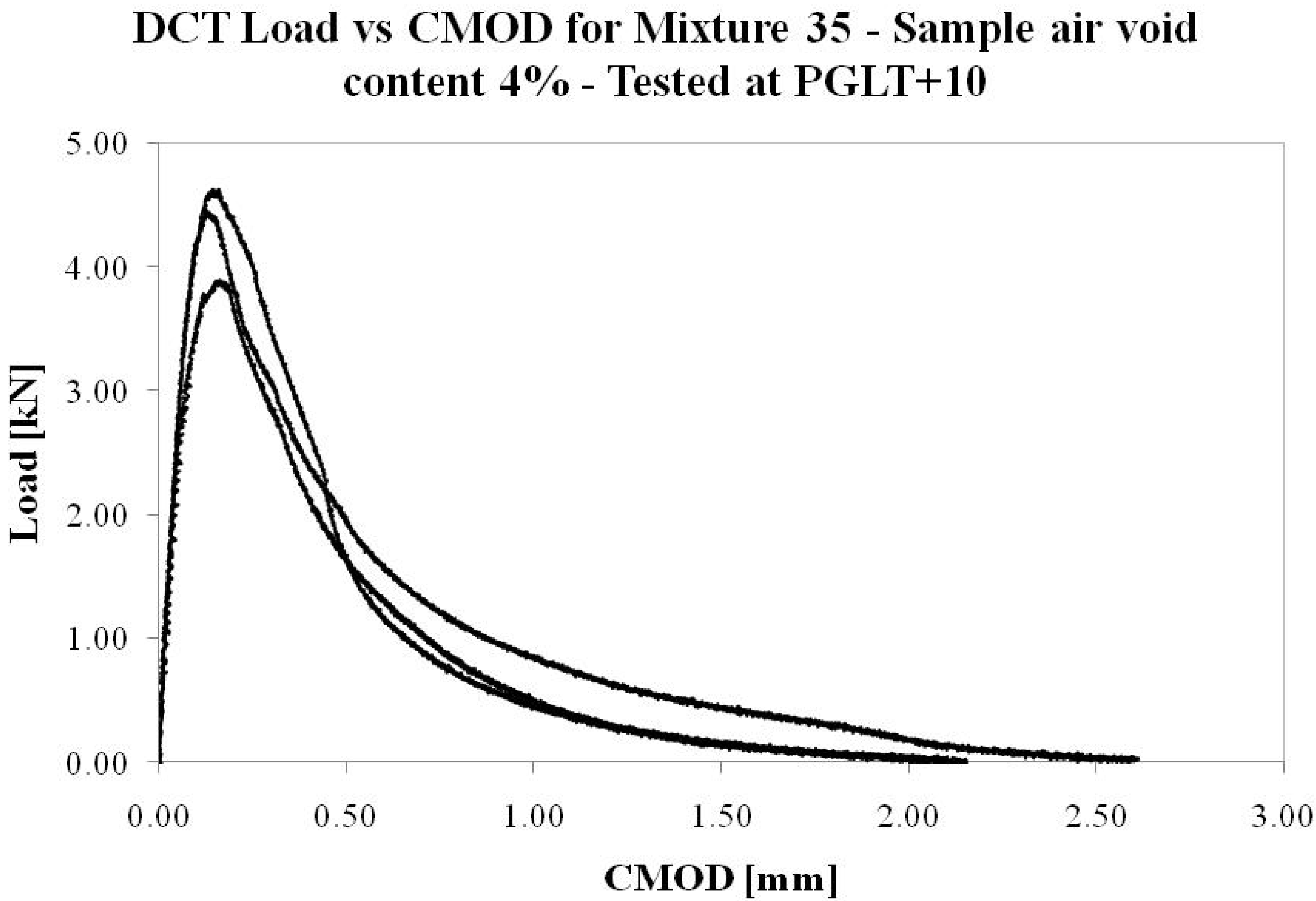
DCT

- Samples conditioned in controlled chamber (min. 2 hours)
- Test performed under tensile loading
- Used pre-load of 0.2 kN
- Loading rate: CMOD rate of 1mm/min (0.017 mm/s)
- Test completed when post-peak level reduced to 0.1 kN
- Fracture energy computed from Load-CMOD plots



DCT test scheme

Experimental work – Test methods

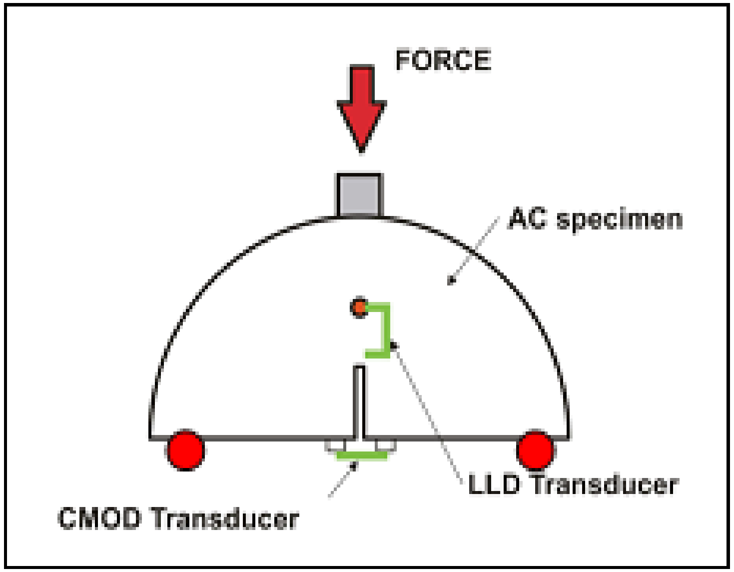


Typical DCT Load-CMOD curves (UIUC)

Experimental work – Test methods

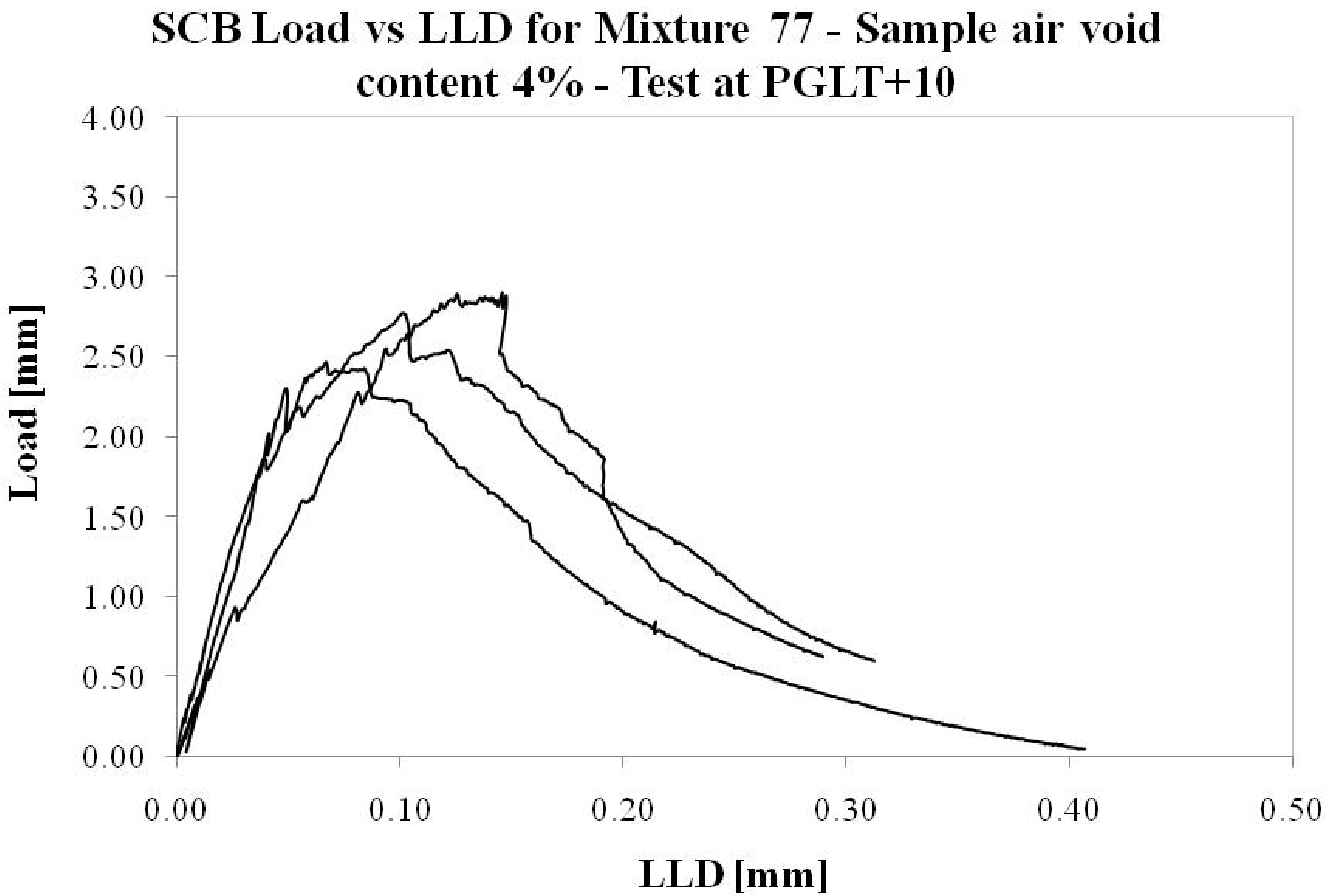
SCB

- Samples conditioned in controlled chamber (2h)
- Contact load of max 0.3 kN
- Loading rate: CMOD rate of 0.0005 mm/s (34 times smaller than DCT)
- Test completed when post-peak level reduced to 0.5 kN
- Fracture toughness computed from peak load
- Fracture energy computed from Load-LLD plots



SCB test scheme

Experimental work – Test methods

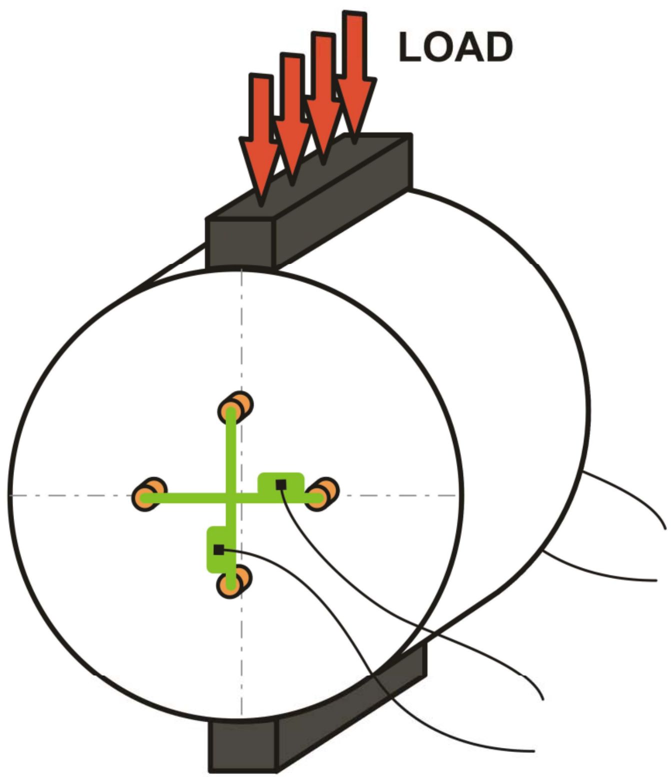


Typical SCB Load-LLD curves (UMN)

Experimental work – Test methods

IDT

- Determination of Creep Stiffness
- Determination of Tensile Strength
- Test protocol AASHTO T 322-03



Analysis of Experimental Data

Analysis layout

✓Presentation of results
✓ Statistical analysis of data
  - Analysis of variance (ANOVA)
    - Null Hypothesis: The effects of all the treatment groups are all null
    - Alternate Hypothesis: The effect of at least one treatment group is not null
  - Multiple comparison
  - Level of error for testing significance: 0.05

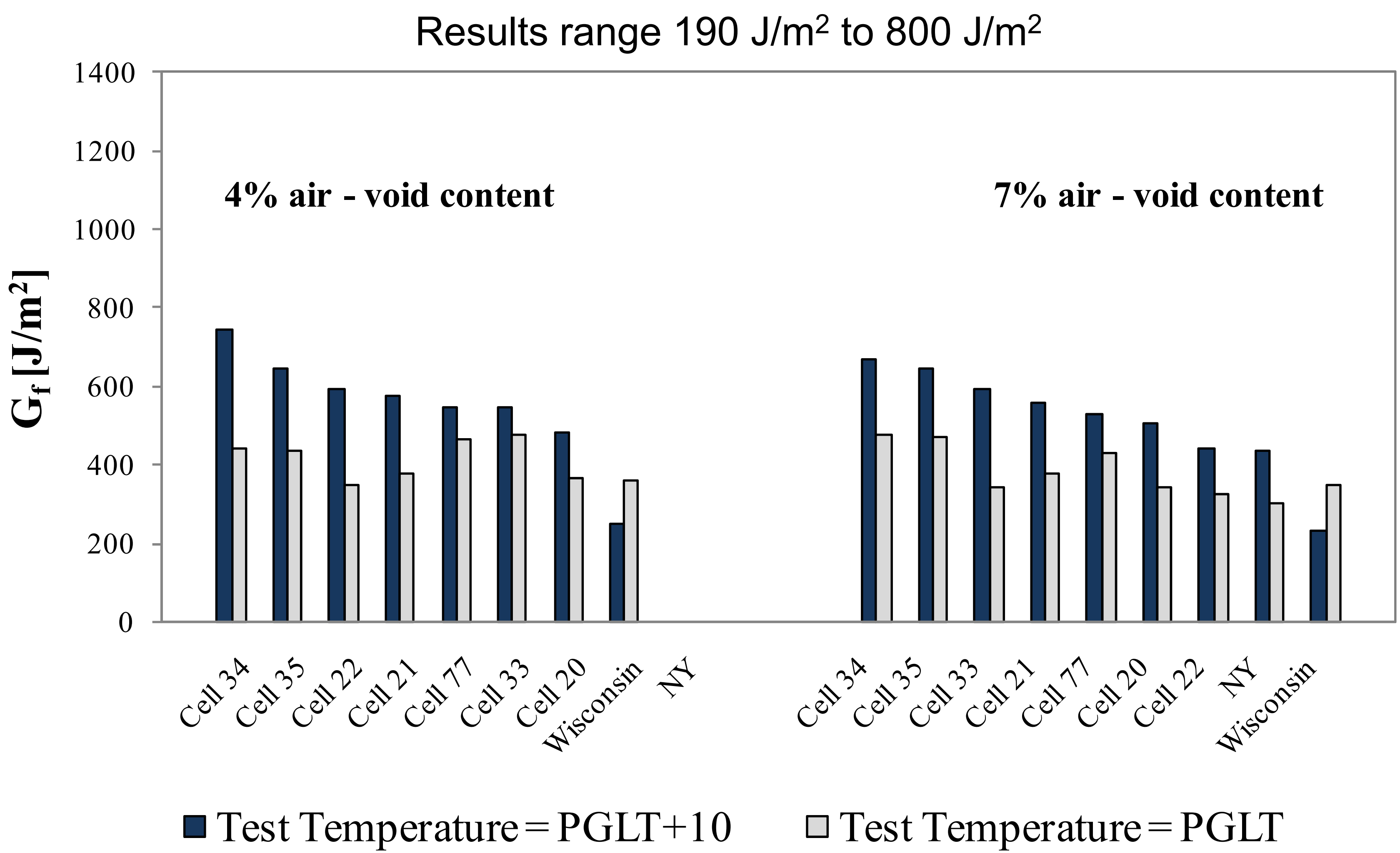
Note:
The 'NY' mixture was not included in the statistical analysis, since information was not available for all factor level combinations.

Effect of Mixture Type, Air Void Content, and Temperature on Fracture Parameters

Data analysis for unconditioned laboratory compacted specimens

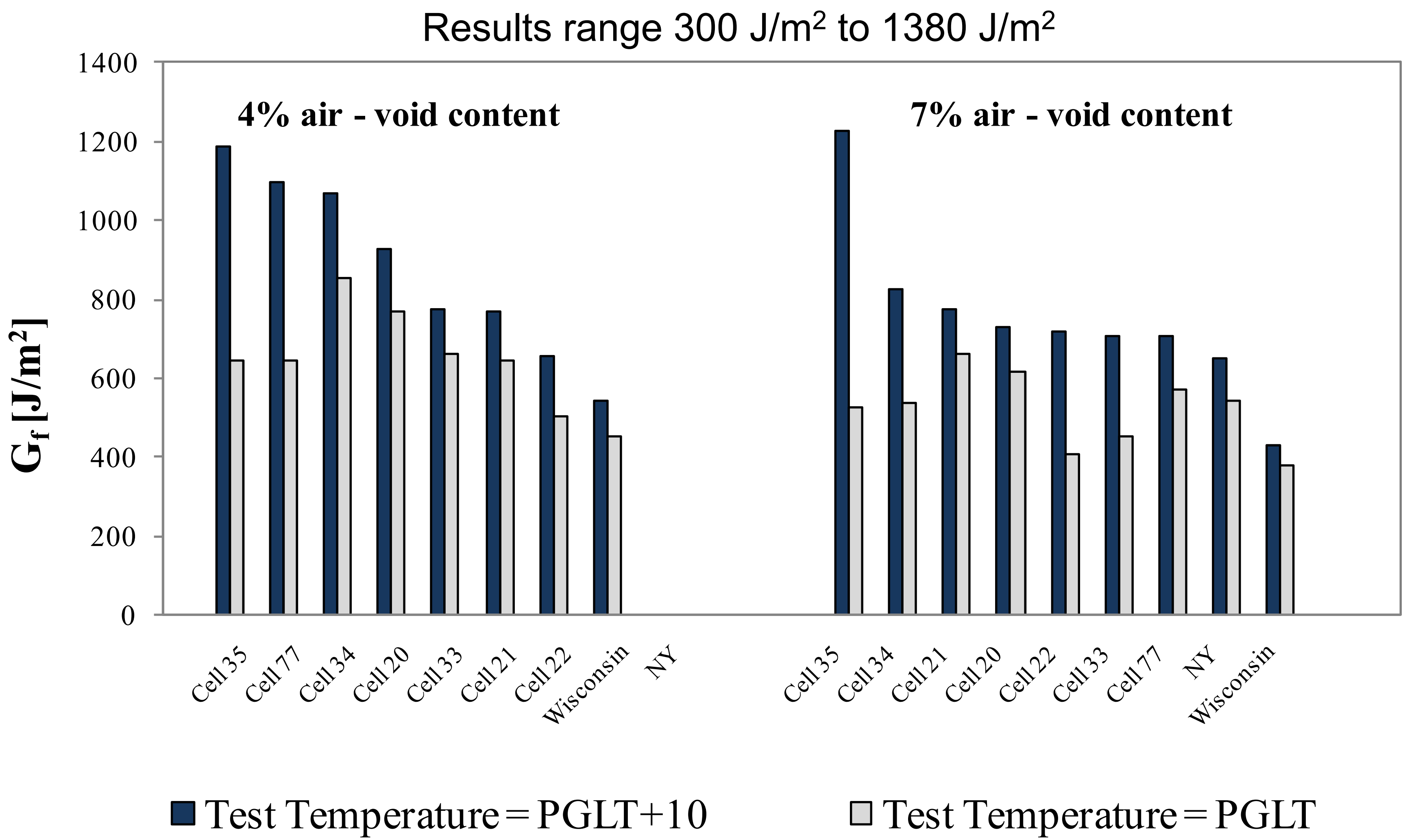
Analysis of Experimental Data

DCT - Fracture energy



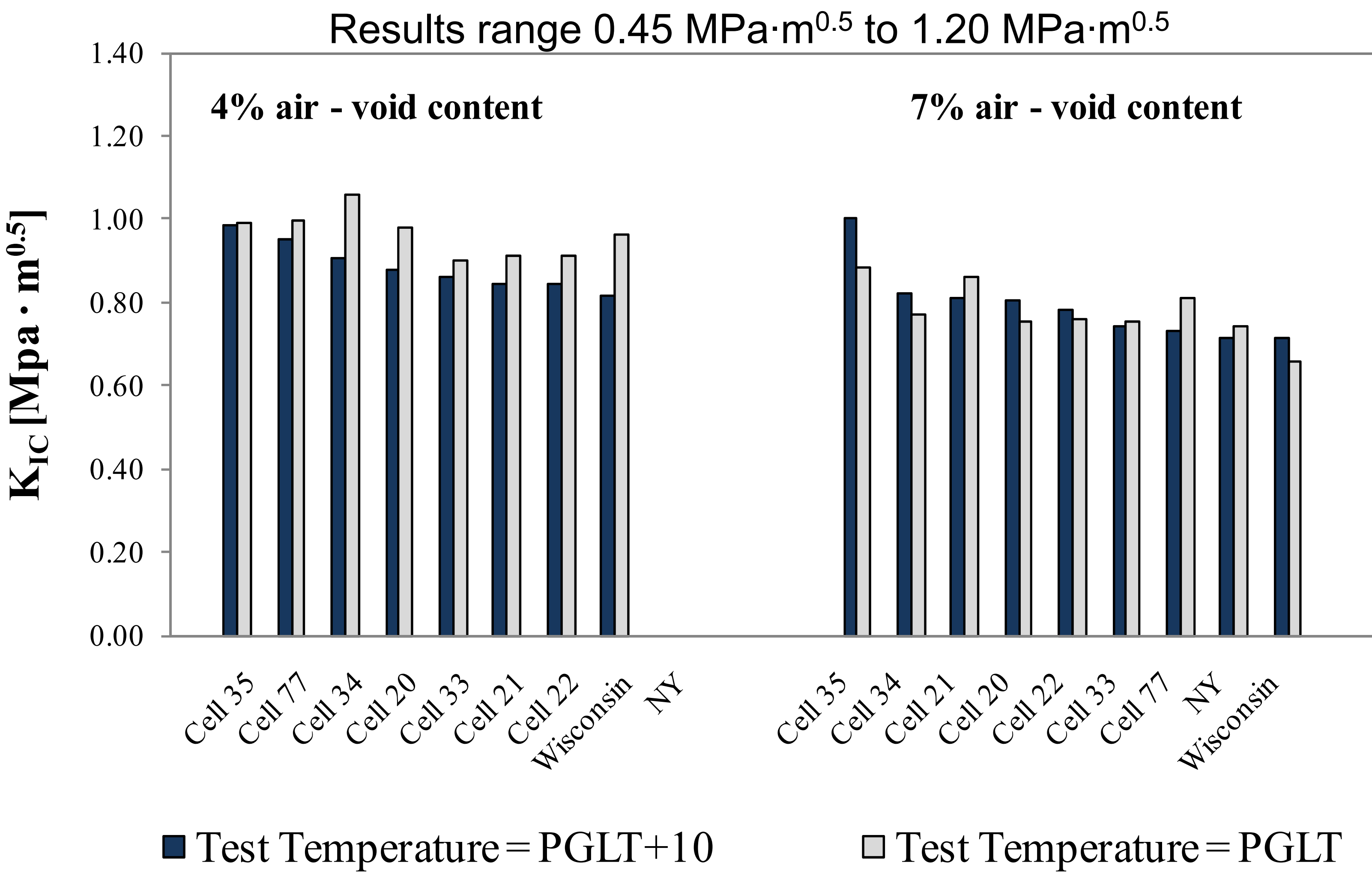
Analysis of Experimental Data

SCB - Fracture energy



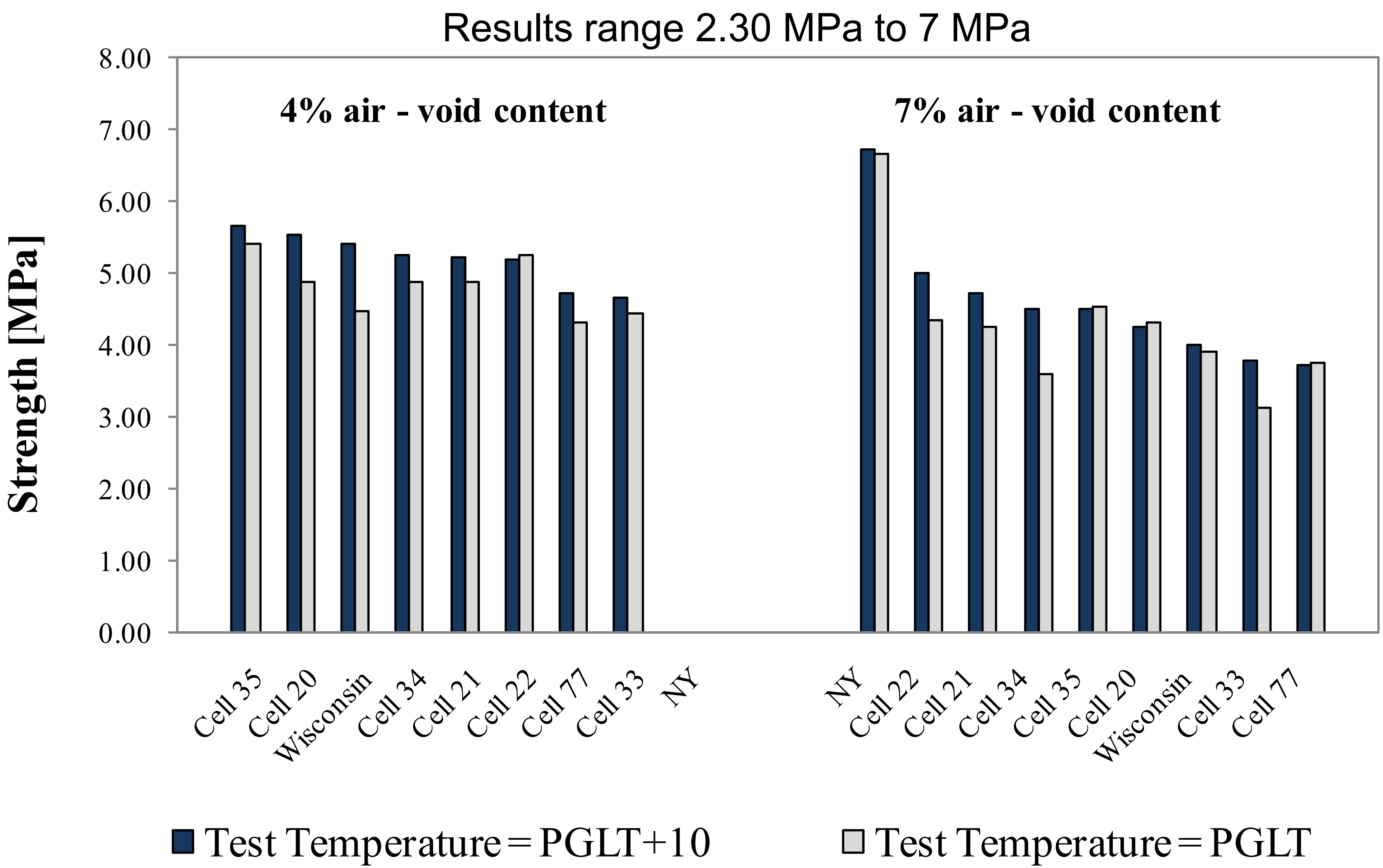
Analysis of Experimental Data

SCB - Fracture toughness



Analysis of Experimental Data

IDT - Tensile strength



Analysis of Experimental Data

Summary of ANOVA tables

Experimental variables	DCT Fracture Energy	SCB Fracture Energy	SCB Fracture Toughness	IDT Strength
Mix type	√	√	√	√
Void content	–	√	√	√
Temperature	√	√	–	√
Mix×Temp	√	√	–	–

√ **:** Effect significant at 0.05 level of error

− : Effect non-significant at 0.05 level of error

Analysis of Experimental Data

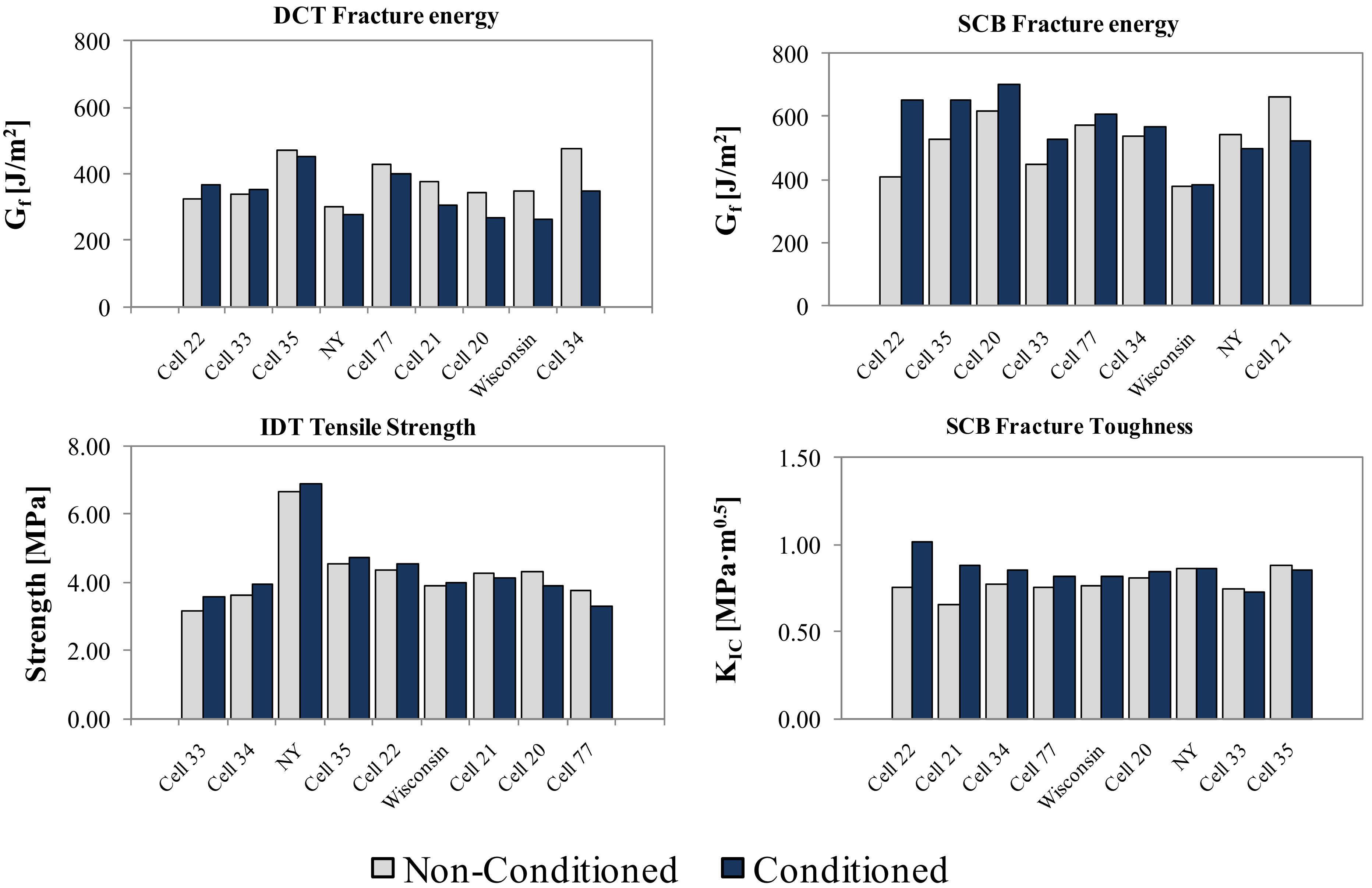
Statistical grouping & ranking of asphalt mixtures

Mixture Type	DCT G_f [J/m^2]		SCB G_f [J/m^2]		SCB K_{IC} [MPa·m$^{0.5}$]		IDT Strength [MPa]	
	Group Mean	Rank	Group Mean	Rank	Group Mean	Rank	Group Mean	Rank
20	423.4	C	741.6	A	0.858	A/B	4.7	A/B/C
21	472.8	B /C	716.6	A	0.787	B	4.7	A/B/C
22	426.1	C	563.1	B/C	0.853	A/B	4.9	A/B
33	489.8	B/C	649.1	A/B	0.804	B	4.01	E
34	583.6	A	821.6	A	0.890	A	4.6	B/C/D
35	560.9	A/B	834.0	A	0.955	A	5.1	A
77	497.7	B/C	772.3	A	0.806	B	4.2	D/E
Wisconsin	298.6	D	457.3	C	0.831	B	4.4	C/D/E

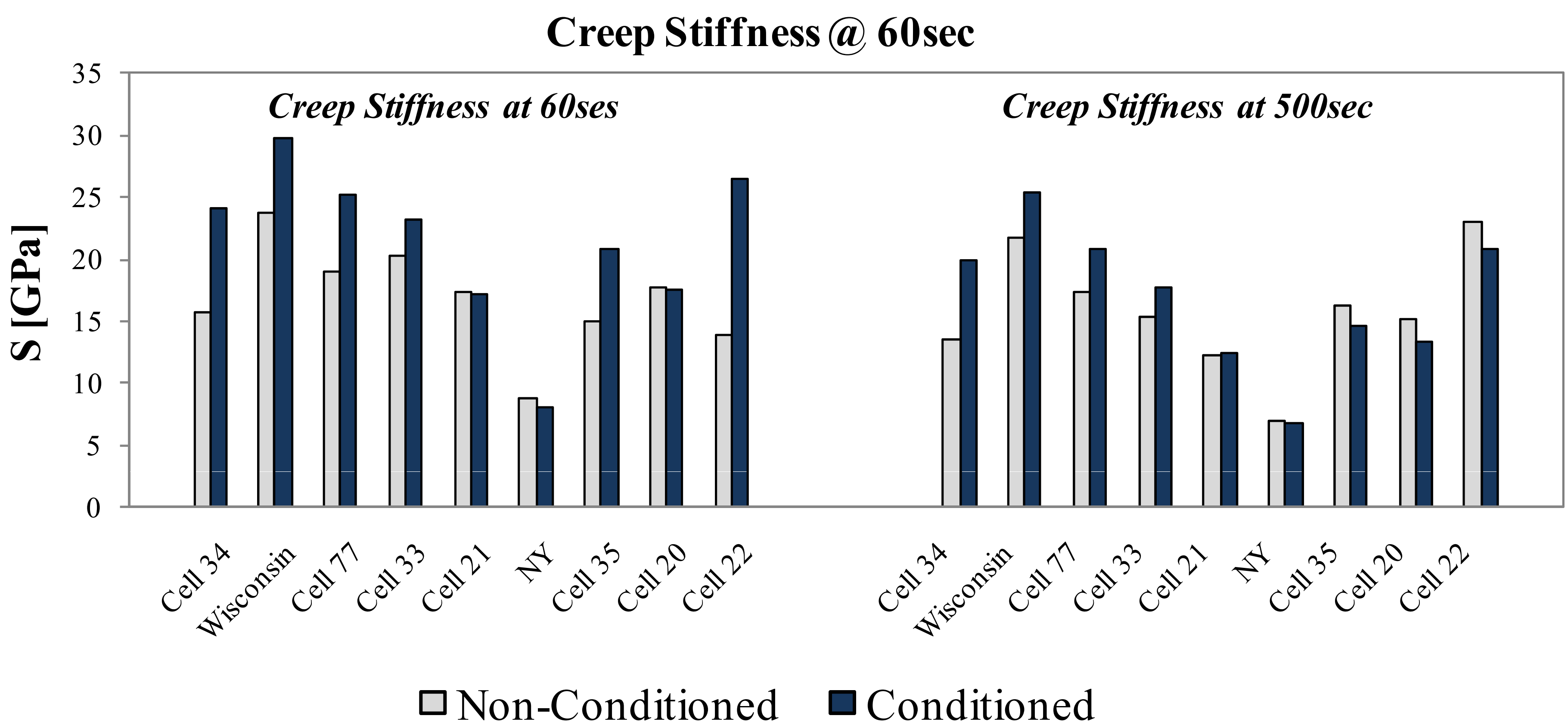
Effect of mixture conditioning

Data analysis for conditioned laboratory compacted specimens

Analysis of Experimental Data



Analysis of Experimental Data



Analysis of Experimental Data

Summary of ANOVA tables

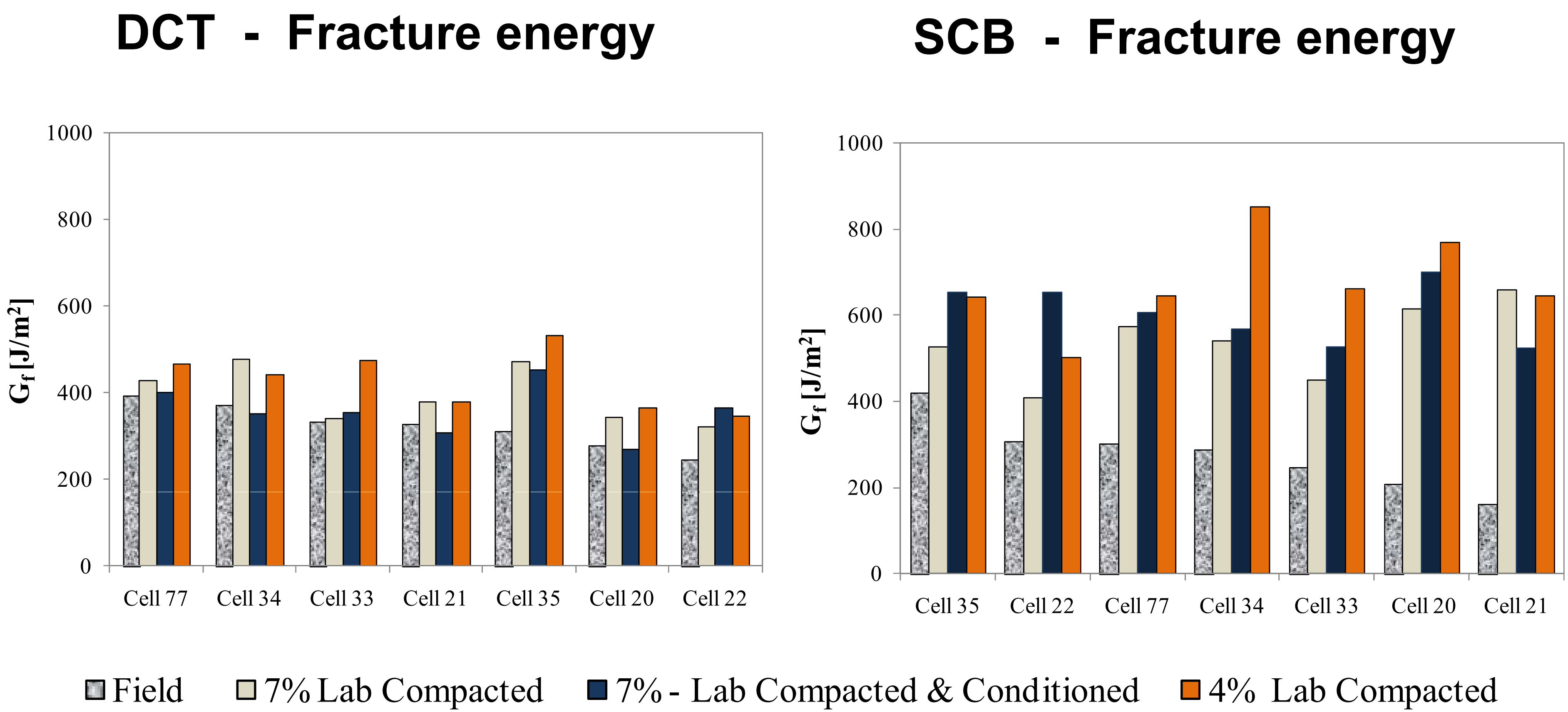
Experimental variables	DCT Fracture energy	SCB Fracture energy	SCB Fracture toughness	IDT Strength
Mix	√	√	–	√
Conditioning	√	–	√	–
Mix.Conditioning	–	–	–	–

Experimental variables	IDT Creep stiffness S60	IDT Creep stiffness S500
Mix	√	√
Conditioning	√	–
Mix.Conditioning	–	–

√ : Effect significant at 0.05 level of error
– : Effect non-significant at 0.05 level of error

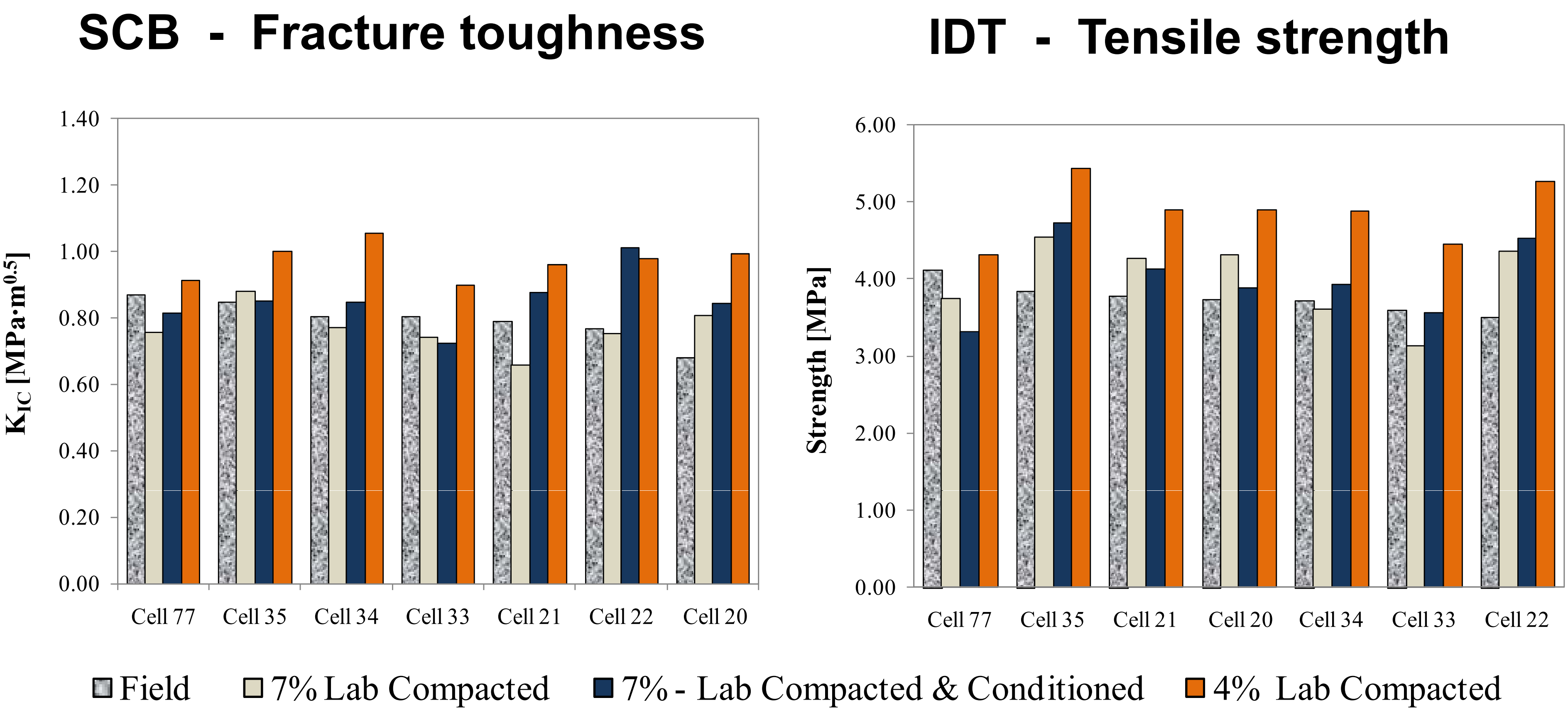
Data analysis for field specimens

Analysis of Experimental Data



Comparison field vs. laboratory compacted specimens (Test temperature PGLT)

Analysis of Experimental Data



Comparison field vs. laboratory compacted specimens (Test temperature PGLT)

Analysis of Experimental Data

Summary of ANOVA tables

Experimental variables	DCT Fracture energy	SCB Fracture energy	SCB Fracture toughness	IDT Strength
Mix	–	–	√	–

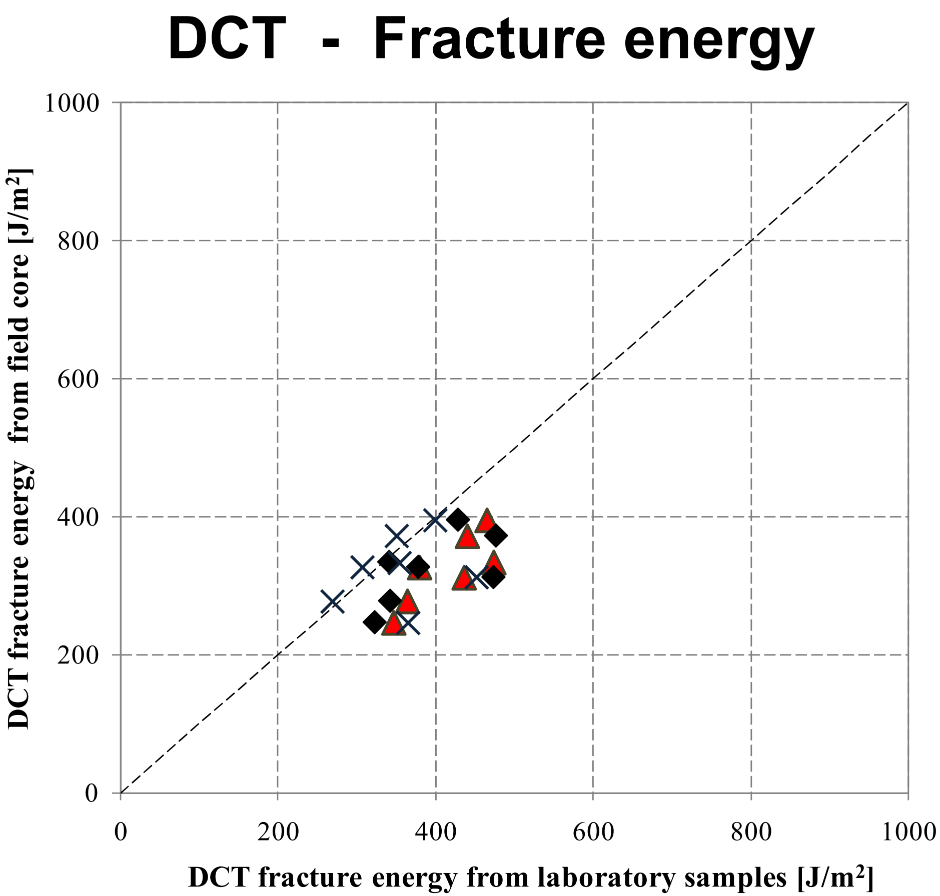
√ : Effect significant at 0.05 level of error
– : Effect non-significant at 0.05 level of error

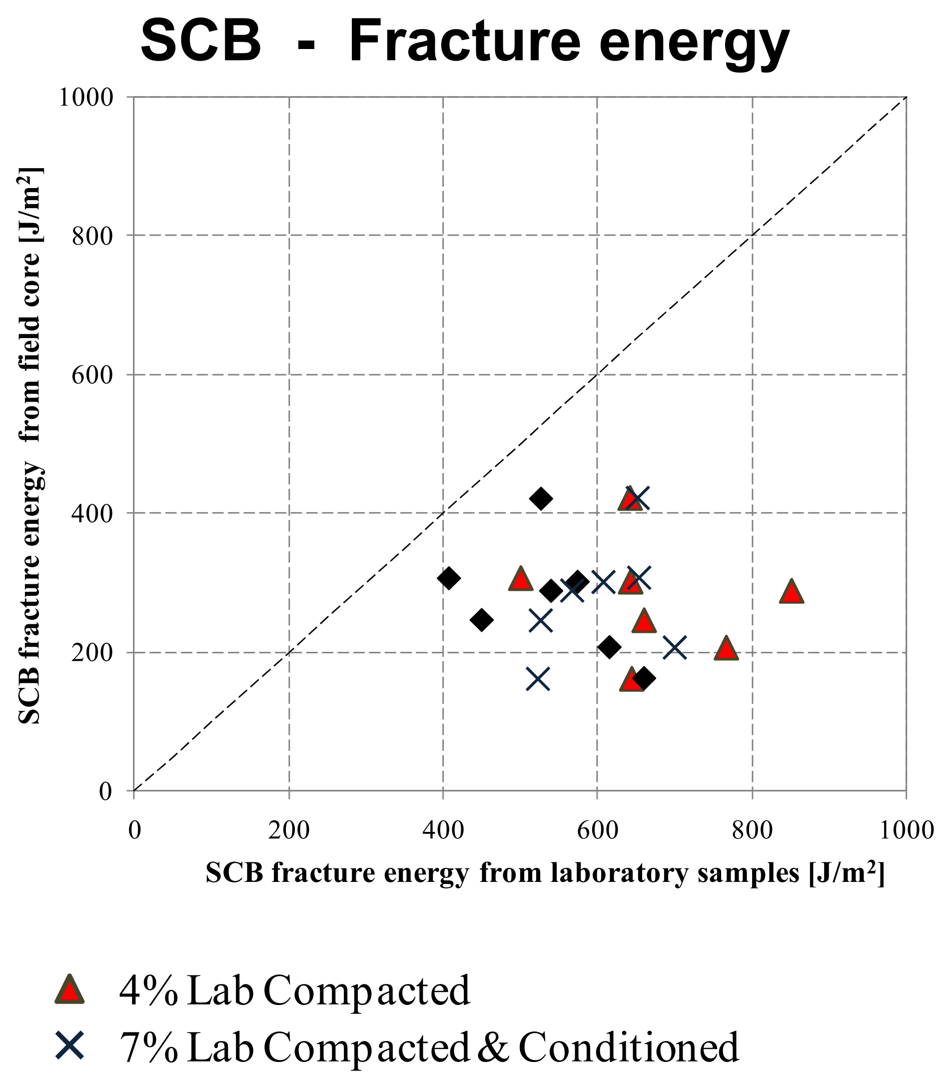
Statistical grouping & ranking of asphalt mixtures

SCB fracture energy [J/m^2]		
Mix Type	Group Mean	Rank
21	162.41	C
20	207.16	B/C
33	246.34	B/C
34	288.36	A/B
77	301.46	A/B
22	306.49	A/B
35	421.29	A

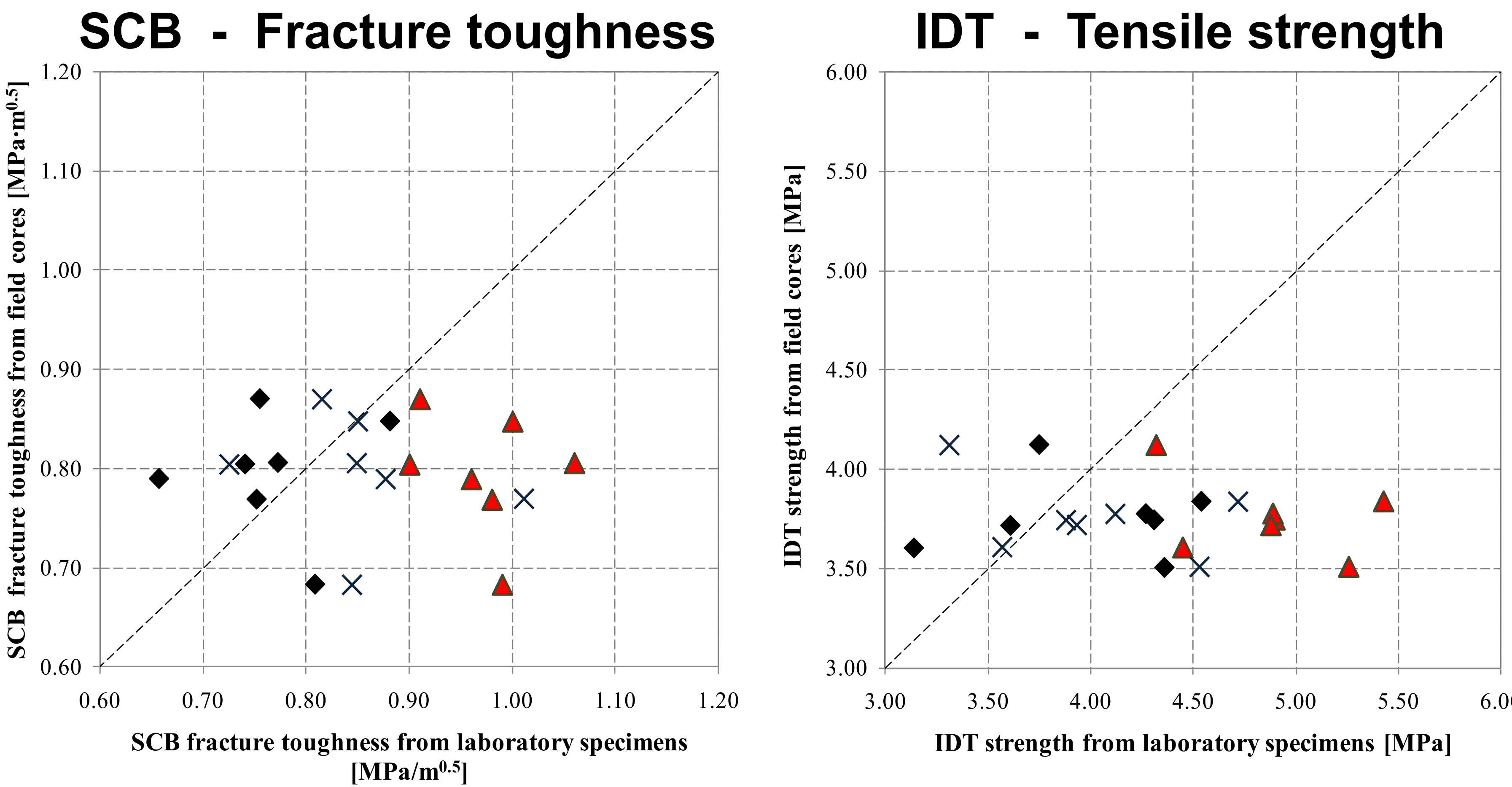
Correlation field to laboratory compacted samples

Analysis of Experimental Data





Analysis of Experimental Data



Identity line
7% Lab Compacted
4% Lab Compacted
7% Lab Compacted & Conditioned

Analysis of Experimental Data

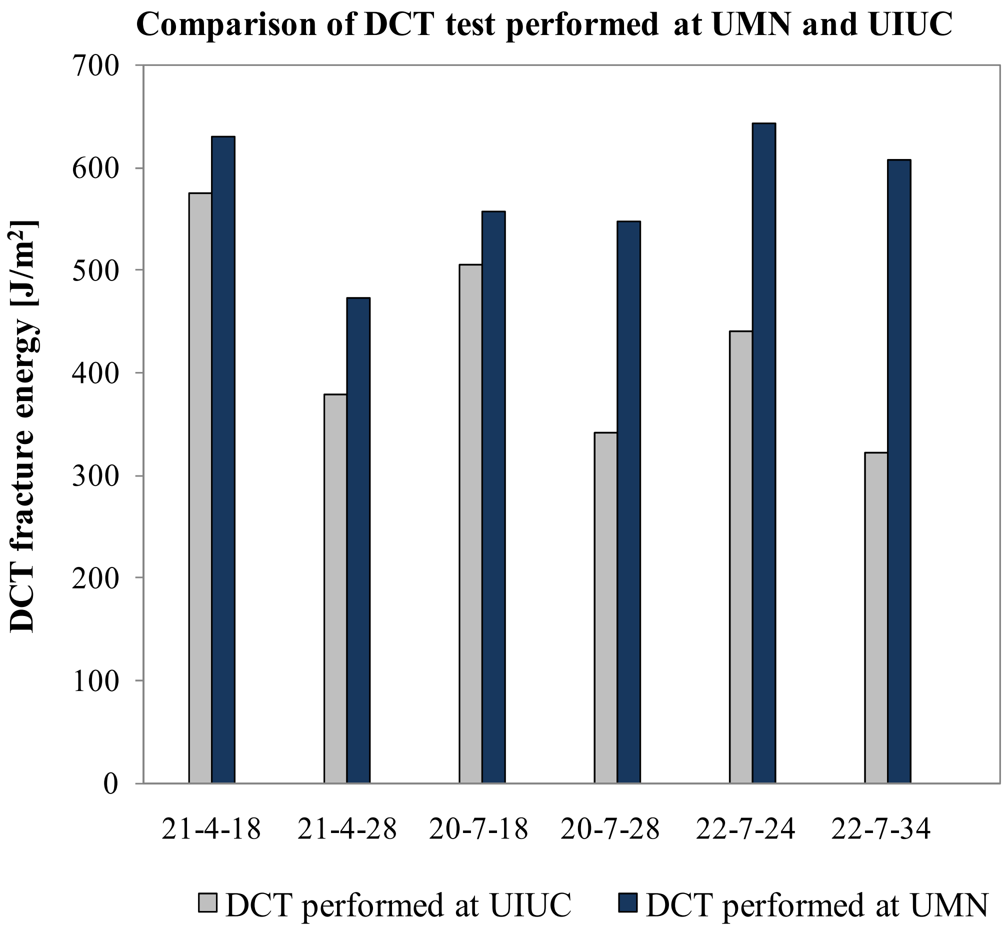
Correlation coefficient

Test conditions for laboratory samples	SCB Fracture energy	SCB Fracture toughness	DCT Fracture energy	IDT Strength
7%- PGLT	-0.48	0.05	0.64	0.02
7%- PGLT-Conditioned	0.38	-0.25	0.26	-0.44
4%- PGLT	-0.20	-0.25	0.81	-0.41

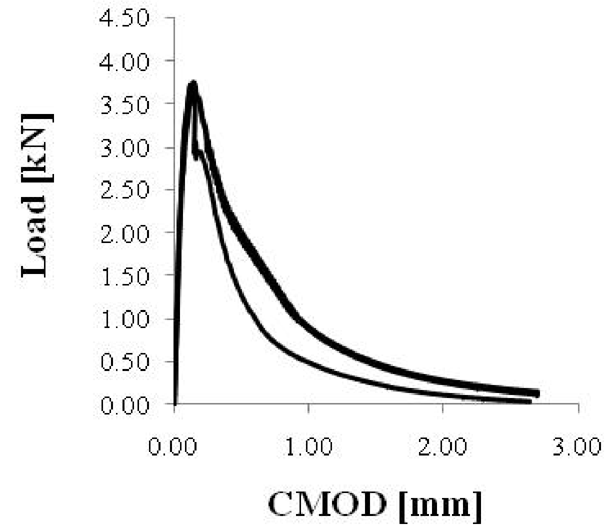
Comparison of experimental results obtained at UIUC and UMN

Analysis of Experimental Data

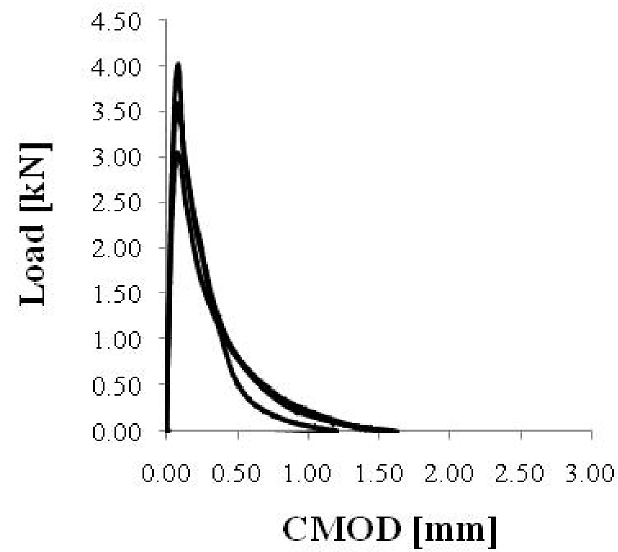
DCT



DCT test at UMN – mixture 22-7-34

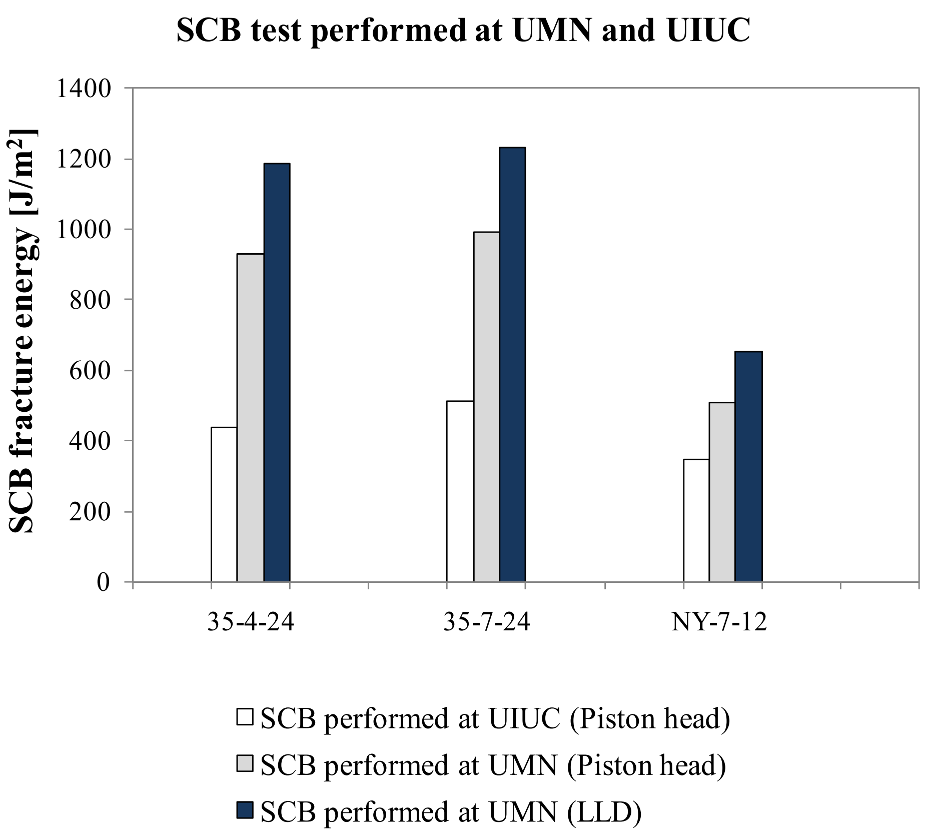


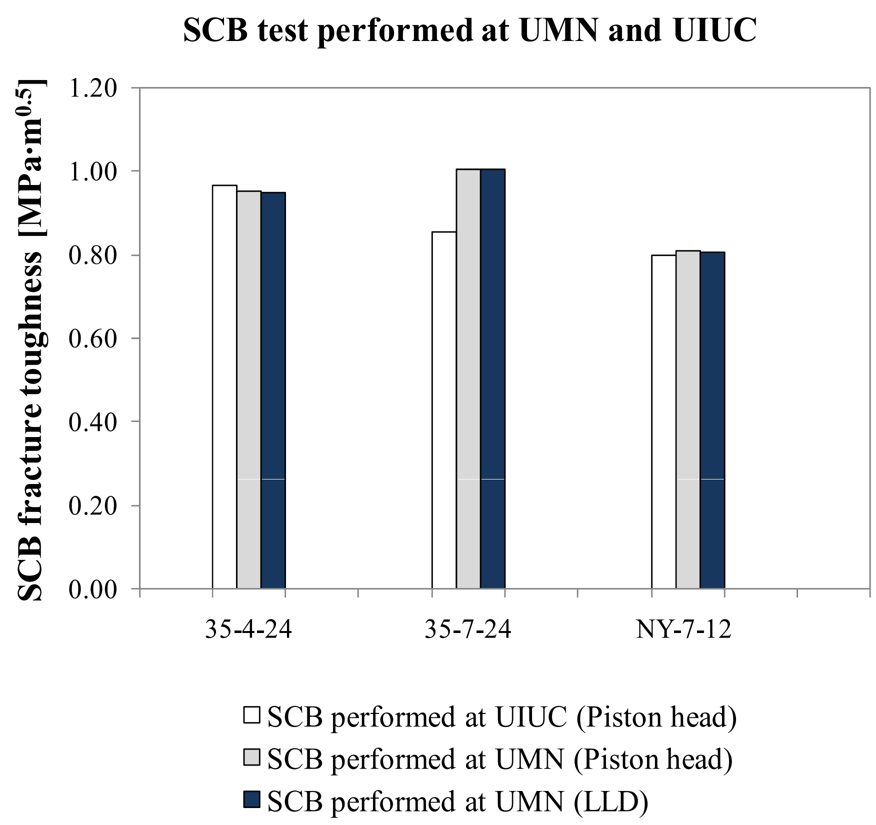
DCT test at UIUC – mixture 22-7-34



Analysis of Experimental Data

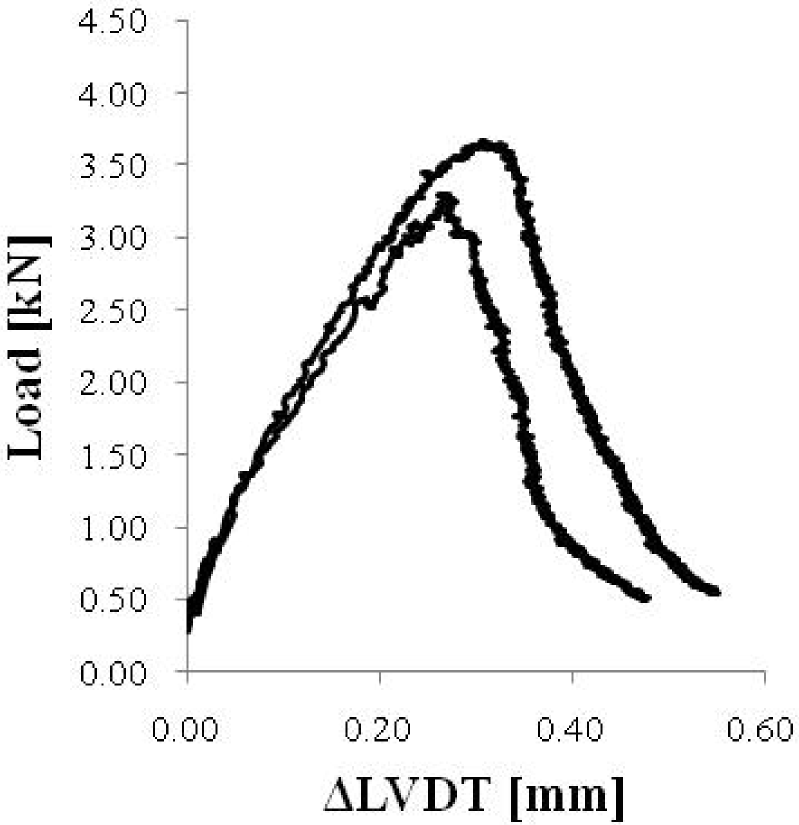
SCB



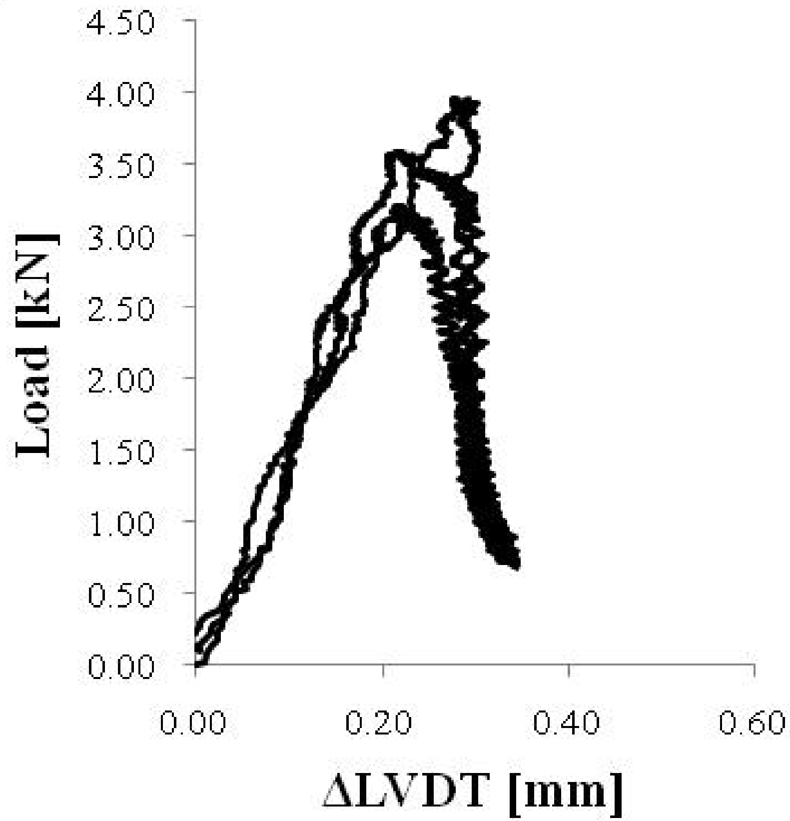


Analysis of Experimental Data

SCB



SCB test at UMN mixture 35-4-24

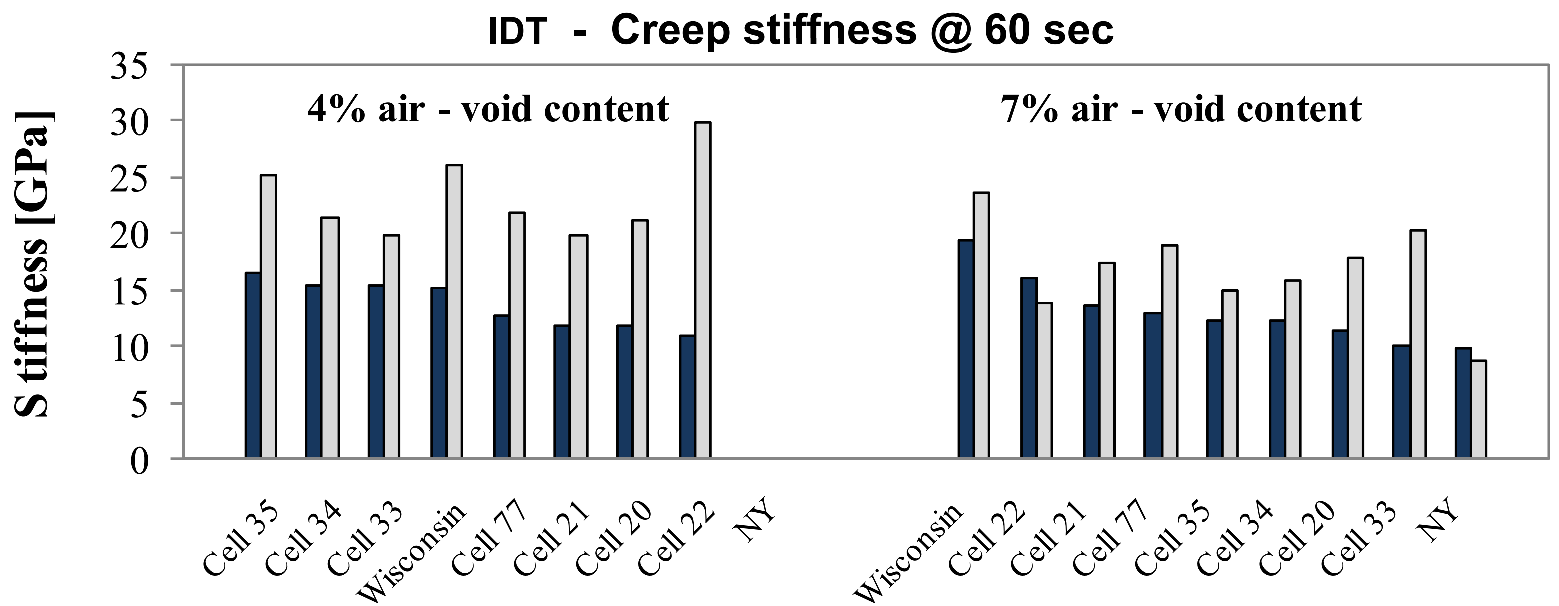


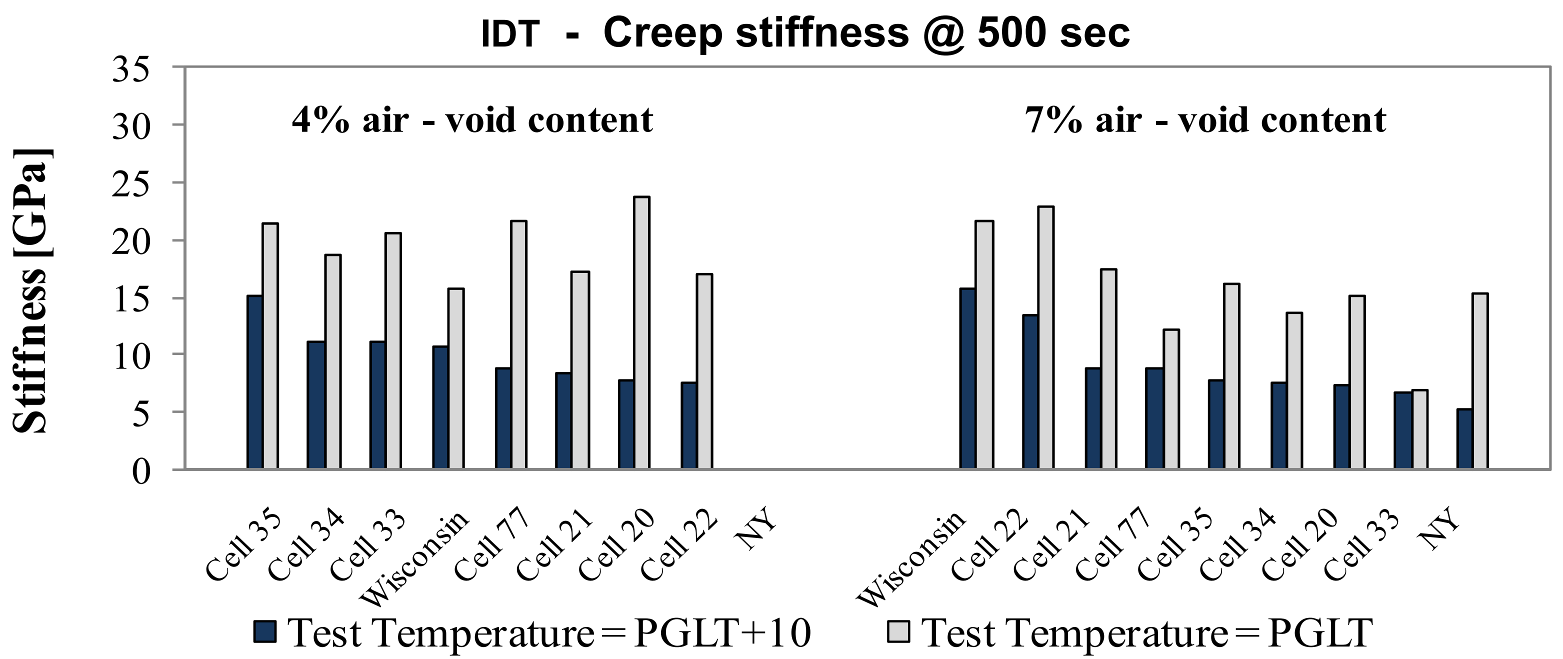
SCB test at UIUC mixture 35-4-24

Effect of Mixture Type, Air Void Content and Temperature on the IDT creep stiffness

Data analysis for laboratory compacted specimens

Analysis of Experimental Data





Analysis of Experimental Data

Summary of ANOVA tables

Experimental variables	IDT Creep Stiffness	
	S60	S500
Mix	√	√
Void	√	√
Temperature	√	√
Mix·Void	√	√
Mix·Temp	–	√
Void·Temp	√	√
Mix·Void·Temp	√	√

√ **:** Effect significant at 0.05 level of error
− : Effect non-significant at 0.05 level of error

Analysis of Experimental Data

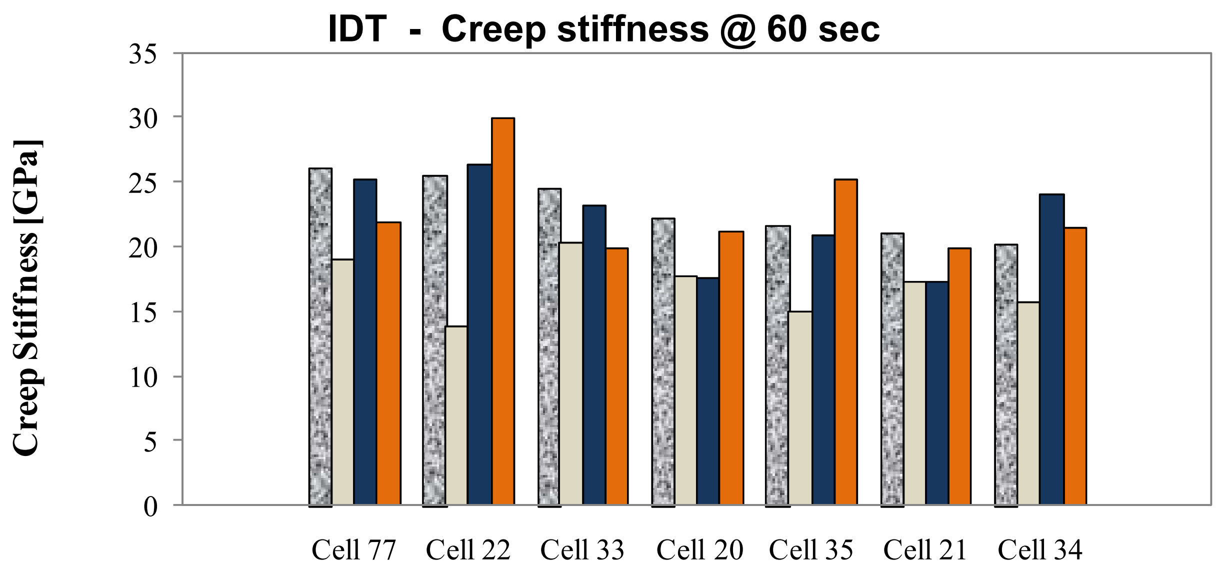
Statistical grouping & ranking of asphalt mixtures

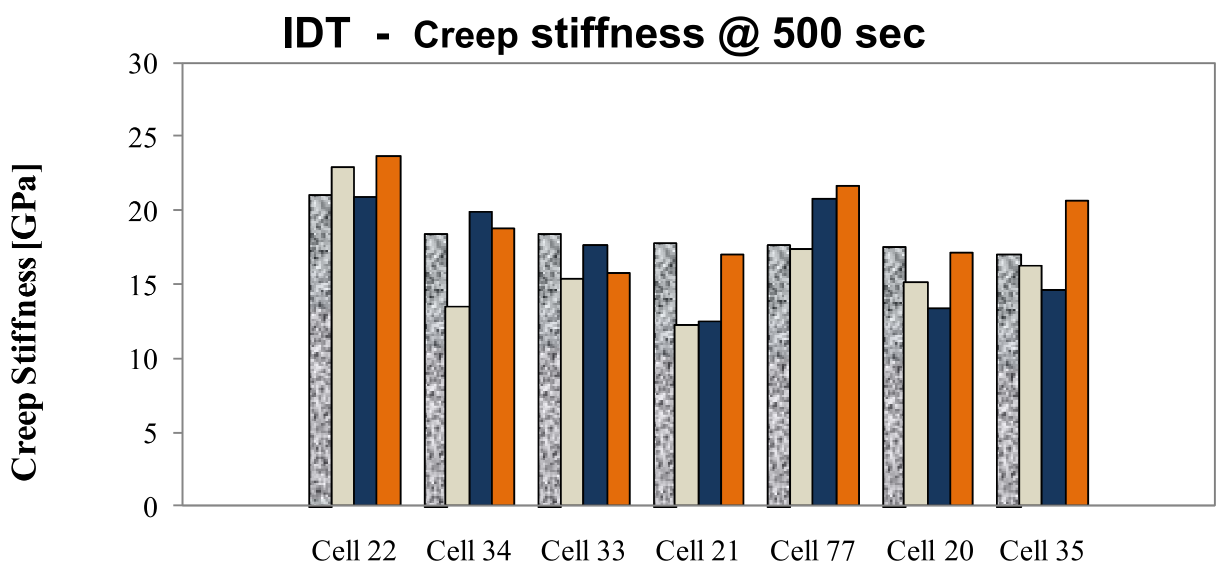
IDT creep stiffness [MPa]				
Mix Type	S60 Mean	Rank	S500 Mean	Rank
20	12.33	B/C	15.878	B
21	12.039	C	16.222	B
22	17.81	A	19.043	A/B
33	12.388	B/C	16.354	B
34	12.69	B/C	16.219	B
35	13.954	B/C	17.418	A/B
77	14.207	B	16.599	B
Wisconsin	18.481	A	21.028	A

IDT creep stiffness

Data analysis for field specimens

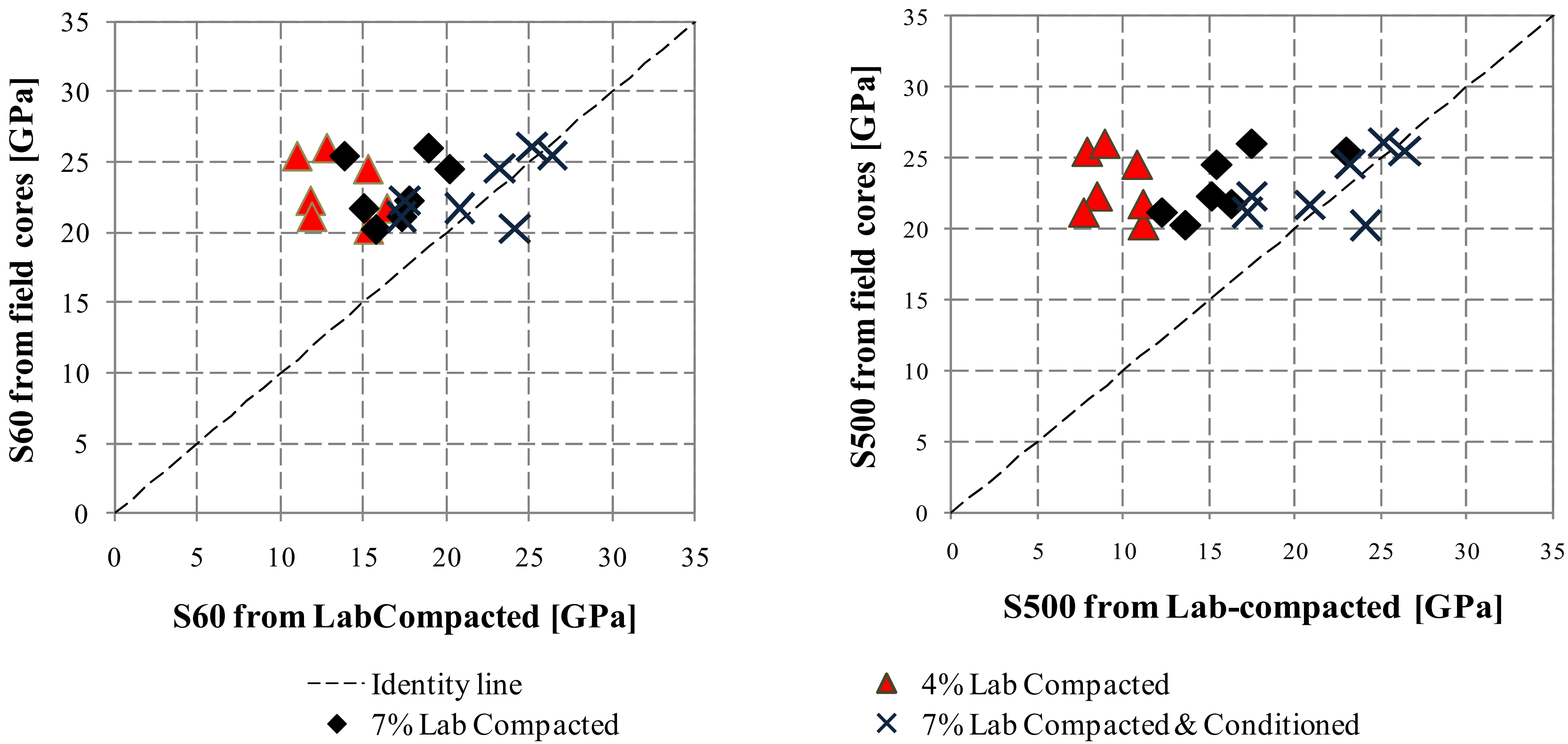
Analysis of Experimental Data





Analysis of Experimental Data

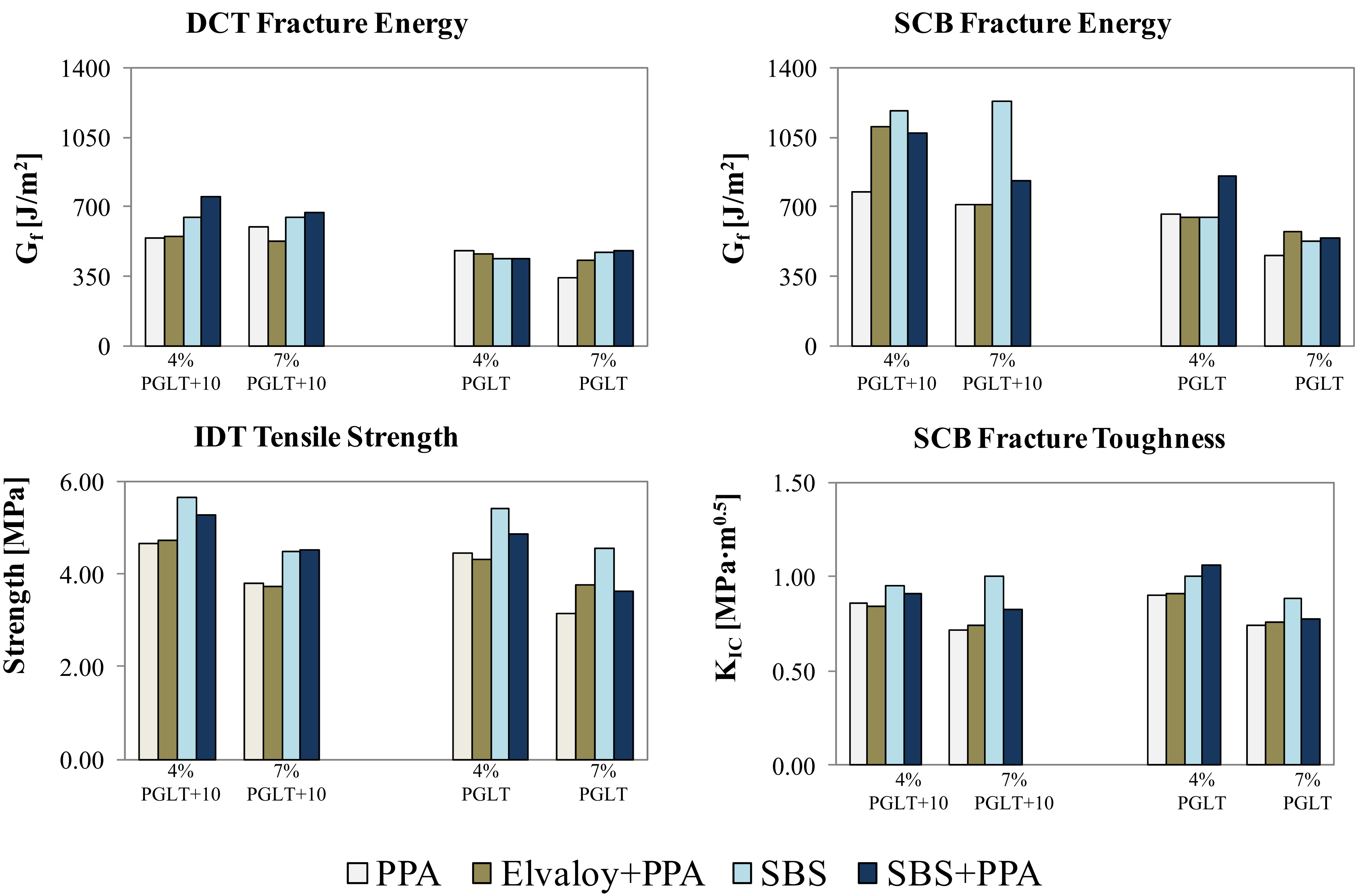
IDT Creep stiffness correlation field to laboratory specimens



Correlation coefficients of Field data to Lab		
Test conditions	S60	S500
7%- PGLT	0.26	0.73
7%- PGLT-Conditioned	0.61	0.61
4%- PGLT	0.36	0.47

Effect of asphalt modification on laboratory compacted specimens

Analysis of Experimental Data



Analysis of Experimental Data

Summary of ANOVA tables

Experimental variables	DCT Fracture energy	SCB Fracture energy	SCB Fracture toughness	IDT Strength
Void	–	√	√	√
Temperature	√	√	–	√
Modifier	√	√	√	√

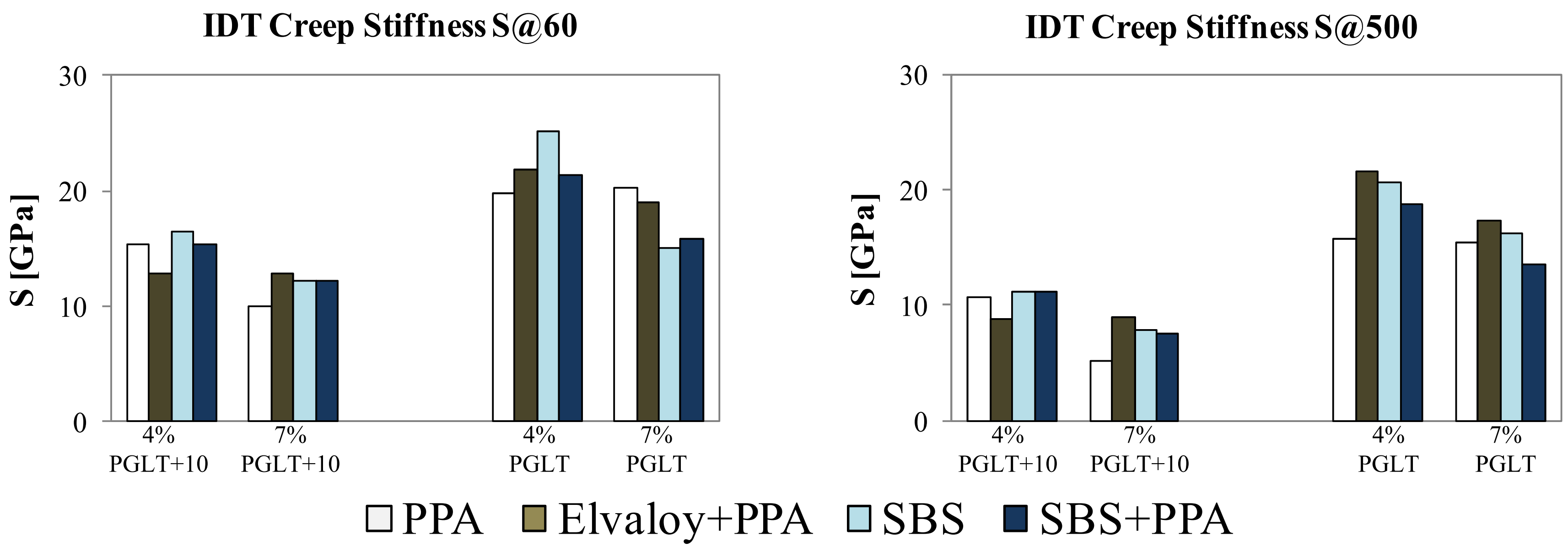
√ **:** Effect significant at 0.05 level of error
− : Effect non-significant at 0.05 level of error

Analysis of Experimental Data

Statistical grouping & ranking of asphalt mixtures

Modifier	DCT G_f [J/m^2]		SCB G_f [J/m^2]		SCB K_{IC} [MPa/m$^{0.5}$]		IDT strength [MPa]	
	Group Mean	Rank	Group Mean	Rank	Group Mean	Rank	Group Mean	Rank
SBS	560.9	A/B	834	A	0.96	A	5.1	A
SBS+PPA	583.6	A	822	A/B	0.89	A/B	4.6	B
Elavaloy+PPA	495.7	B	772	A/B	0.81	B	4.2	C
PPA	489.8	B	649	B	0.80	B	4.0	C

Analysis of Experimental Data



Summary of ANOVA tables

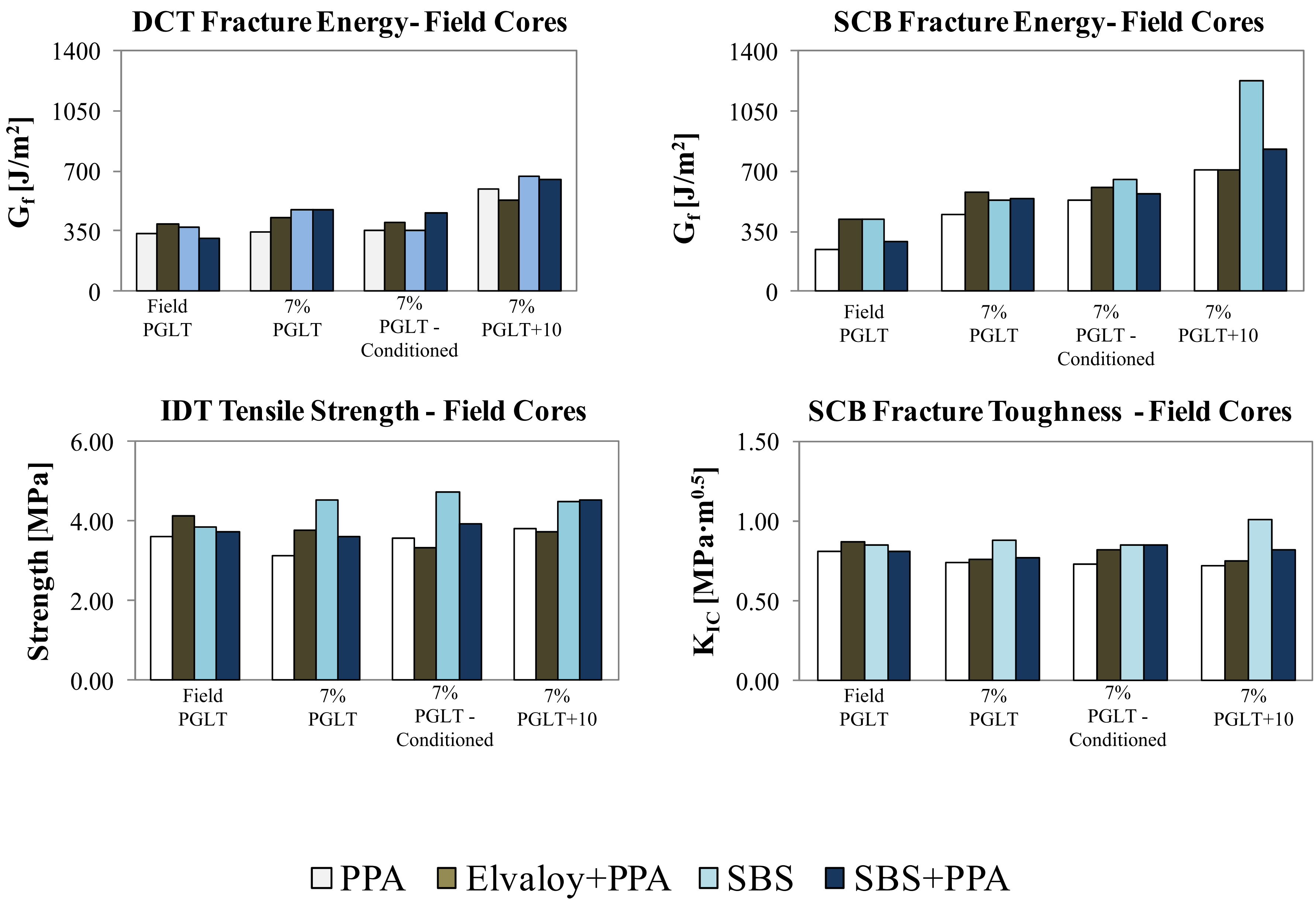
Experimental variables	IDT Creep stiffness S60	S500
Void	√	√
Temperature	√	√
Modifier	–	–

√ : Effect significant at 0.05 level of error

− : Effect non-significant at 0.05 level of error

Effect of asphalt modification on field specimens

Analysis of Experimental Data



Analysis of Experimental Data

Summary of ANOVA tables

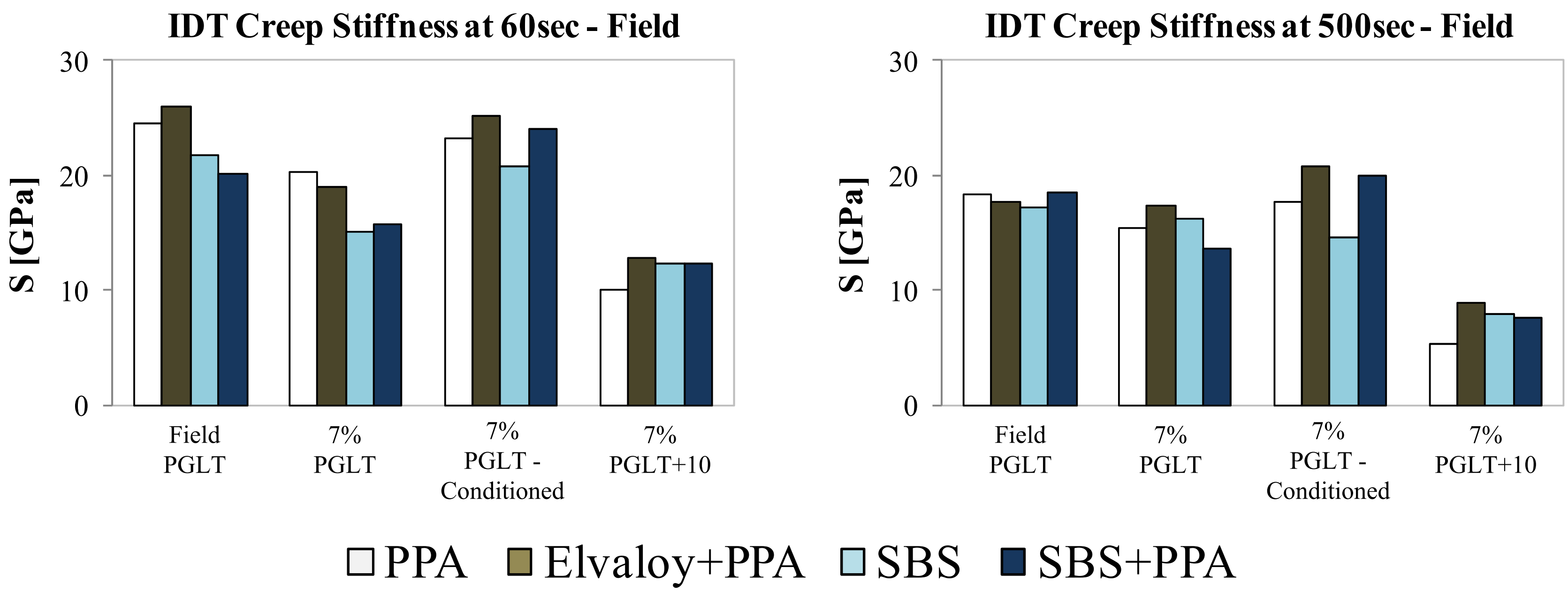
Experimental variables	DCT Fracture energy	SCB Fracture energy	SCB Fracture toughness	IDT Strength
Modifier	–	√	–	–

√ **:** Effect significant at 0.05 level of error
− : Effect non-significant at 0.05 level of error

Statistical grouping & ranking of asphalt mixtures

SCB fracture energy [J/m^2]		
Modifier	Group Mean	Rank
SBS	421.9	A
Elvaloy+PPA	301.6	A/B
SBS+PPA	288.6	A/B
PPA	246.3	B

Analysis of Experimental Data



Summary of ANOVA tables

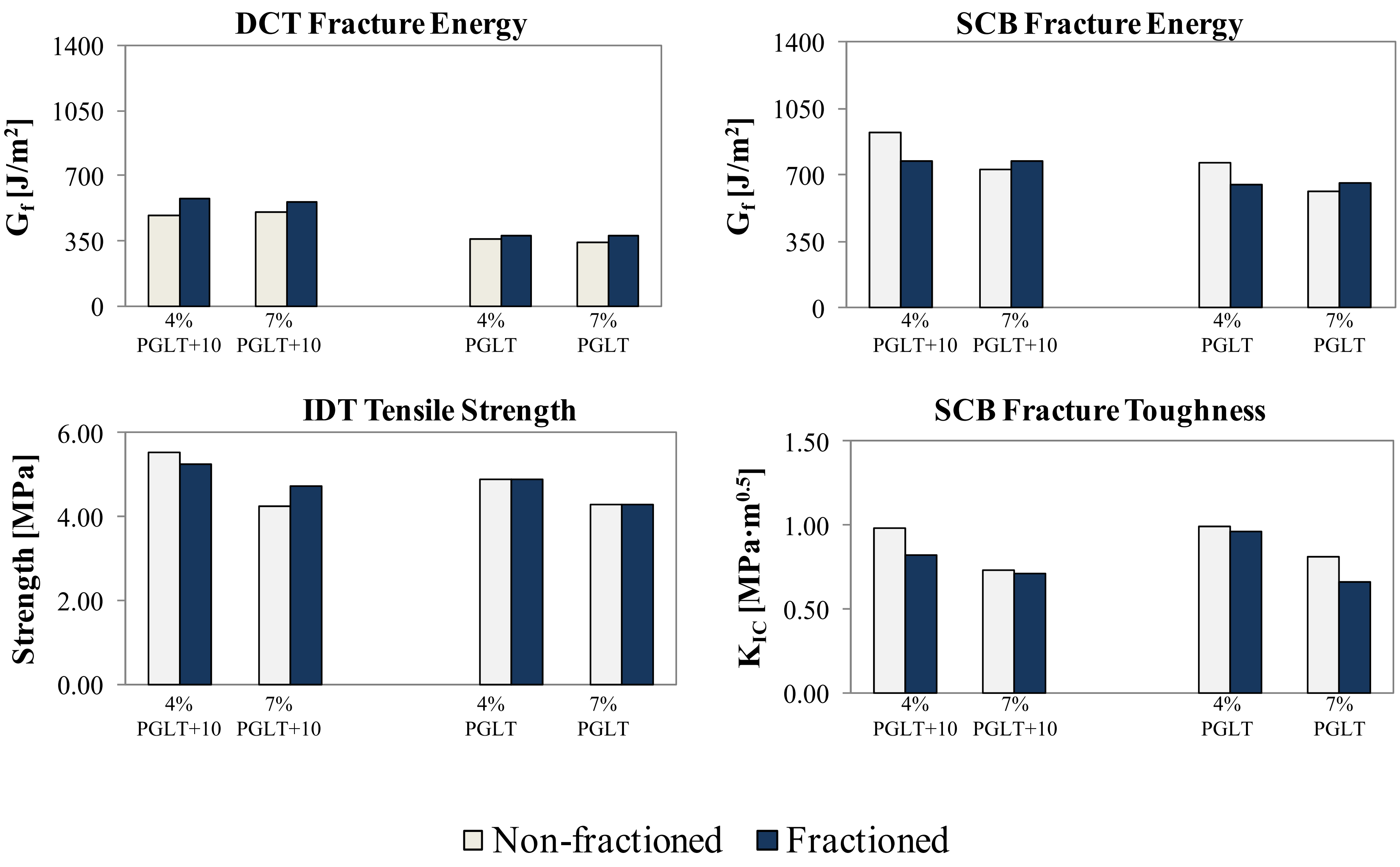
Experimental variables	IDT Creep stiffness S60	IDT Creep stiffness S500
Modifier	–	–

√ : Effect significant at 0.05 level of error

– : Effect non-significant at 0.05 level of error

Effect of RAP fractioning on laboratory compacted specimens

Analysis of Experimental Data



Analysis of Experimental Data

Summary of ANOVA tables

Experimental variables	DCT Fracture energy	SCB Fracture energy	SCB Fracture toughness	IDT Strength
Void	–	–	√	√
Temperature	√	–	–	√
Fractioning	–	–	√	–

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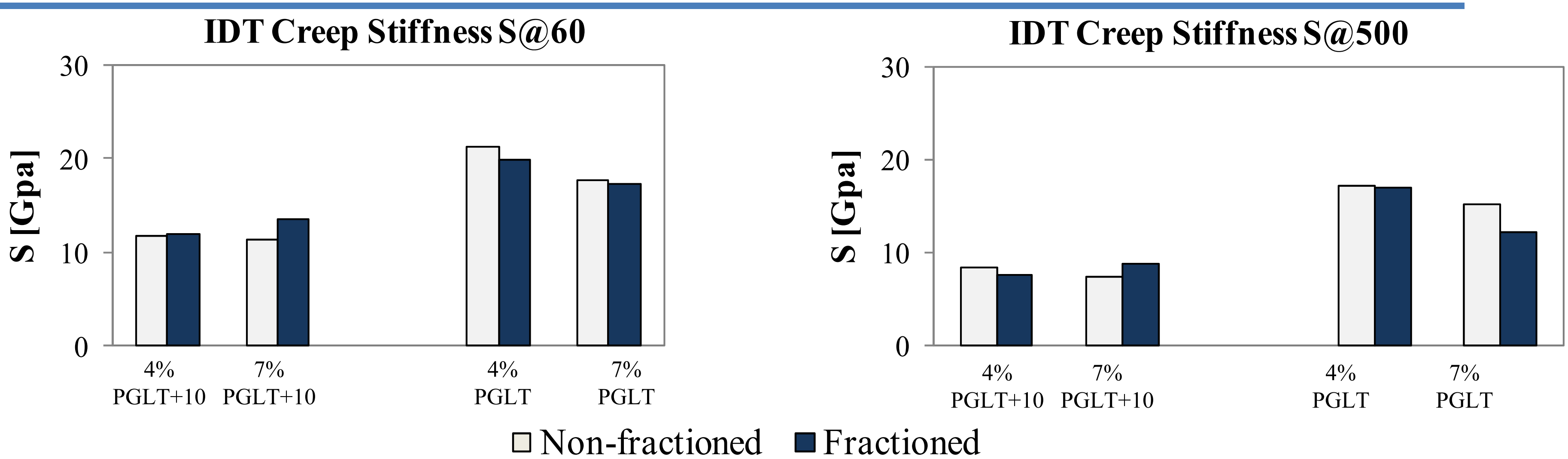
− : Effect non-significant at 0.05 level of error

Analysis of Experimental Data



Summary of ANOVA tables

Experimental variables	IDT Creep stiffness S60	IDT Creep stiffness S500
Void	–	√
Temperature	√	√
Fractioning	–	–

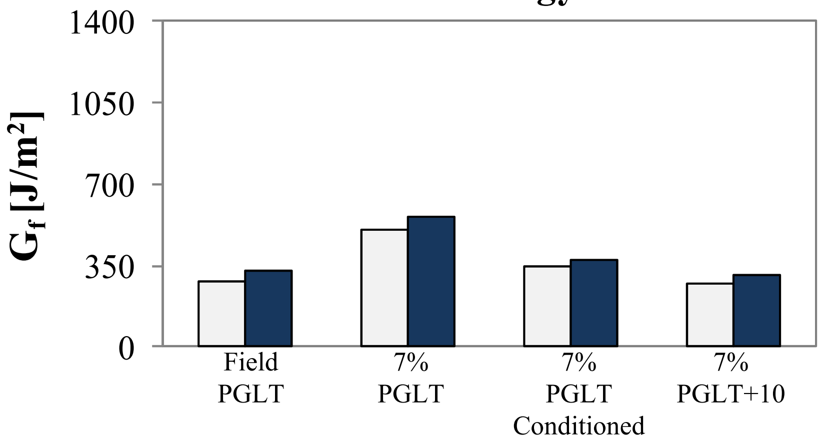
√ : Effect significant at 0.05 level of error

− : Effect non-significant at 0.05 level of error

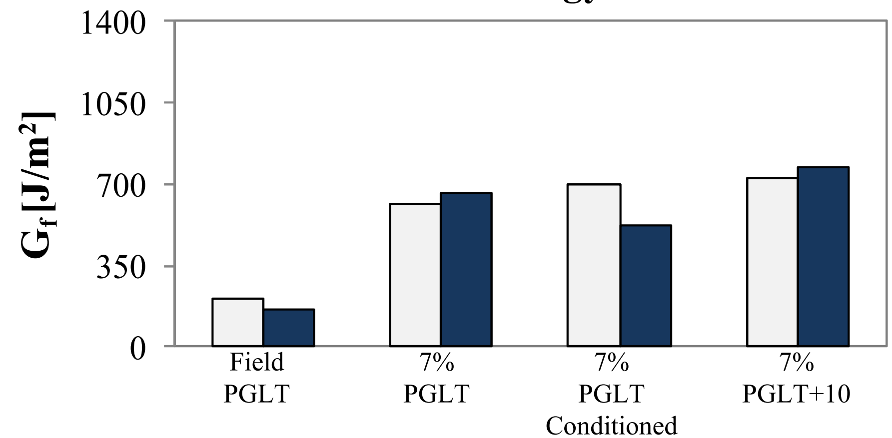
Effect of RAP fractioning on field specimens

Analysis of Experimental Data

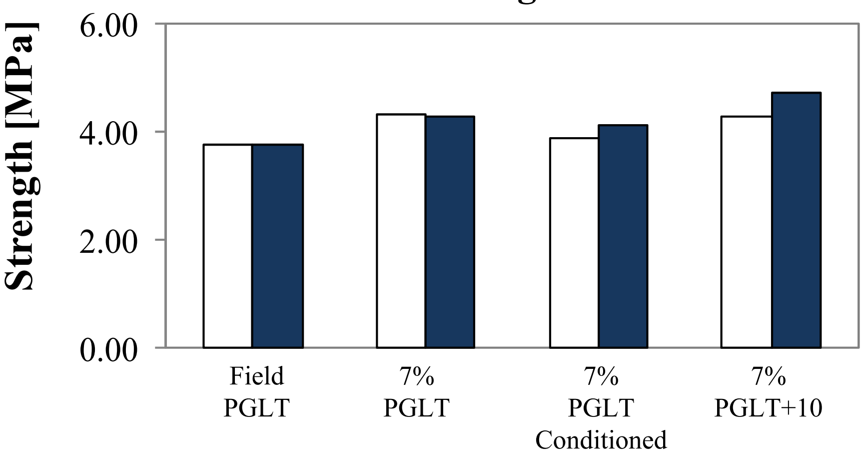
DCT Fracture Energy- Field Cores



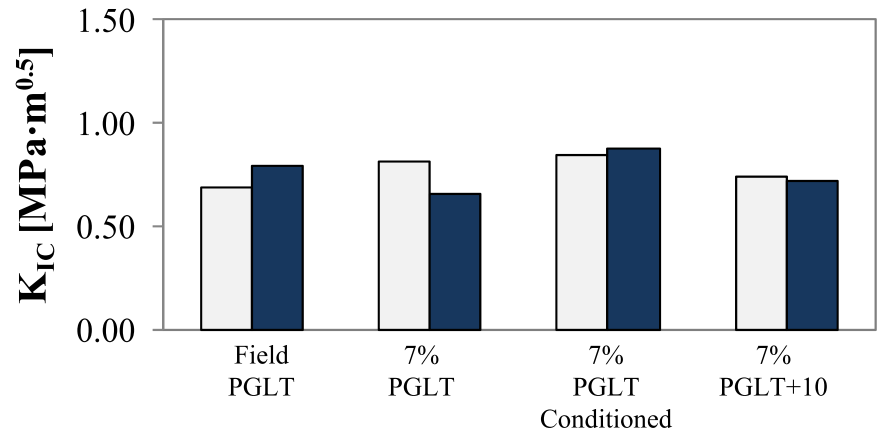
SCB Fracture Energy - Field Cores



IDT Tensile Strength - Field Cores



SCB Fracture Toughness - Field Cores



□ Non-fractioned ■ Fractioned

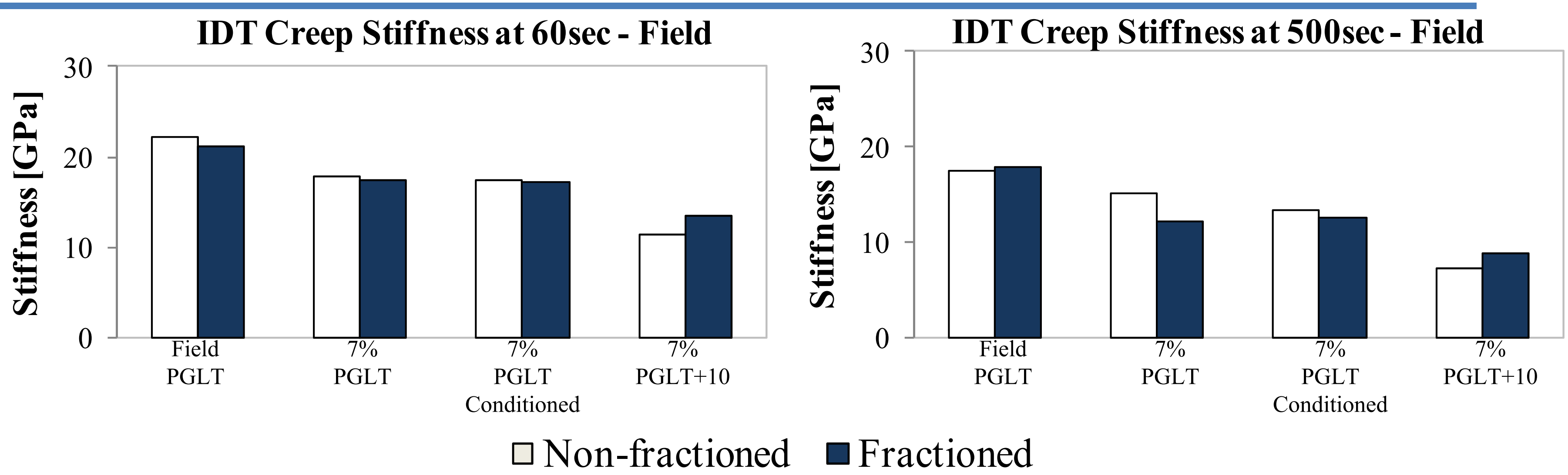
Analysis of Experimental Data

Summary of ANOVA tables

Experimental variables	DCT Fracture energy	SCB Fracture energy	SCB Fracture toughness	IDT Strength
Fractioning	–	–	–	–

√ : Effect significant at 0.05 level of error
− : Effect non-significant at 0.05 level of error

Analysis of Experimental Data



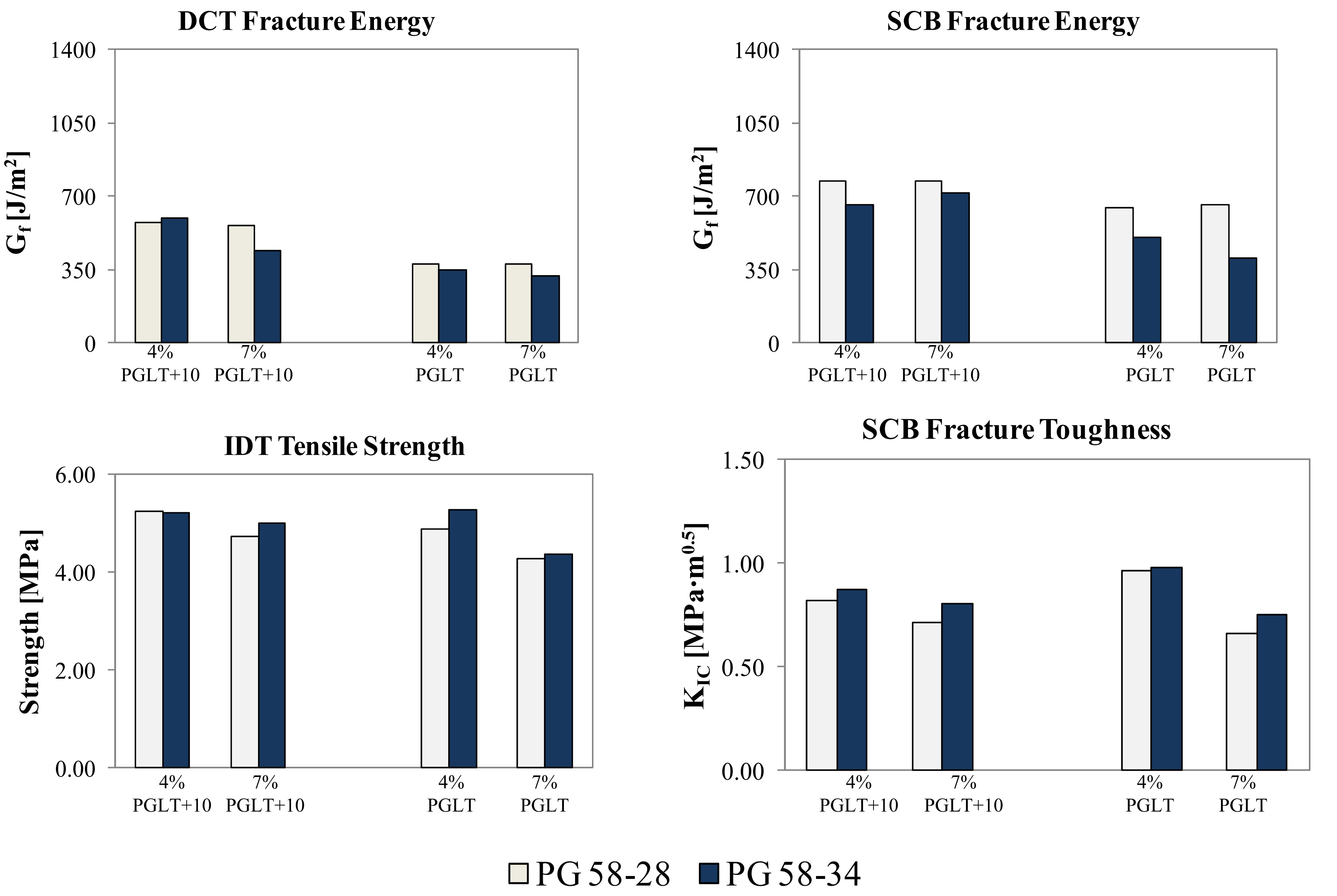
Summary of ANOVA tables

Experimental variables	IDT Creep stiffness	
	S60	S500
Fractioning	–	–

√ : Effect significant at 0.05 level of error
– : Effect non-significant at 0.05 level of error

Effect of binder PG low limit on laboratory compacted specimens

Analysis of Experimental Data



Analysis of Experimental Data

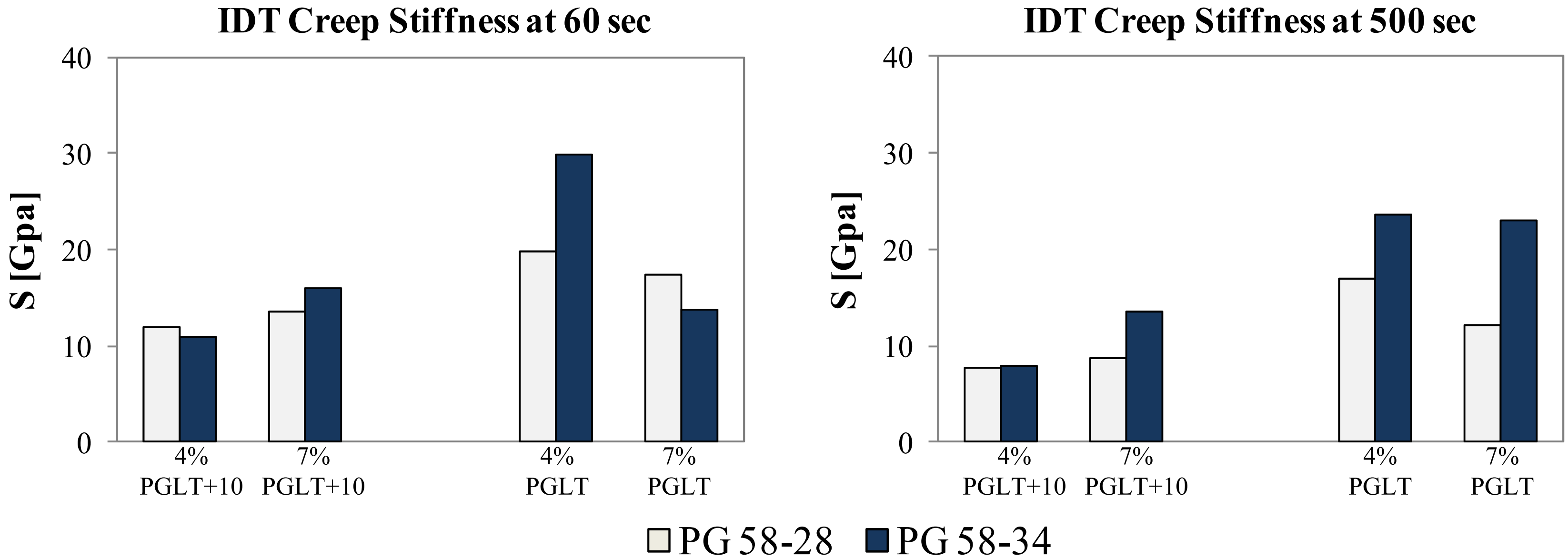
Summary of ANOVA tables

Experimental variables	DCT Fracture energy	SCB Fracture energy	SCB Fracture toughness	IDT Strength
Void	√	–	√	√
Temperature	√	√	–	√
PG	–	√	–	–

√ : Effect significant at 0.05 level of error

− : Effect non-significant at 0.05 level of error

Analysis of Experimental Data



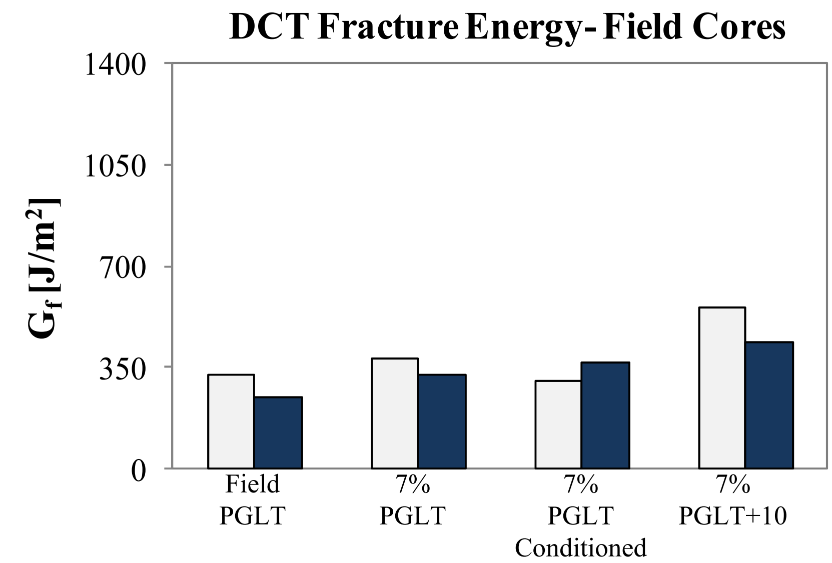
Summary of ANOVA tables

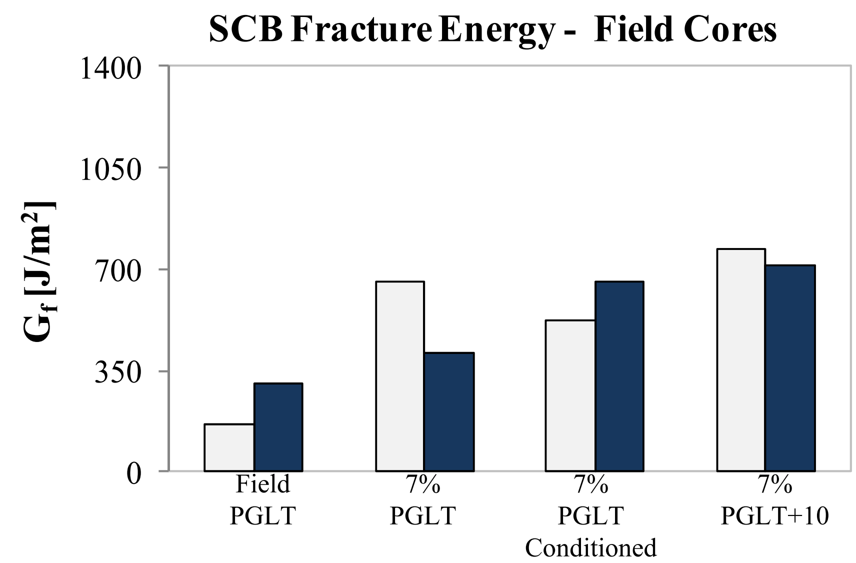
Experimental variables	IDT Creep stiffness S60	S500
Void	–	–
Temperature	√	√
PGLT	–	√

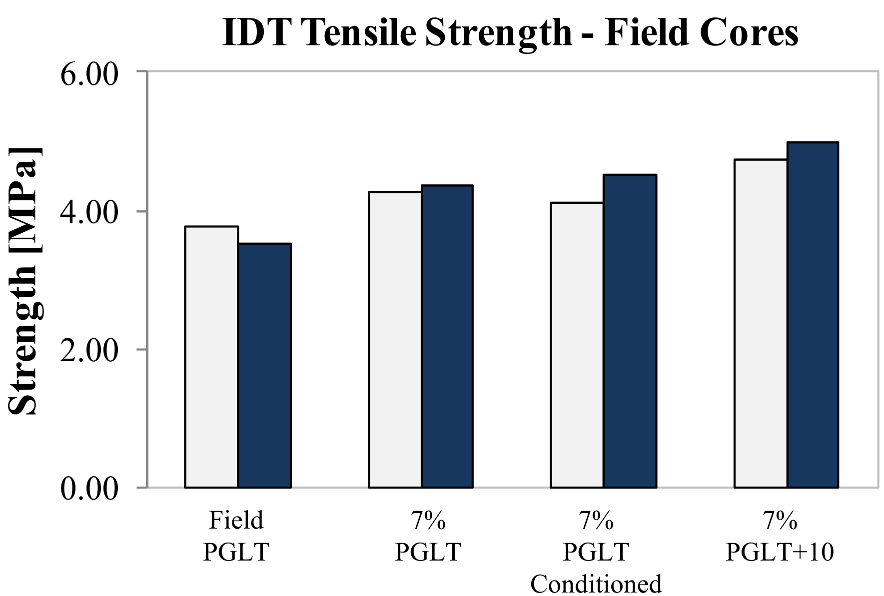
√ : Effect significant at 0.05 level of error
− : Effect non-significant at 0.05 level of error

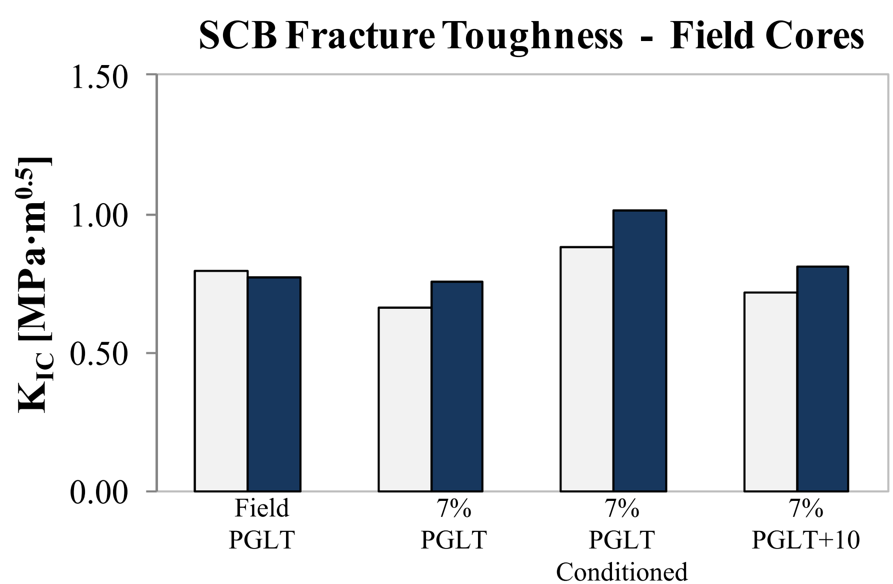
Effect of binder PG low limit on field specimens

Analysis of Experimental Data









PG 58-28 PG 58-34

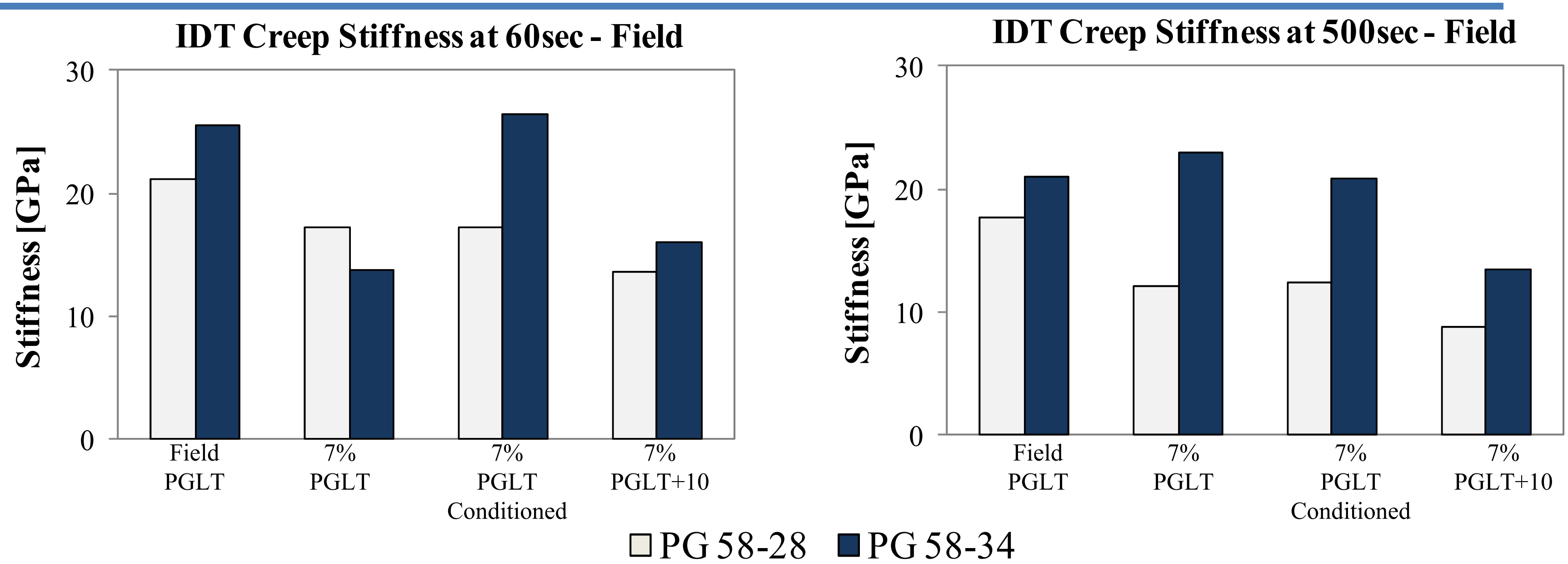
Analysis of Experimental Data

Summary of ANOVA tables

Experimental variables	DCT Fracture energy	SCB Fracture energy	SCB Fracture toughness	IDT Strength
PG	–	√	–	–

√ : Effect significant at 0.05 level of error
− : Effect non-significant at 0.05 level of error

Analysis of Experimental Data



Summary of ANOVA tables

Experimental variables	IDT Creep stiffness S60	S500
PG	–	√

√ : Effect significant at 0.05 level of error
− : Effect non-significant at 0.05 level of error

Conclusions & Summary of Findings

Unconditioned laboratory compacted mixtures

- **DCT fracture energy** from approximately **190 J/m^2 to 800 J/m^2**. Values at PGLT+10˚C always larger than those at PGLT, except for mixture '*Wisconsin*'. Overall, effect of the air void content on DCT fracture energy appeared to be minimal.

- **SCB fracture energy** between **300 and 1380 J/m^2**. Values at PGLT+10˚C always higher than those at PGLT. SCB fracture energy decreases when air void content increases.

- **SCB fracture toughness** from **0.45 to 1.20 MPa•m$^{0.5}$**. For 4% air voids, SCB fracture toughness increased with temperature decrease. Contrarily to SCB fracture energy, K_{IC} results suggest temperature has a minimal effect.

Conclusions & Summary of Findings

- **IDT tensile strength** ranged from **2.30 to 7 MPa**. Strength was higher for mixtures with lower air void content. In addition, except for a few mixtures, the strength values obtained at PGLT+10˚C were higher than the values obtained at PGLT. **NY mixture** had significantly **higher IDT strength at** 7% air voids. This mixture could not be compacted to 4% air voids.

- **Multiple comparisons**, at 5% level of significance, performed to compare and rank **laboratory mixtures**, according to different test methods. Mixture in **cell 35 scored the best and ranked in first category for all test methods**. The mixture from **Wisconsin ranked the least favorable** out of all mixtures tested (NY mixture not included in the analysis since it could not be compacted to 4%).

Conclusions & Summary of Findings

Field Cores

- Except for SCB fracture energy, the mixtures are statistically similar. For SCB fracture energy, the best performer was again the mixture from cell 35.

- Comparison between laboratory mixtures and field cores was performed by means of data correlation and correlation plots. The best match was observed for DCT fracture energy. **For SCB fracture energy, significantly lower values were obtained for field cores compared to laboratory samples.**

Conclusions & Summary of Findings

Factor Effects

- **Mix conditioning** was found significant only for DCT fracture energy and SCB fracture toughness. DCT fracture energy decreased with mix conditioning, and SCB fracture toughness increased with mix conditioning.

- **Asphalt modification** had a significant effect on fracture properties of laboratory mixtures. A multiple comparison indicates that the SBS modified mixture (cell 35) ranked the best overall.

- For the **field cores**, however, **asphalt modification** was significant only for SCB fracture energy. The statistically significant higher fracture energy was again observed for cell 35 mixture

Conclusions & Summary of Findings

Factor Effects

- The effect of **RAP fractioning** in laboratory compacted asphalt mixtures was found statistically not significant except for the SCB fracture toughness. For the field cores, RAP fractioning was found insignificant for all test results.

- The effect of **PG lower limit** was found statistically significant only for SCB fracture energy. For the laboratory mixtures, the PG 58-28 mixture tested at PGLT had higher fracture energy compared to the PG 58-34 mixture. The opposite was true for the field cores.

Conclusions & Summary of Findings

- The limited comparison of the **results obtained at UMN and UIUC** laboratories, respectively, indicated significant differences for both DCT and SCB test results

THANK YOU …