Asphalt Modifiers and Low Temperature Properties of Asphalt Mixtures

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Low Temperature Cracking Pooled Fund Study, Phase I

- Comprehensive project
  - Experimental investigation
    - Asphalt mixtures
      - Laboratory prepared
      - Cores and beams from selected pavements
    - Asphalt binders
      - Laboratory aged
      - Extracted from field cores
    - Experimental data analysis
  - Pavement system modeling

Mixture Testing

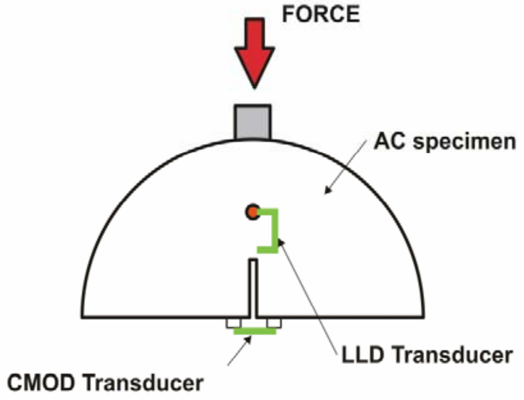
- Two sets of asphalt mixtures
  - Twenty eight laboratory prepared
    - Ten binders
    - Two aggregates
    - Two film thicknesses (asphalt content)
    - Two air voids levels
  - Thirteen samples taken from nominated sites
    - Seven Minnesota (five from MnROAD)
    - Two Wisconsin
    - Three Illinois
    - One North Dakota

Air Voids		**Design (4%)**				**As constructed (7%)**			
Aggregate Type		**Granite**		**Limestone**		**Granite**		**Limestone**	
Binder Content		Design	Film thickness	Design	Film thickness	Design	Film thickness	Design	Film thickness
Binder Type	PG58-40 SBS 1	☐	☐	☐					
	PG58-34 Elvaloy	☐	☐	☐					
	PG58-34 SBS 1	☐		☐					
	PG58-28 plain 1	☐	☐	☐	☐	☐	☐	☐	☐
	PG58-28 plain 2	☐		☐					
	PG64-34 Elvaloy	☐		☐					
	PG64-34 Black Max	☐		☐					
	PG64-28 plain 1	☐		☐					
	PG64-28 SBS 2	☐		☐					
	PG64-22 Plain 1	☐		☐					

Site	Code name	Original grade	Equivalent grade
MnROAD Cell 03	MnROAD 03	120/150	PG 58-28
MnROAD Cell 19	MnROAD 19	AC-20	PG 64-22
MnROAD Cell 33	MnROAD 33	PG 58-28	PG 58-28
MnROAD Cell 34	MnROAD 34	PG 58-34	PG 58-34
MnROAD Cell 35	MnROAD 35	PG 58-40	PG 58-40
MN CSAH-75, section 2 EB	MN75 2	PG 58-28	PG 58-28
MN CSAH-75, section 4 WB	MN75 4	PG 58-34	PG 58-34
WI US-45	WI US 45	PG 58-34	PG 58-34
WI STH-73	WI STH 73	PG 58-28	PG 58-28
IL US-20, section 6	IL US20 6	AC-10	PG 58-28
IL US-20, section 7	IL US20 7	AC-20	PG 64-22
IL I-74	IL I74	AC-20	PG 64-22
ND SH-18	ND 18	120/150	PG 58-28

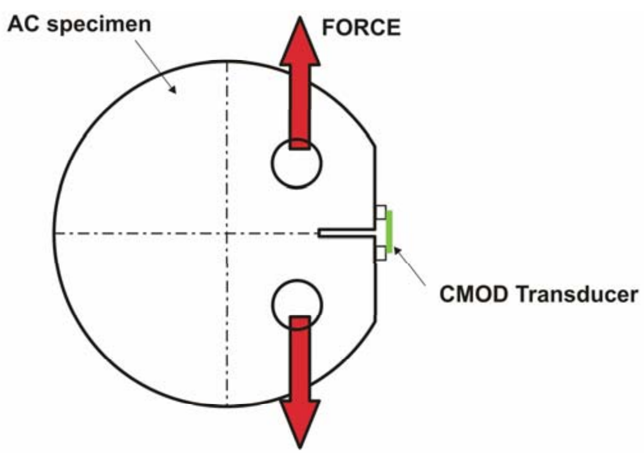
Mixture tests performed

- IDT
  - Creep (multiple load levels)
  - Strength (multiple loading rates)

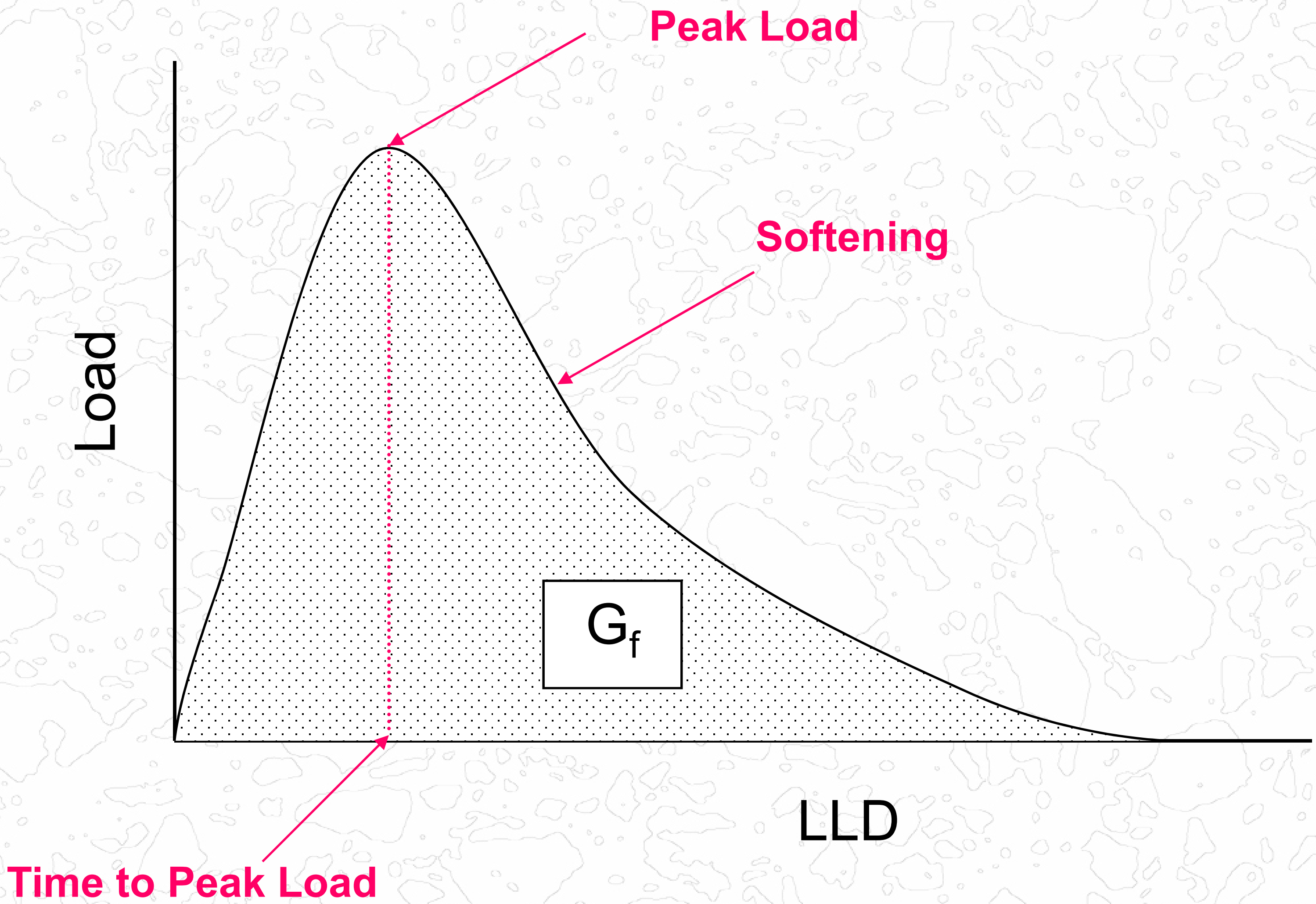


- Semi Circular Bending (SCB)

- Disc-Shaped Compact Tension DC(T)

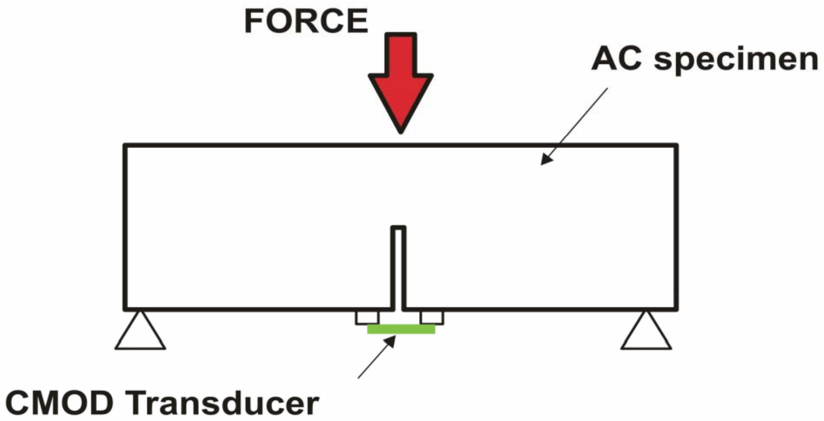


Load vs. Load Line Displacement



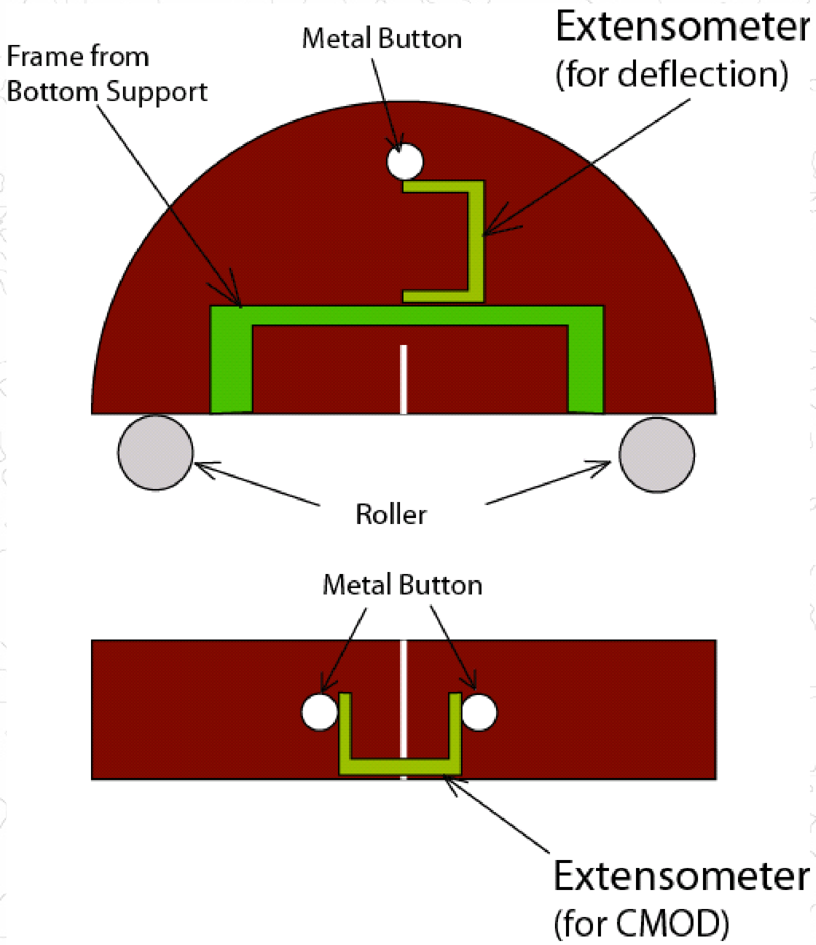
Mixture tests performed

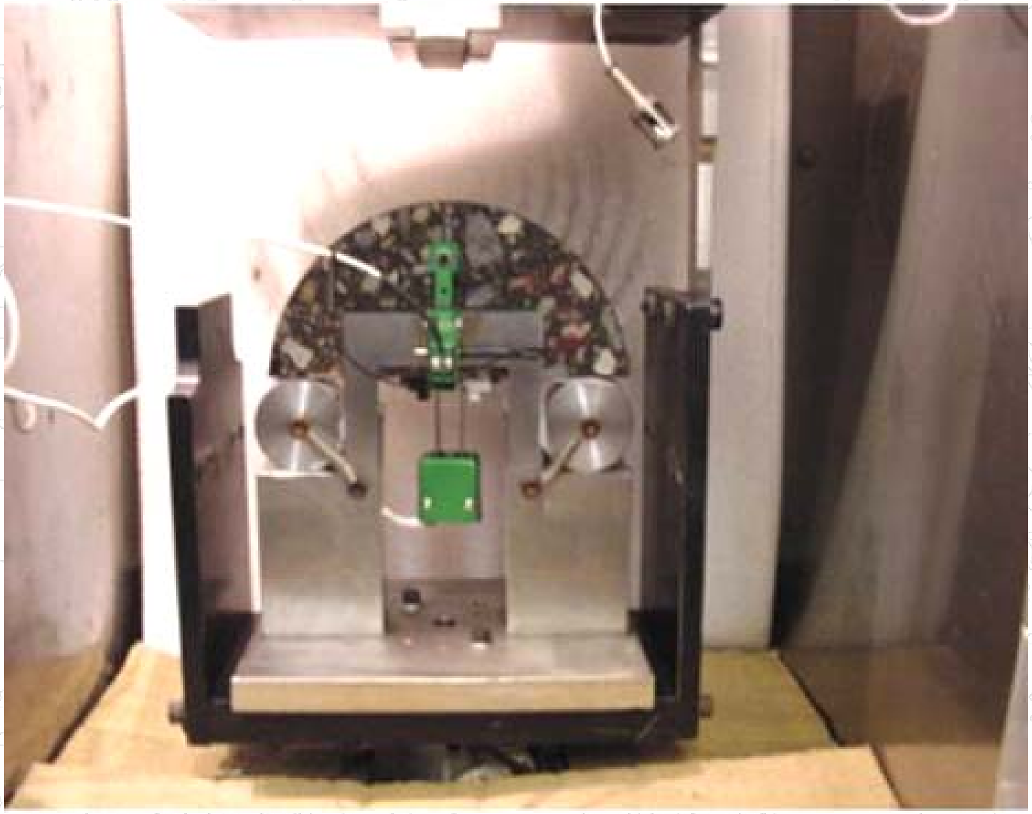
- Single-Edge Notched Beam, SE(B)
  - Limited testing



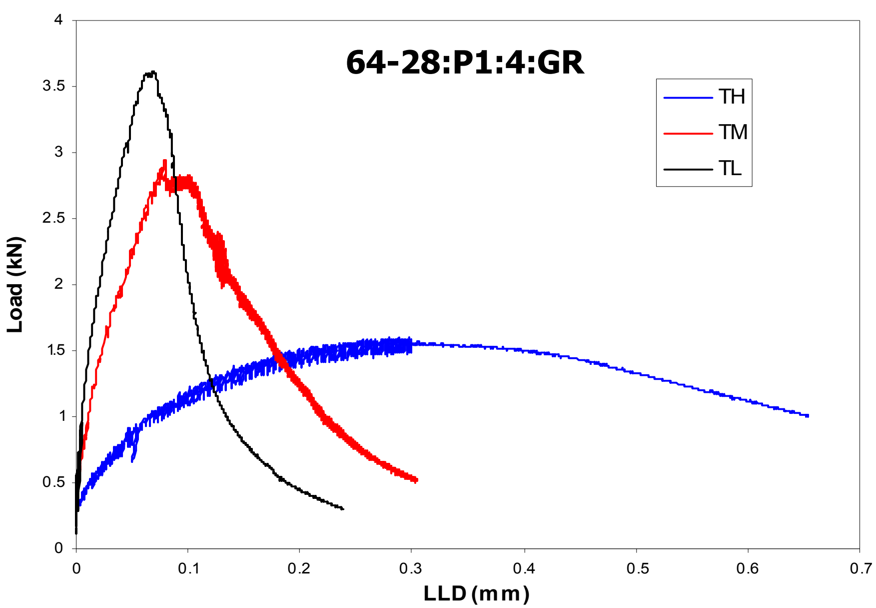
- Thermal Stress Restrained Specimen Test (TSRST)

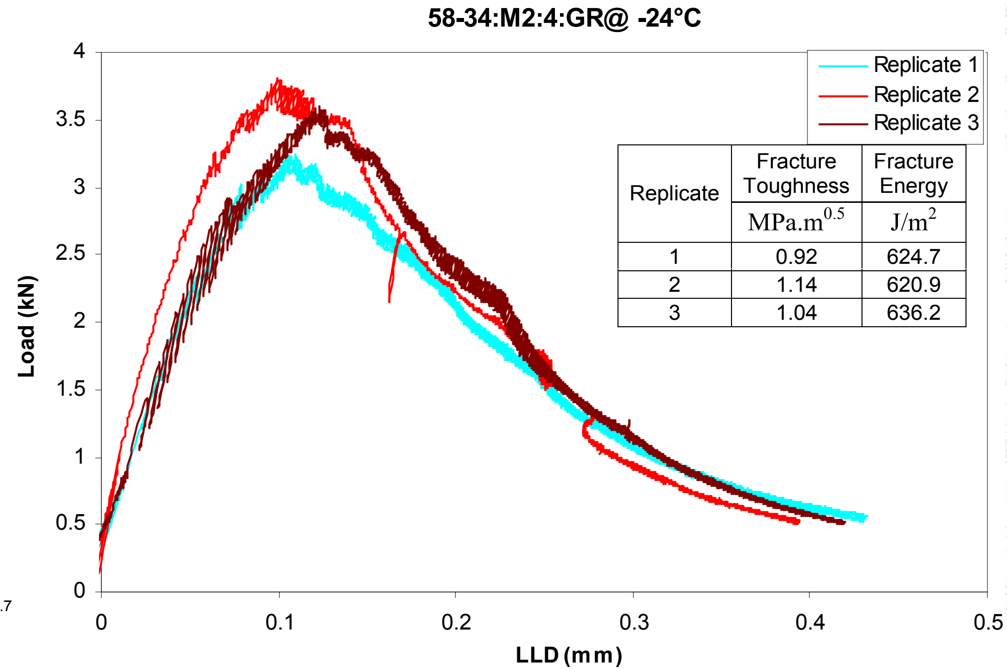
Semi Circular Bend Test





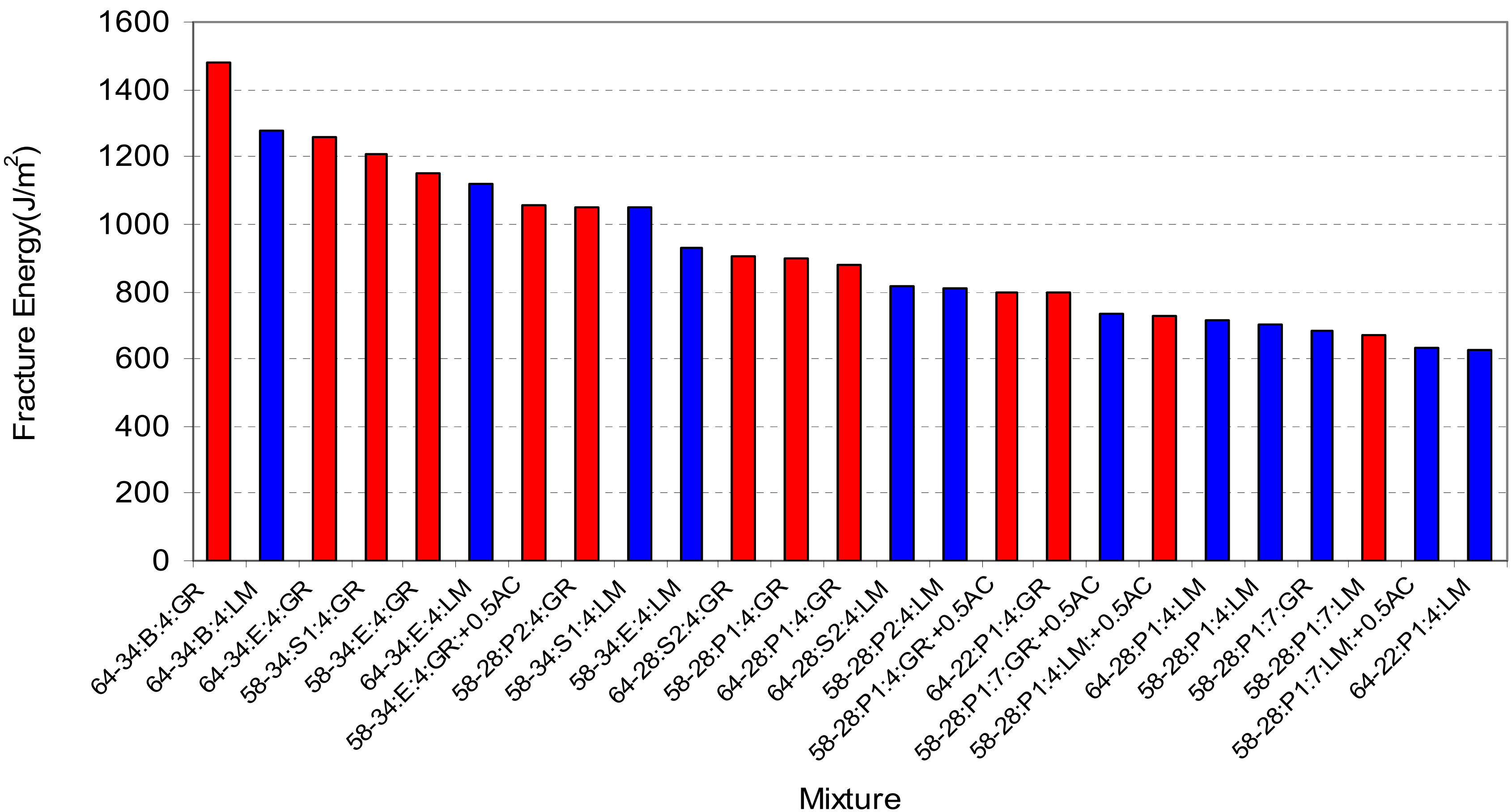
Experimental Results





Replicate	Fracture Toughness	Fracture Energy
	$MPa.m^{0.5}$	J/m^2
1	0.92	624.7
2	1.14	620.9
3	1.04	636.2

Fracture Energy at T_H (PG +10°C + 12°C)



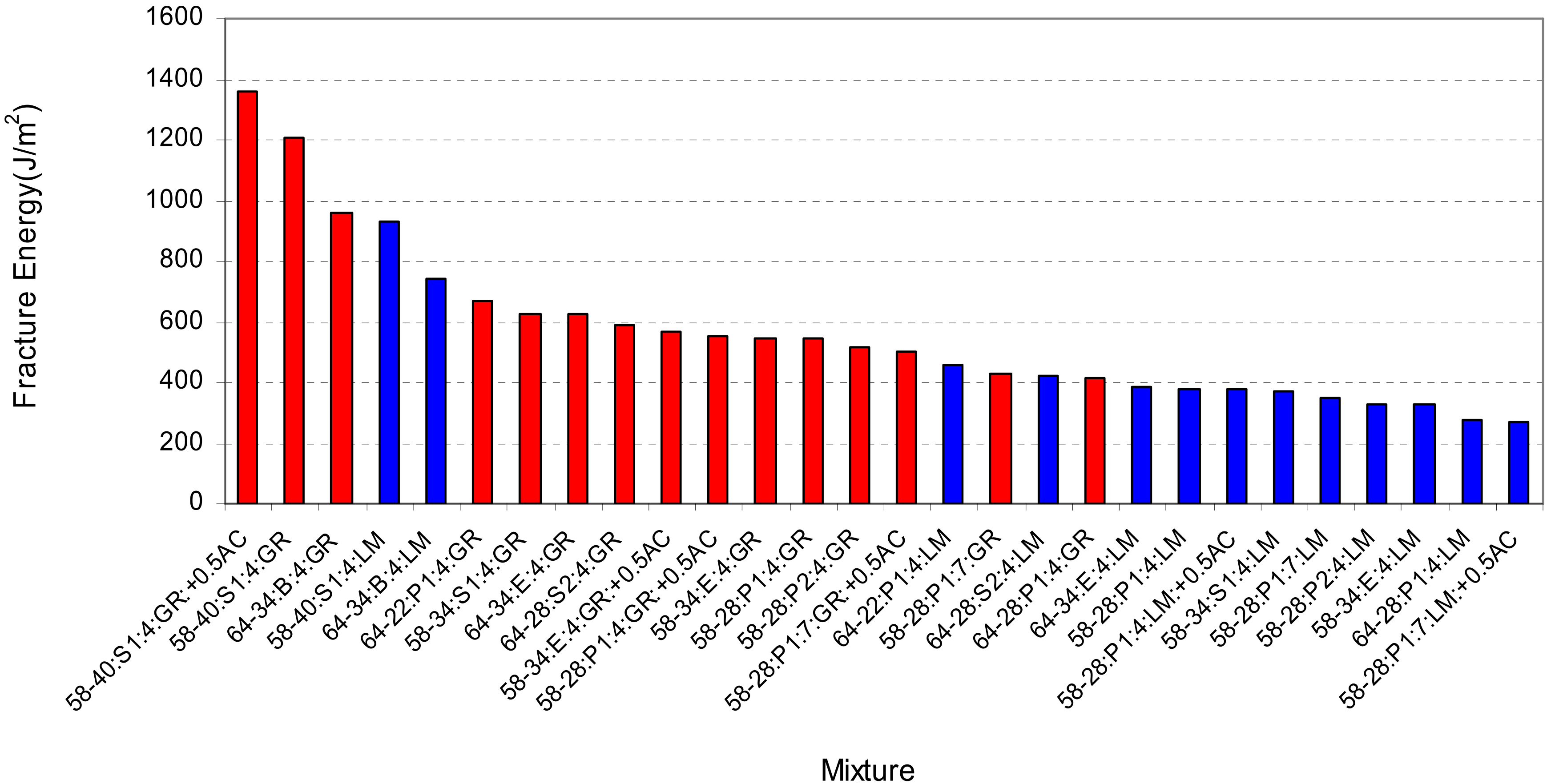
Fracture Energy Ranking at T_H

Highest: 64-34:B:4:GR

Not calculated: 58-40:M1

Lowest: 64-22:P1:4:LM

Fracture Energy at T_M (PG +10°C)

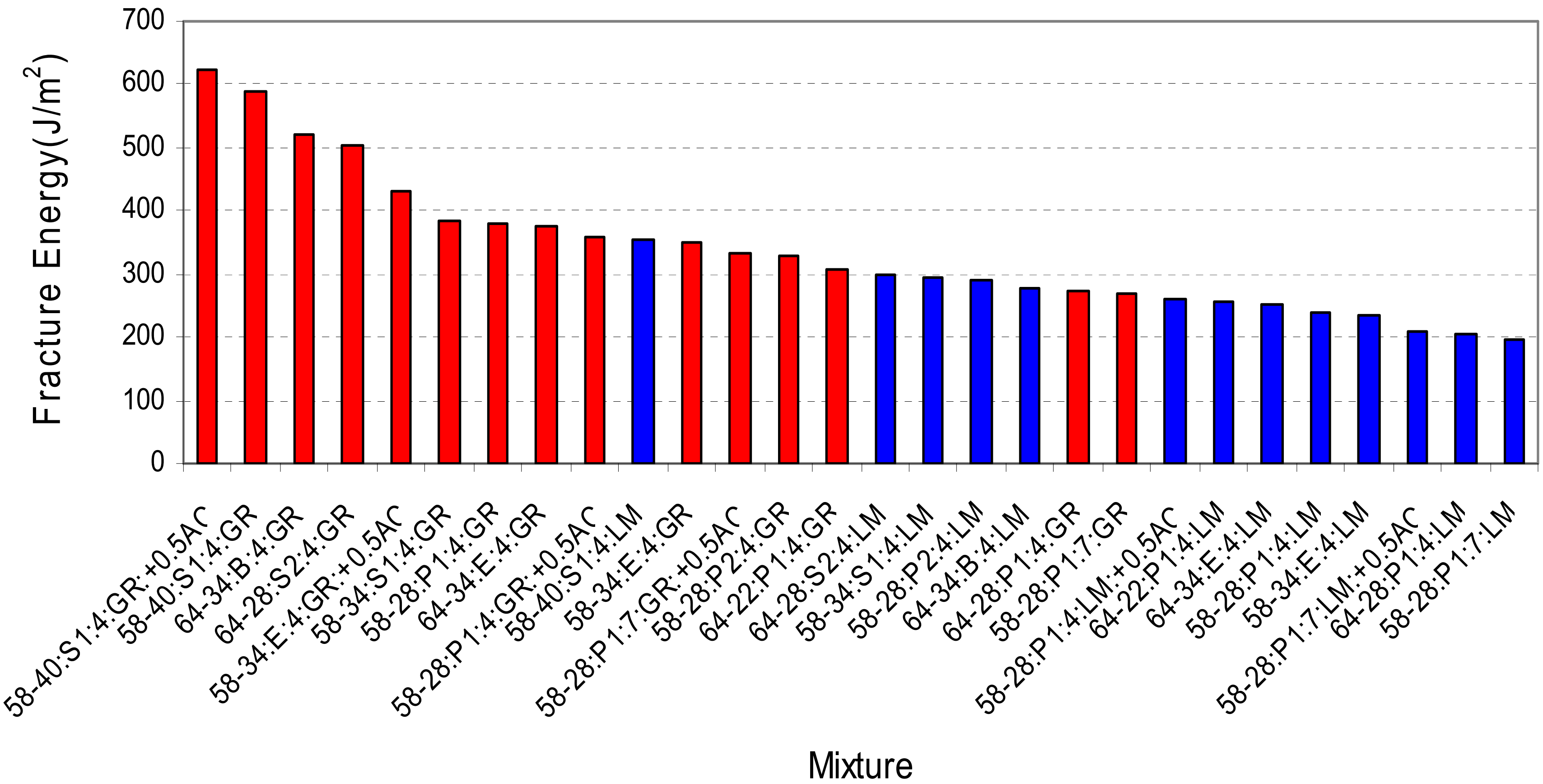


Fracture Energy Ranking at T_M

Highest: 58-40:S1:4:GR:+0.5AC

Lowest: 58-28:P1:7:LM:+0.5AC

Fracture Energy at T_L (PG +10°C -12°C)

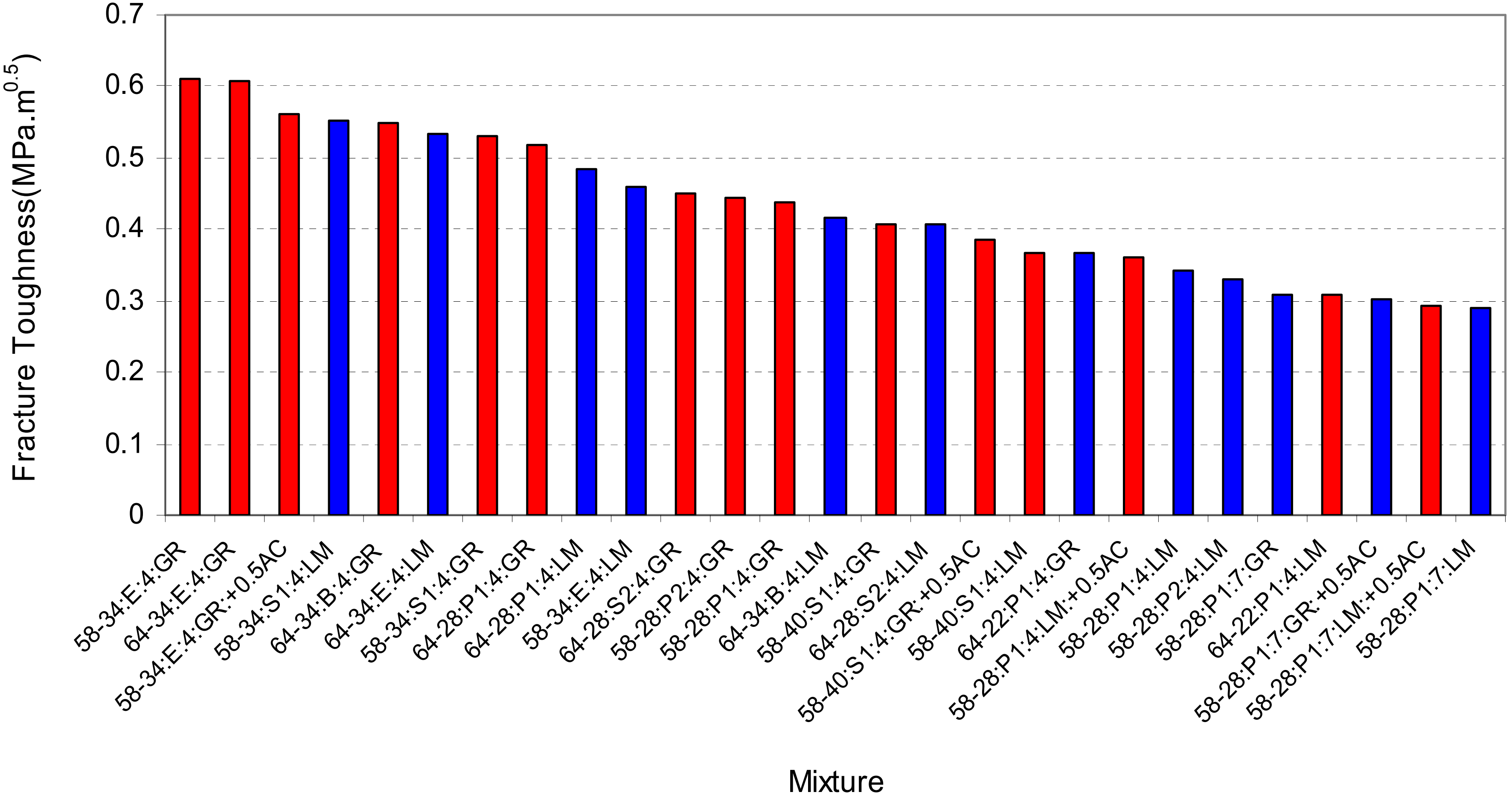


Fracture Energy Ranking at TL

Highest: 58-40:S1:4:GR:+0.5AC

Lowest: 58-28:P1:7:LM

Fracture Toughness at T_H

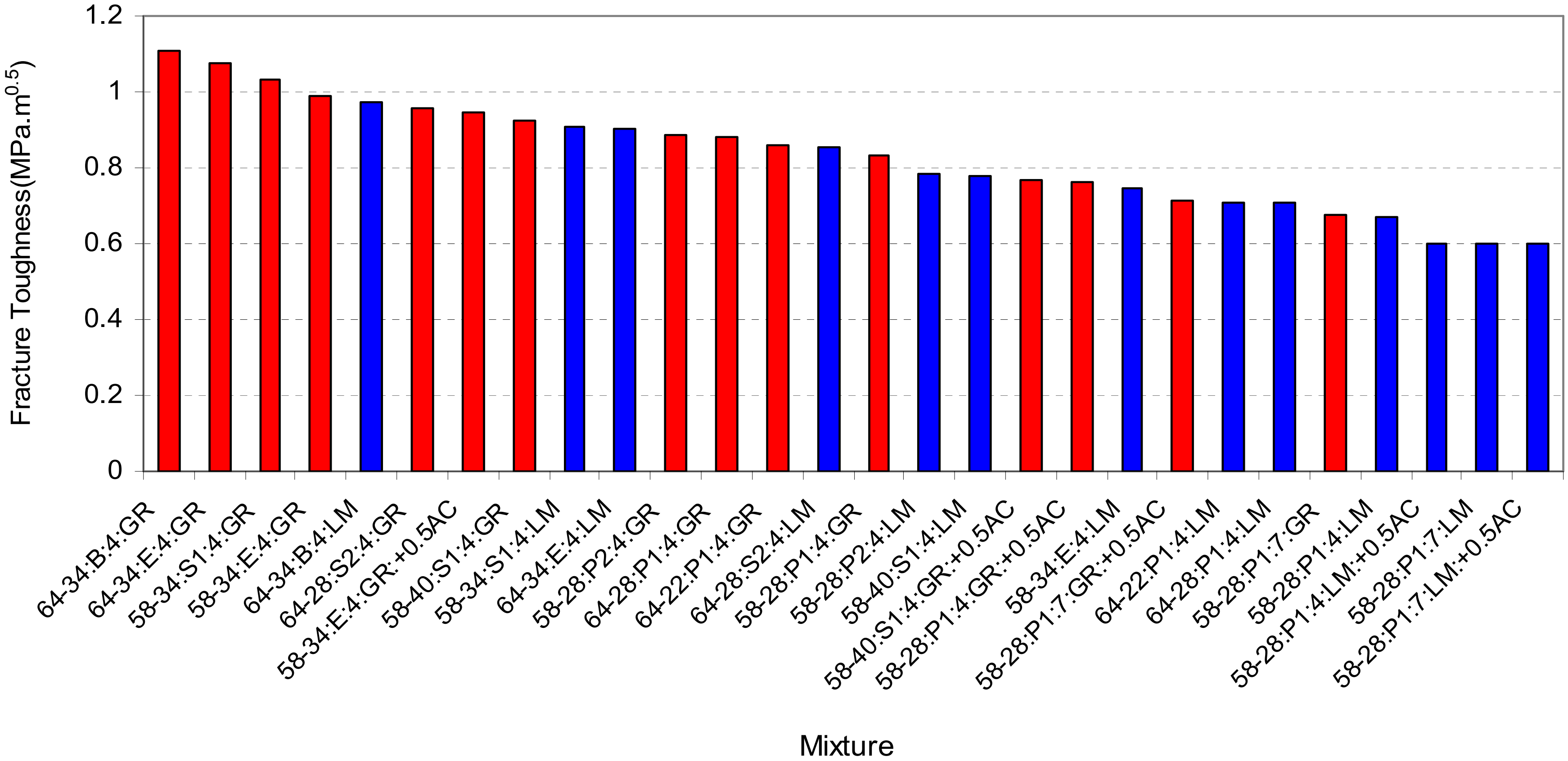


Fracture Toughness Ranking at T_H

Highest: 58-34:E:4:GR

Lowest: 58-28:P1:7:LM

Fracture Toughness at T_M

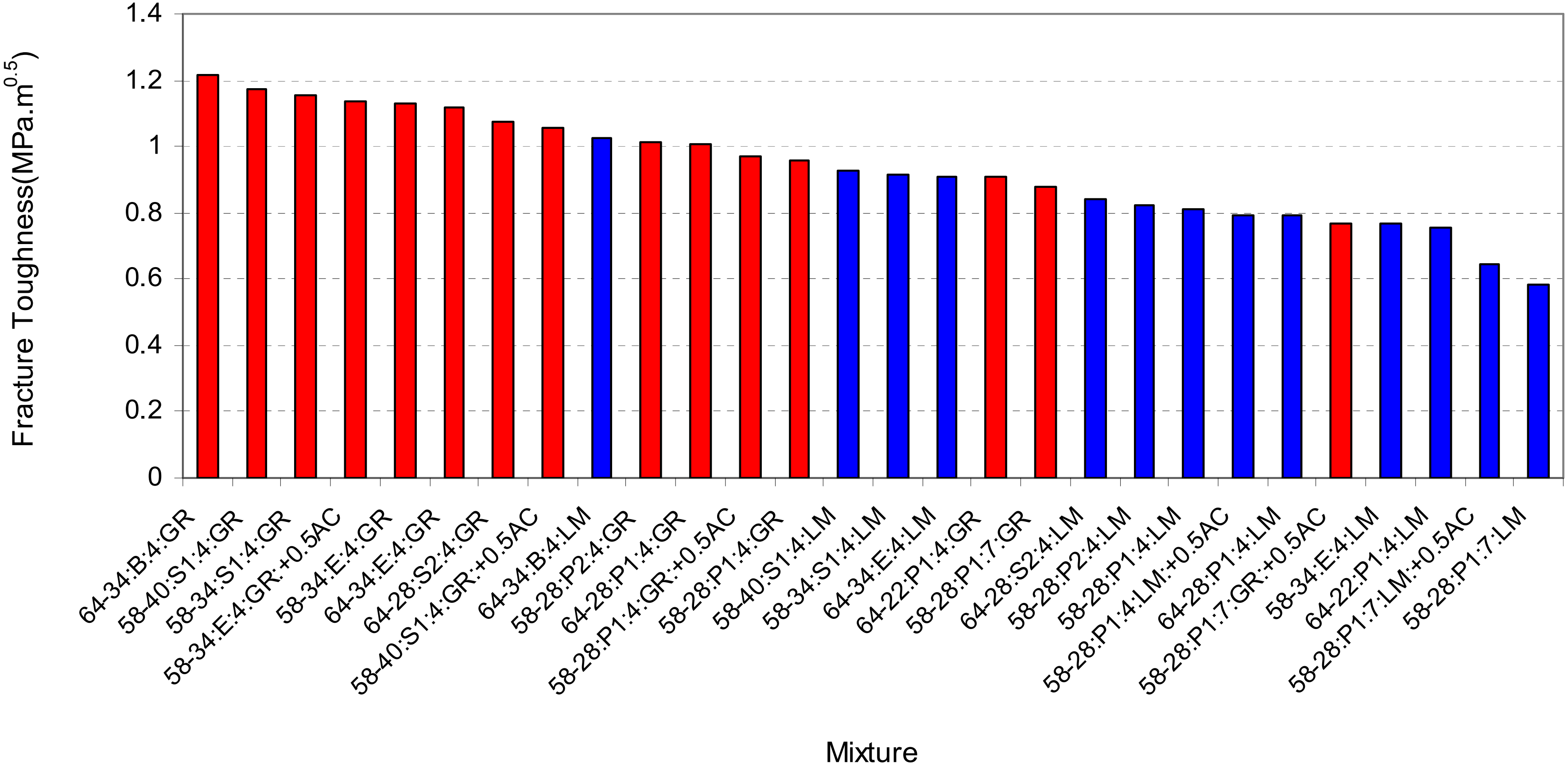


Fracture Toughness Ranking at T_M

Highest: 64-34:B:4:GR

Lowest: 58-28:P1:7:LM+0.5AC

Fracture Toughness at T_L



Fracture Toughness Ranking at T_L

Highest: 64-34:B:4:GR

Lowest: 58-28:P1:7:LM

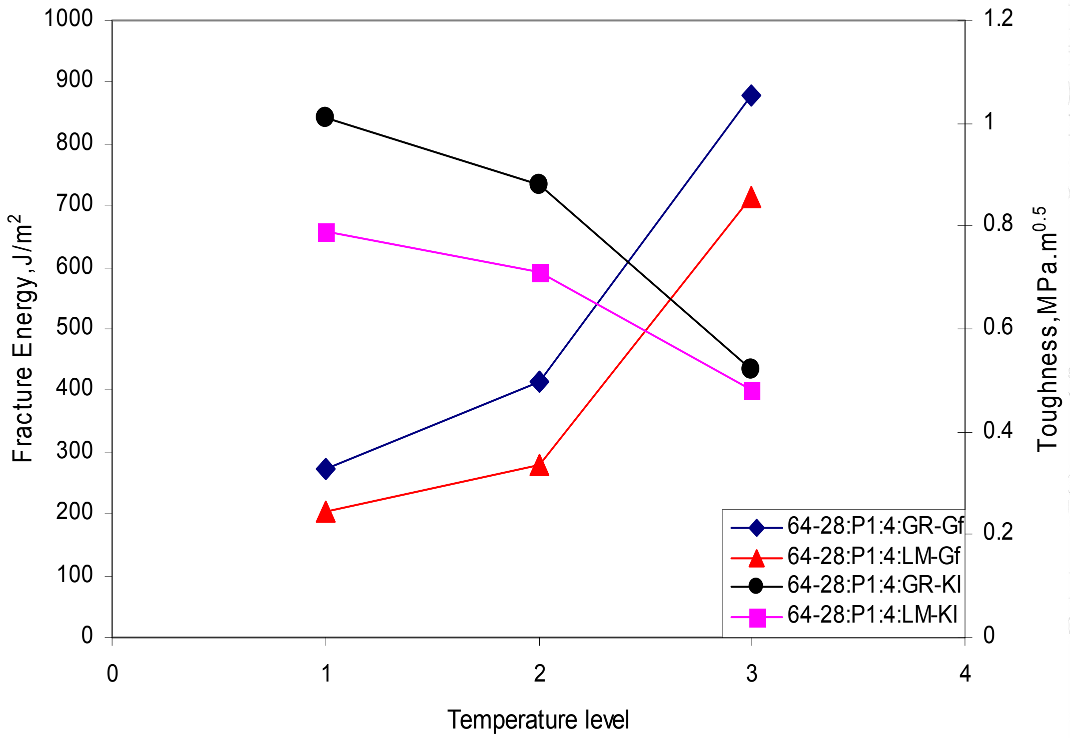

G3 -24 22
3 6 8


G1 -24 22
2 3 6

Effect of Aggregate on Fracture Resistance

Fracture Parameter	p-value
Fracture Toughness	<2.2e-16
Fracture Energy	6.4e-14

Significant Effect on Both Parameters

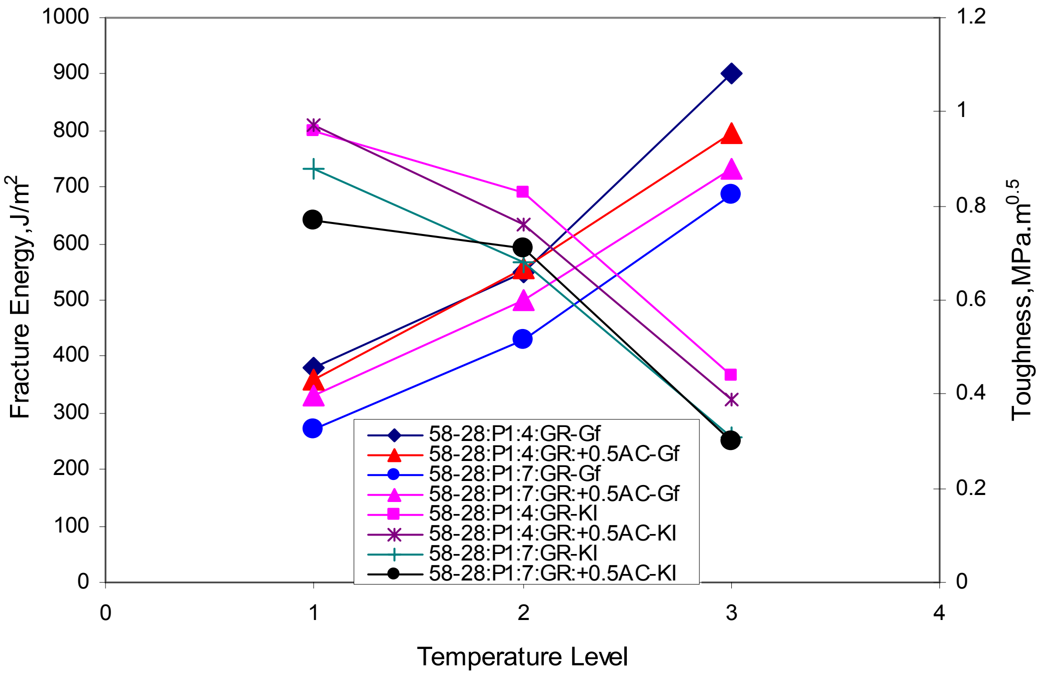


Mean fracture toughness granite > Mean fracture toughness limestone
Var. granite fracture toughness > Var. fracture toughness limestone
Same for fracture energy

Effect of Air Voids on Fracture Resistance

Fracture Parameter	p-value
Fracture Toughness	1.97e-11
Fracture Energy	3.6e-5

Significant Effect on Both Parameters



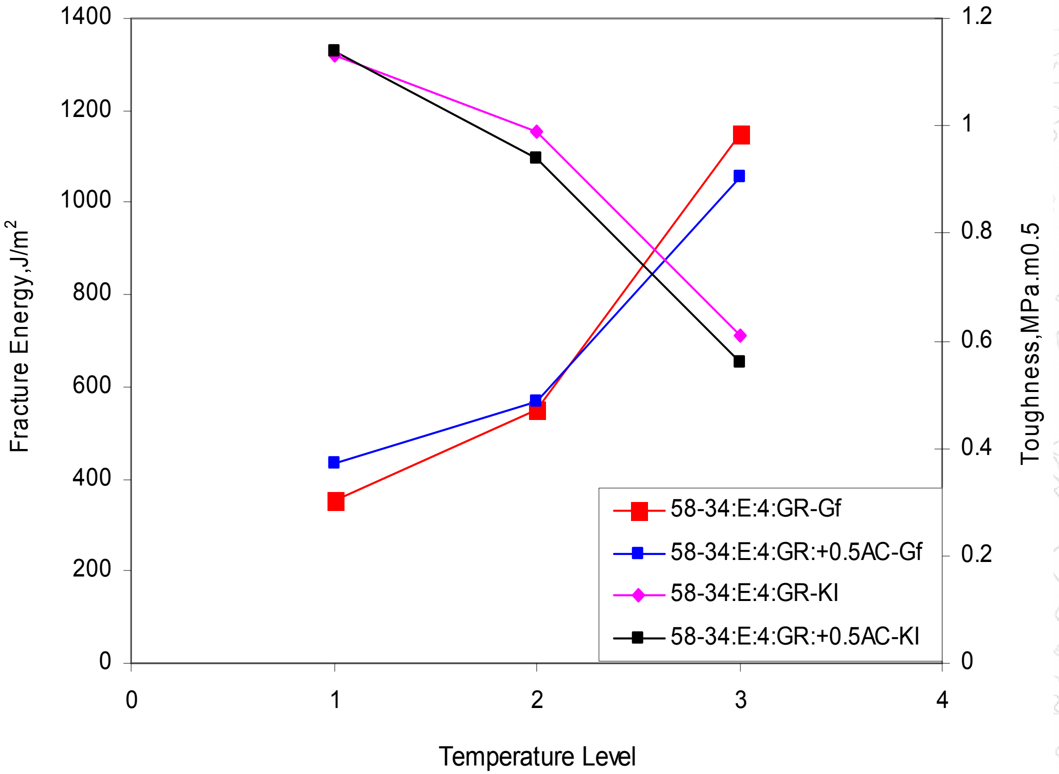
Mixtures with 4% air void overall have higher fracture toughness and fracture energy than mixtures with 7% air void specimens

Effect of Asphalt Content on Fracture Resistance

Fracture Parameter	p-value
Fracture Toughness	0.047
Fracture Energy	0.67

Significant Effect on Fracture Toughness

No Significant Effect on Fracture Energy



For fracture energy, no statistical difference
For fracture toughness, optimum asphalt content mixtures overall higher toughness than binder bump mixtures

Effect of Modifier on Fracture Resistance

Comparison Group	P-value Fracture Toughness	P-value Fracture Energy
SBS1 vs. Elvaloy PG 58-34	0.03379	0.00233
Elvaloy vs. Black Max PG 64-34	1.154E-07	0.1391
SBS2 vs. Plain1 PG 64-28	0.0415	2.05E-07

5 out of the 6 comparisons statistically significant

PG 58-34 SBS1 mixtures have higher fracture energy and toughness than Elvaloy mixtures

PG 64-34 Black Max mixtures have higher fracture toughness than Elvaloy mixtures

PG 64-28 SBS2 mixtures have higher fracture energy and fracture toughness than unmodified mixtures

Effect of PG High Limit on Fracture Resistance

Comparison Group	P-value Fracture Energy	P-value Fracture Toughness
PG 58-**34** vs. PG 64-**34** Elvaloy modified	0.0245	5.27E-05
PG 58-**28** vs. PG 64-**28** Plain 1	0.044	0.00081

At same PG low limit, high limit significantly affects both fracture energy and toughness
Elvaloy PG 64-34 mixtures have higher fracture energy and toughness than Elvaloy PG 58-34 mixtures
Plain PG 64-28 mixtures have higher fracture toughness than plain PG 58-28 mixtures. However, the opposite trend can be observed for fracture energy

LTPP low pavement temperature 50% reliability level

Section	Station	Temp. [°C]
IL I74	Urbana, IL	-16.4
MN75 2	Collegeville, MN	-24.4
MN75 4	Collegeville, MN	-24.4
MnROAD 03	Buffalo, MN	-23.8
MnROAD 19	Buffalo, MN	-23.8
MnROAD 33	Buffalo, MN	-23.8
MnROAD 34	Buffalo, MN	-23.8
MnROAD 35	Buffalo, MN	-23.8
US20 6	Freeport, IL	-19.7
US20 7	Freeport, IL	-19.7
WI STH 73	Stanley, WI	-24.7

Correlation coefficients between laboratory parameters and field data

Laboratory parameters		Correlation coefficients	
		Pearson	Spearman
Mixture	SCB, fracture energy	-0.708	**-0.718**
	IDT, S(60sec)	-0.713	-0.405
	IDT S(500sec)	-0.590	-0.071
	SCB, Fracture Toughness	-0.639	**-0.736**
	IDT, strength	-0.325	**-0.571**
	DCT, fracture energy	-0.265	**-0.500**
	SEB energy	-0.291	**-0.500**
Binder	BBR S @ 60sec	0.105	0.248
	m-value S @ 60sec	-0.252	0.152
	DT strain at 3%	-0.694	**-0.673**
	DENT Stress at failure	-0.045	0.217
	DENT Strain at failure	-0.239	-0.250

Investigation of Low Temperature Cracking in Asphalt Pavements

National Pooled Fund 776

Phase II Work Plan

- **Task 1 – Update on low temperature cracking research**
  - Document new research in the area of low temperature cracking
    - Work performed by the Asphalt Research Consortium (ARC)
    - Details of the MnROAD test cells constructed in 2007 and 2008
    - Other work

- **Task 2 – Expand Phase I test matrix with additional field samples**
  - Up to eight new asphalt mixtures used in field studies will be tested and analyzed with respect to their low temperature cracking resistance
    - Potential candidate sites include warm mixtures, mixtures with RAP, and acid modified
  - Tests will consists of IDT creep and strength tests as well as SCB and DC(T) fracture tests
    - IDT only to develop and validate new method to predict mixture creep compliance from Bending Beam Rheometer (BBR) binder creep compliance or other methods

Location	Construction Date	Description
MnROAD 33	September 2007	58-34 Acid only no RAP
MnROAD 34		58-34 SBS + Acid no RAP
MnROAD 35		58-34 SBS only no RAP
MnROAD 77		58-34 Elvaloy + Acid no RAP
MnROAD 20	August 2008	58-28, 30% non-fractionated RAP, level 4 SP, wear & non-wear
MnROAD 21		58-28, 30% fractionated RAP, level 4 SP, wear & non-wear
MnROAD 22		58-34, 30% fractionated RAP, level 4 SP, wear & non-wear
Wisconsin 9.5 mm SMA	2008	will provide materials
New York State "Typical Mix"	2008	with PG 64-22 binder and an aggregate other than limestone and granite.

- **Task 2 – Subtask on physical hardening**
  - Develop protocol to simplify the measurements of physical hardening (reduce conditioning time) and include a numerical approach to adjust S and m values
  - Collect physical hardening for variety of binders and verify model that will be developed in task 5
    - PPA, Warm Mix Additives and Polymers effect on physical hardening not well understood
  - Use glass transition measuring technique to quantify effect of isothermal storage on dimensional stability of asphalt mixtures

- **Task 3 – Develop low temperature specification for asphalt mixtures**
  - Subtask 1 – develop test method
    - Refine and possibly simplify the SCB and DC(T) fracture tests used in phase I
    - Propose a standard fracture test method based on SCB configuration for asphalt mixtures. Note that the DC(T) has been already approved as an ASTM D7313-06 standard
    - Develop standard fracture method. At the end of this task the research team *will recommend only one fracture test* but provide correlations between the results from the two methods.

- **Task 3 – Develop low temperature specification for asphalt mixtures**
  - Subtask 2 – develop specification
    - Revisit field and experimental data that used to develop the current PG system; similar approach, based on criteria providing limiting temperature values, will be used for the mixture specification
    - Based on the experimental work performed in phase I and the work performed in task 2 and data available in previous research projects, develop limiting criteria for selecting asphalt mixtures resistant to low temperature cracking
    - Criteria will be based on fracture tests performed on specimens prepared from original loose mix

- **Task 3 – Develop low temperature specification for asphalt mixtures**
  - Subtask 3 – propose simplified method to obtain mixture creep compliance
    - Directly from SCB and DC(T) configuration
    - BBR testing of thin asphalt mixture beams
    - Investigate if strength can be obtained from BBR testing of thin asphalt mixture beams to failure
      - Performed in conjunction with ARC work performed by University of Wisconsin

- **Task 4 - Develop Improved TCMODEL**
  - Similar to MEPDG, although it will use mixture fracture tests instead of tensile strength and will have an improved fracture model (cohesive zone fracture model instead of the Paris law model)
  - Will allow multiple HMA layers, non-linear thermal coefficients (including different functions for heating and cooling), and will be capable of updating mixture properties with time (aging effects, for instance), including more severe aging near surface of pavement
  - TCMODEL program will be made available as a freeware program, to be posted on University, FHWA, and State DOT websites

Task 5 - Modeling of Asphalt Mixtures Contraction & Expansion Due to Thermal Cycling

- Expand data base for thermo-volumetric properties of asphalt binders and mixtures to fully quantify the effects of binders and aggregates in the asymmetrical thermo-volumetric behavior (glass transitions and coefficients).
- Develop micromechanics model to estimate the glass transition temperatures and coefficients from commonly measured parameters
- Conduct sensitivity analysis to determine which of the glass transition parameters are statistically important for cracking
- Task will be coordinated with ARC project

- **Task 6 – Validation of new specification**
  - Based upon the outcomes of the testing of the preliminary validation experimental plan, the best test device and method of conditioning mixes for long-term aging will be selected for the final validation
  - Validation will be based upon testing of the 11 Olmstead County, Minnesota mixes placed in the 2006 construction season

Location	Constr. Date	Description
Olmsted Co Rd 104	Jul-07	Reinke's Warm Mix (58-28 w/ RAP & antistrip)
Rd 112	Aug-06	WRI-Mathy Study (Citgo, 58-28, 12.5 mm)
Rd 112	Aug-06	WRI-Mathy Study (Citgo, 58-28, 19mm)
Rd 112	Aug-06	WRI-Mathy Study (Marathon, 58-28, 12.5 mm)
Rd 112	Aug-06	WRI-Mathy Study (Marathon, 58-28, 19mm)
Rd 112	Aug-06	WRI-Mathy Study (MIF, 58-34 RAP, 12.5 mm)
Rd 112	Aug-06	WRI-Mathy Study (MIF, 58-34 Virgin, 12.5 mm)
Rd 112	Aug-06	WRI-Mathy Study (MIF, 58-34, 19mm RAP)
Rd 112	Aug-06	WRI-Mathy Study (MIF, 58-34, 19mm virgin)
Rd 112	Aug-06	WRI-Mathy Study (Valero, 58-28, 12.5 mm)
Rd 112	Aug-06	WRI-Mathy Study (Valero, 58-28, 19mm)

- **Task 7 - Development of draft AASHTO standards and Final Report**
  - Final report containing updated reports from task 1 to 6 will be delivered plus
    - Access database containing all the experimental results as well as additional information on the field samples and laboratory prepared specimens
    - Proposed test protocols (experimental set up and data analysis) for selecting asphalt binders and mixtures with enhanced fracture resistance to low temperature thermal cracking
    - Software and documentation describing a new fracture mechanics-based thermal cracking program (improved TCMODEL). Stand alone program and user manual will be provided.

Thank You!