Low-Temperature Cracking in Asphalt Pavements

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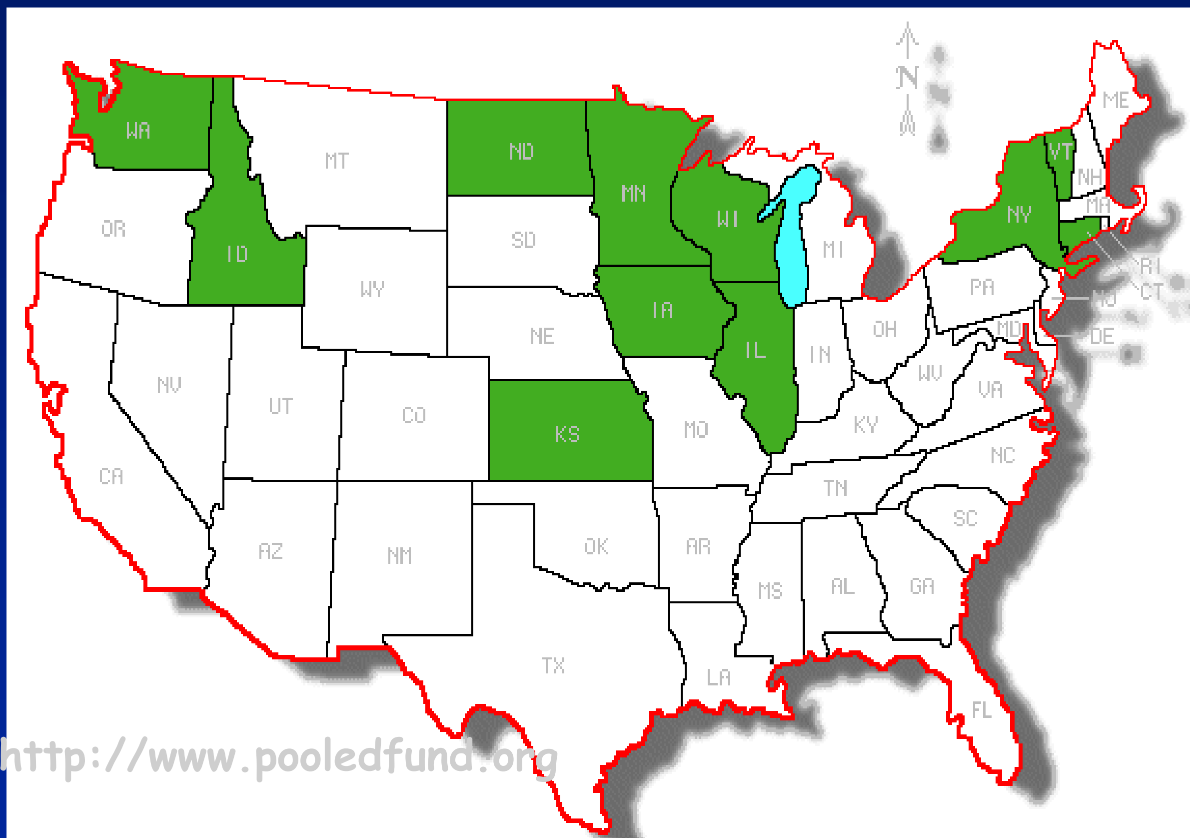
NCAUPG Annual Meeting, January 2007

Low-Temperature Cracking

- Good fracture resistance essential for asphalt pavements in northern US and in Canada
  - ✓ Low-temperature cracking represents the prevalent distress in Minnesota and neighboring states

Low Temperature Cracking Pooled Fund State Participation



Connecticut
Idaho
Iowa
Illinois
Kansas
Minnesota
North Dakota
New York
Vermont
Wisconsin
Washington
and
FHWA

Research team - four universities
UMN, UIUC, WISC, ISU

Low Temperature Cracking Pooled Fund (Overall Plan)

State Field Samples
(Good / Poor Performance)

Laboratory Prepared Samples

Laboratory Testing and Data Analysis

Verify Models

Phase 1

Field Validation of Results
(Test Sections)

Phase 2

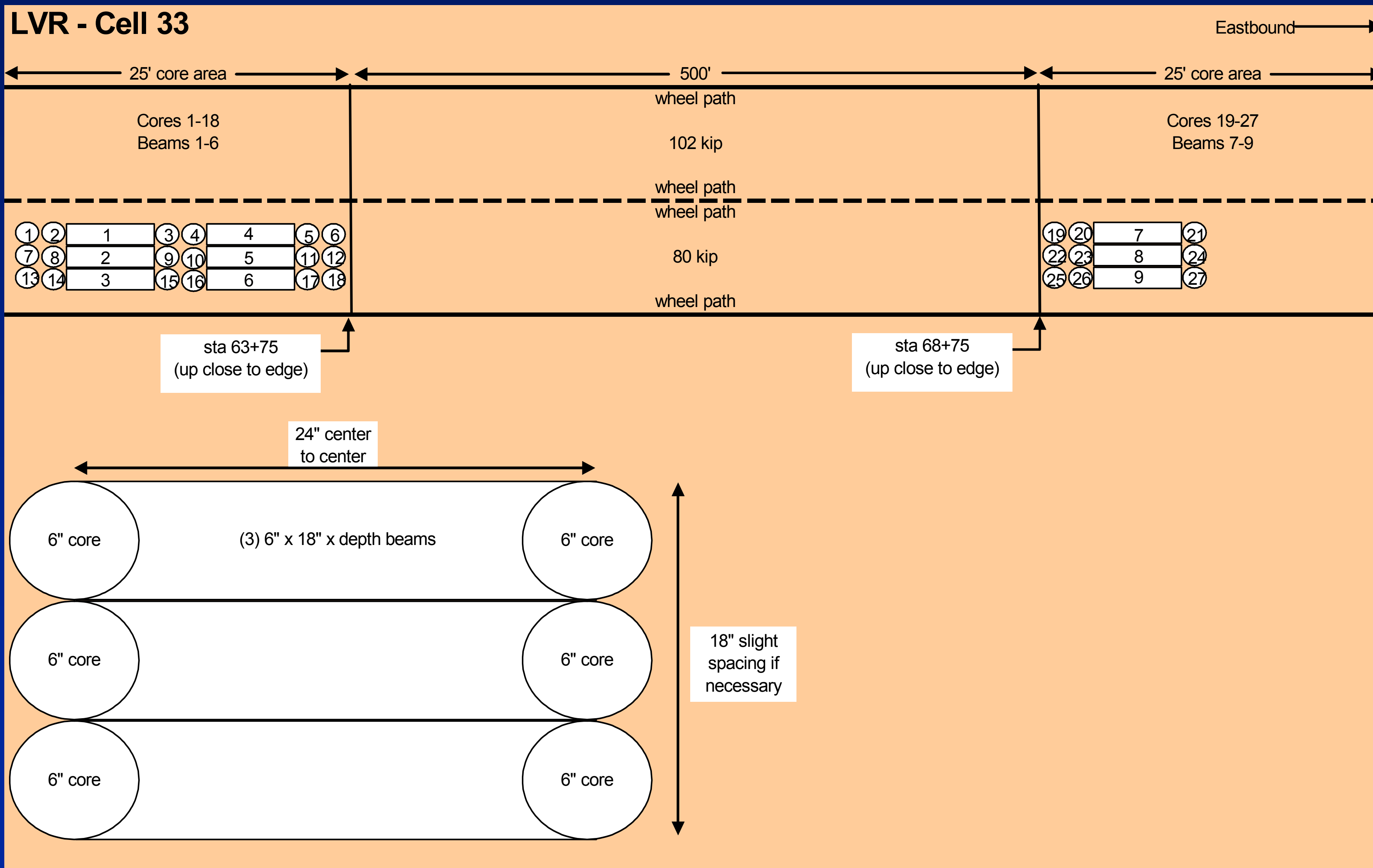
Pooled Fund Study Goals

- Development of test methods / protocols for LTC
  - What is the best test for binders and mixtures?
- Validate / refine MEPDG thermal cracking model
- Establish guidelines for MnROAD field validation

Field Samples

State	Road	Asphalt Binder	Performance (1=Good) (5=Bad)	Age (Years)	Pavement Comment	Recommendation
IL	US-20	AC-10, AC-20	2	20		Accepted
IL	I-74	AC-20	2	15	original surface will soon be milled and replaced	Accepted
MN	Cell 33	PG 58-28	3	6	silty clay subgrade constructed in 1994	Accepted
MN	Cell 34	PG 58-34	1	6	silty clay subgrade constructed in 1994	Accepted
MN	Cell 35	PG 58-40	4	6	silty clay subgrade constructed in 1994	Accepted
MN	Cell 3	PG 58-28 120/150	3	14	silty clay subgrade constructed in 1992	Accepted
MN	Cell 19	PG 64-22 AC-20	4	14	silty clay subgrade constructed in 1992	Accepted
MN	CSAH-75 section 4WB	PG 58-34	3	10	sand-gravel subgrade constructed in 1955	Accepted
MN	CSAH-75 section 2EB	PG 58-28	4	10	sand-gravel subgrade constructed in 1955	Accepted
ND	SH-18	120/150	4	8	A thin lift overlay has been placed over part of this project	Not recommended: overlay placed on original pavement
WI	US-45	PG 58-34, 58-40 85/100, 120/150	2	10	only difference in NB and SB lanes was binder	Accepted
WI	STH-73	PG 58-28	1	5	subbase stabilized with asphaltic base course	Accepted

Field Samples



MnROAD Sample Extraction

IL US20 Slab Extraction

Field Samples Information

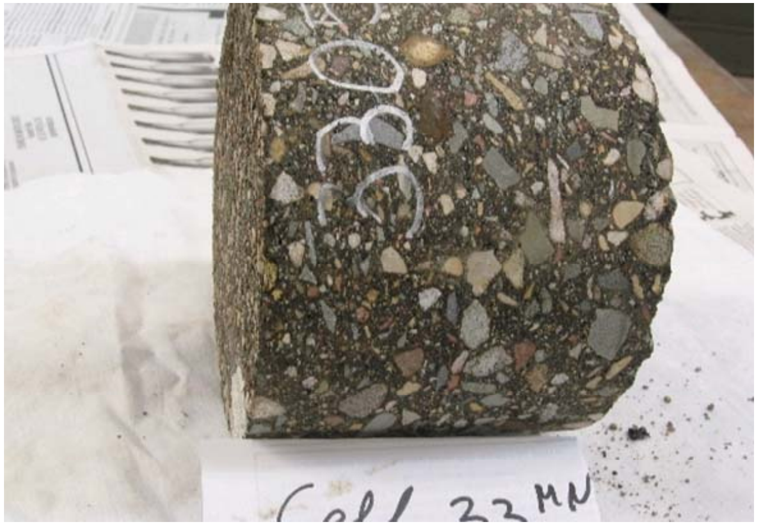
Beams - received Spring 2005

		Cell	Year	Mix	Spot	Dimensions		
						L	l	h
1	MnRoad	03	05	BB	008	470	176	160
2	MnRoad	33	05	BB	006	405	195	115
3	MnRoad	33	05	BB	005	405	195	113
4	MnRoad	19	05	BB	07	480	212	205
5	MnRoad	19	05	BB	08	480	203	200
6	MnRoad	35	05	BB	08	470	155	102
7	MnRoad	34	05	BB	01	445	168	111
8	MnRoad	35	05	BB	09	470	192	107
9	MnRoad	34	05	BB	06	470	183	112

Field Samples Information

Cell 33

	L=105 D=150	Cell	Year	Mix	Spot	Received
1	MnRoad	33	05	BC	3	Nov-05
2	MnRoad	33	05	BC	7	Nov-05
3	MnRoad	33	05	BC	10	Nov-05
4	MnRoad	33	05	BC	16	Nov-05
5	MnRoad	33	05	BC	23	Nov-05
6	MnRoad	33	05	BC	24	Nov-05
7	MnRoad	33	05	BC	25	Nov-05
8	MnRoad	33	05	BC	26	Nov-05
9	MnRoad	33	05	BC	27	Nov-05
10	MnRoad	33	05	BC	09	spring 2005
11	MnRoad	33	05	BC	15	spring 2005
12	MnRoad	33	05	BC	11	spring 2005
13	MnRoad	33	05	BC	05	spring 2005
14	MnRoad	33	05	BC	08	spring 2005
15	MnRoad	33	05	BC	13	spring 2005
16	MnRoad	33	05	BC	12	spring 2005
17	MnRoad	33	05	BC	14	spring 2005
18	MnRoad	33	05	BC	04	spring 2005



Laboratory Experiment

Air Voids		Design (4%)				As constructed (7%)			
Aggregate Type		**Granite**		**Limestone**		**Granite**		**Limestone**	
Binder Content		Design	+0.5%	Design	+0.5%	Design	+0.5%	Design	+0.5%
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	×		×					

Laboratory Prepared Specimens

		MTU	*UIUC*	*UMN*	*WISC*
	Mixture Indirect Tension Creep and Strength			**X**	
	Mixture Fracture Test Disc Compact Tension		**X**		
	Mixture Fracture Test SE(B)		**X**		
	Mixture Fracture Test SCB			**X**	
	Mixture Thermal Stress Test TSRST	**X**		**X***	
	Binder Low Temperature BBR and DTT			**X**	**X**
	Binder Fracture Test SENB			**X**	
	Mixture and Binder Dilatometric Measurements				**X**

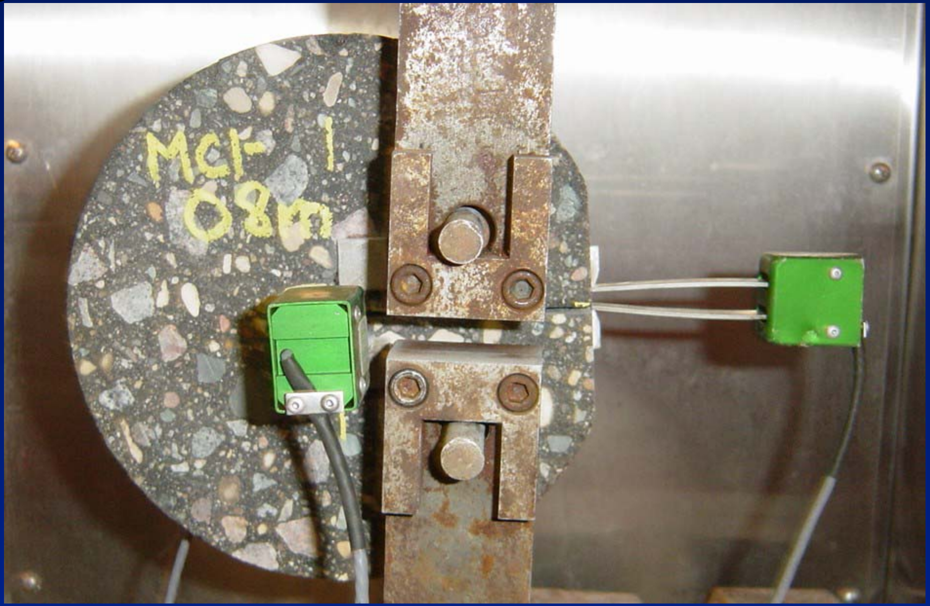
B1
D5
D1

Mixture and Binder Test Temperatures

- Test at 3 temperatures
  - ✓Match 2 out of 3 temperatures for binders and mixtures
    - -For mixtures 6°C do not lead to big change in properties
- Binders:
  - ✓PG +10°C (for a -28 it will be -18°C), 6°C below it (-24°C) and 12°C below it (-30°C)
- Mixtures:
  - ✓PG +10°C, 12°C below it, 12°C above it.

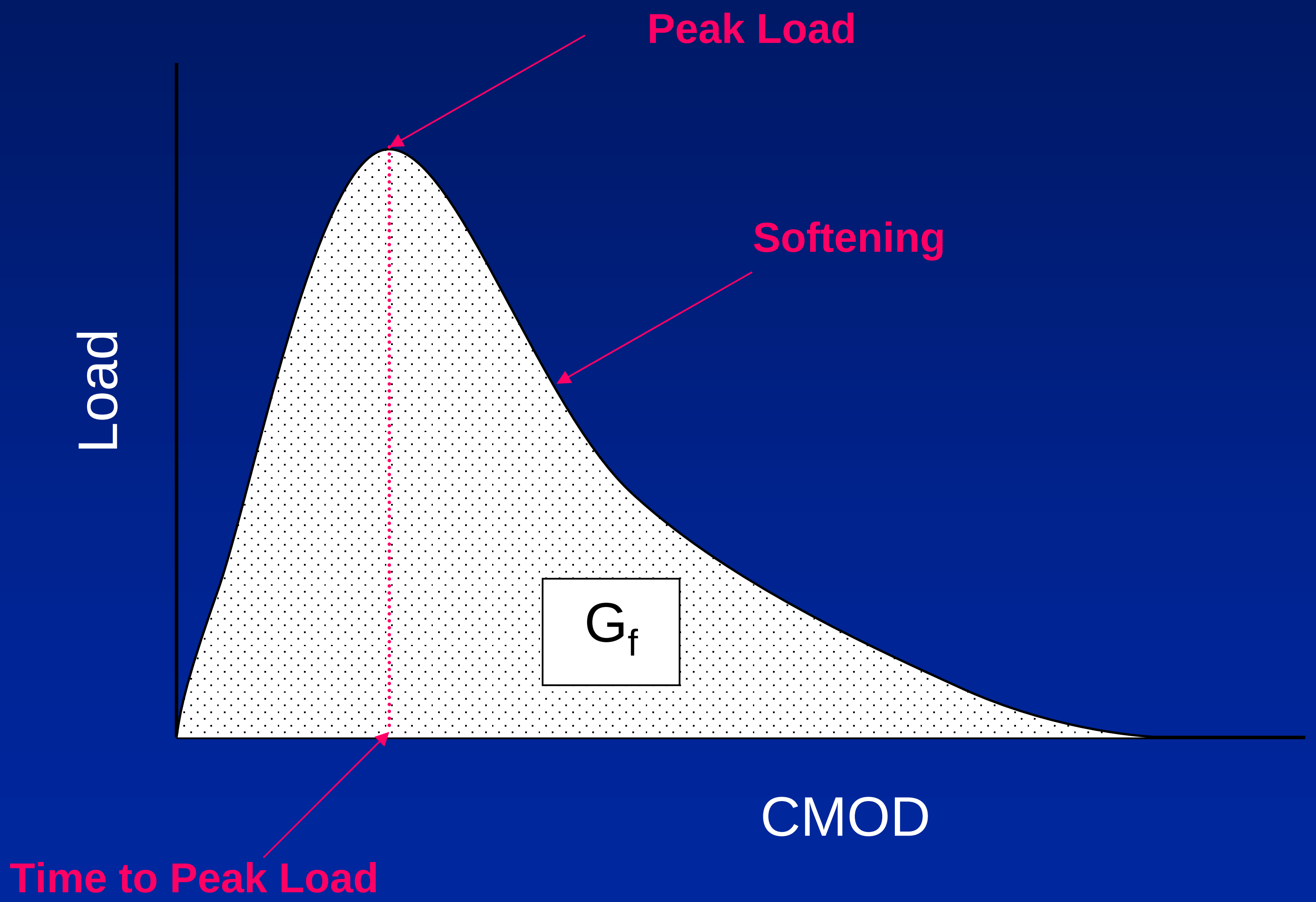
Fracture Testing - UIUC

- Disc Shaped Compact Tension
  - ✓DC(T)
  - ✓1 mm/min CMOD
  - ✓150mm

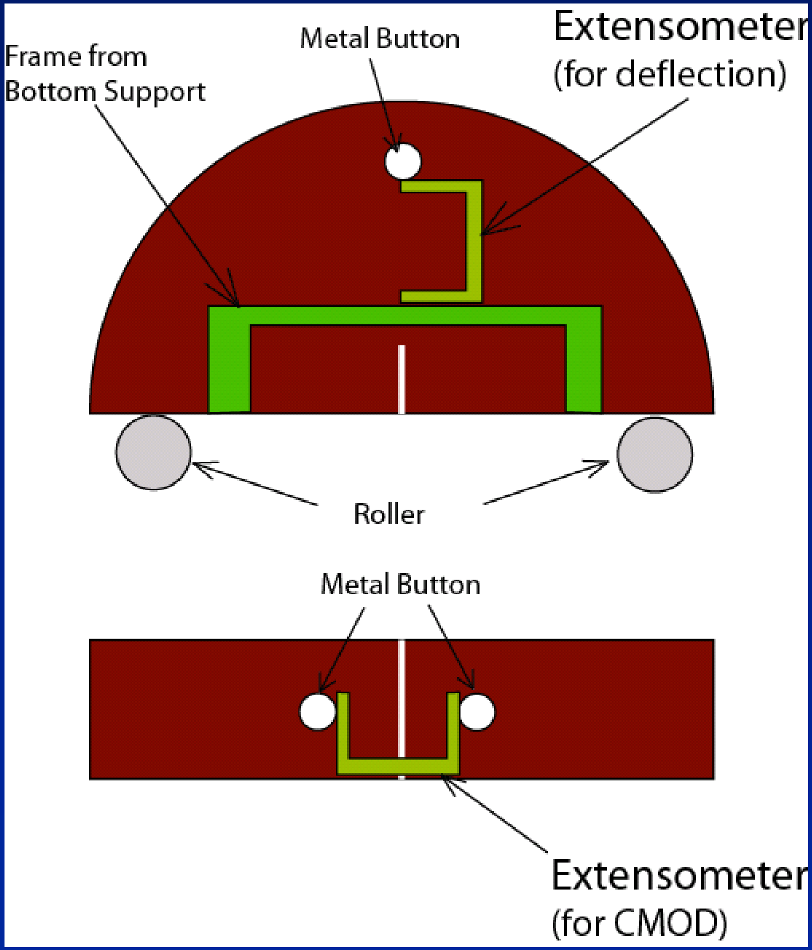


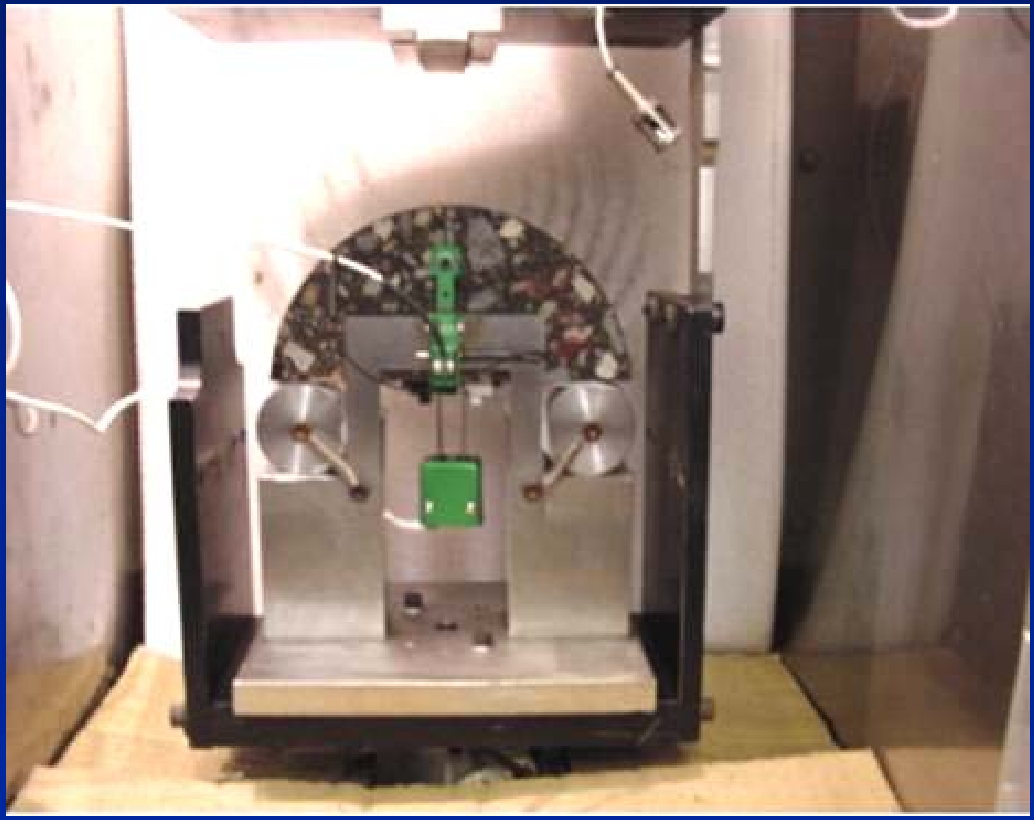
- Single Edge Notched Beam
  - ✓SE(B)
  - ✓1 mm/min CMOD
  - ✓50x75x375mm

Fracture Energy - G_f (J/m^2)

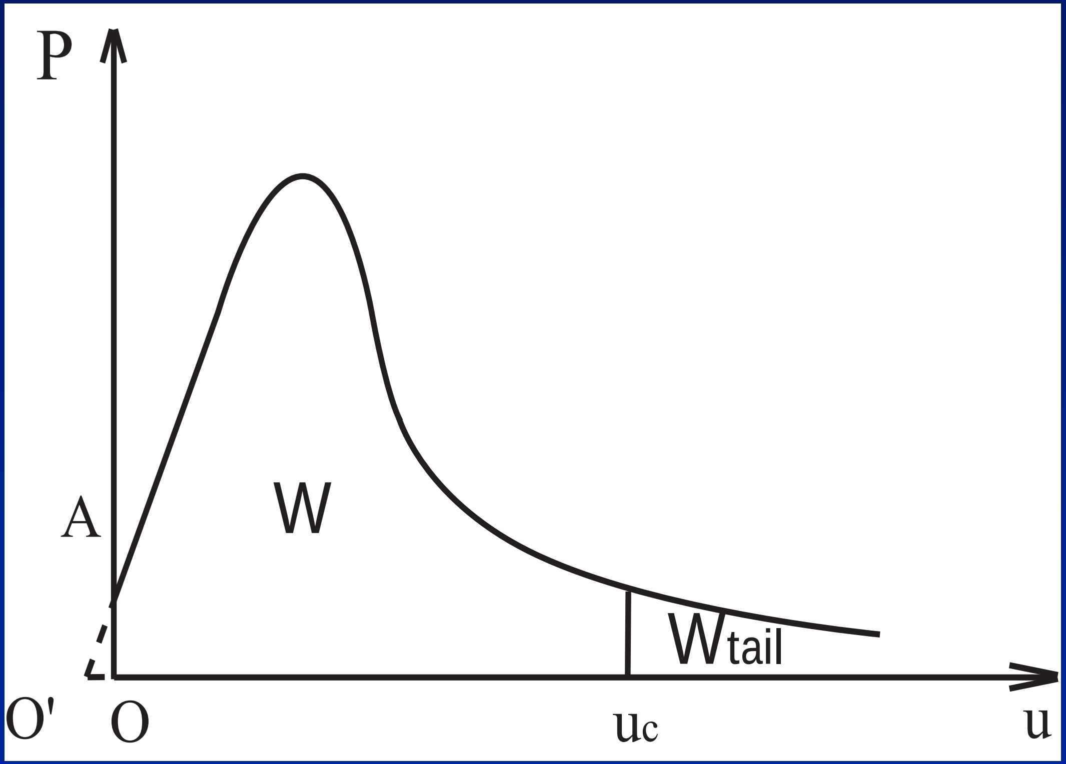


SCB


Metal Button
Extensometer
(for deflection)
Frame from
Bottom Support
Roller
Metal Button
Extensometer
(for CMOD)



Fracture Energy

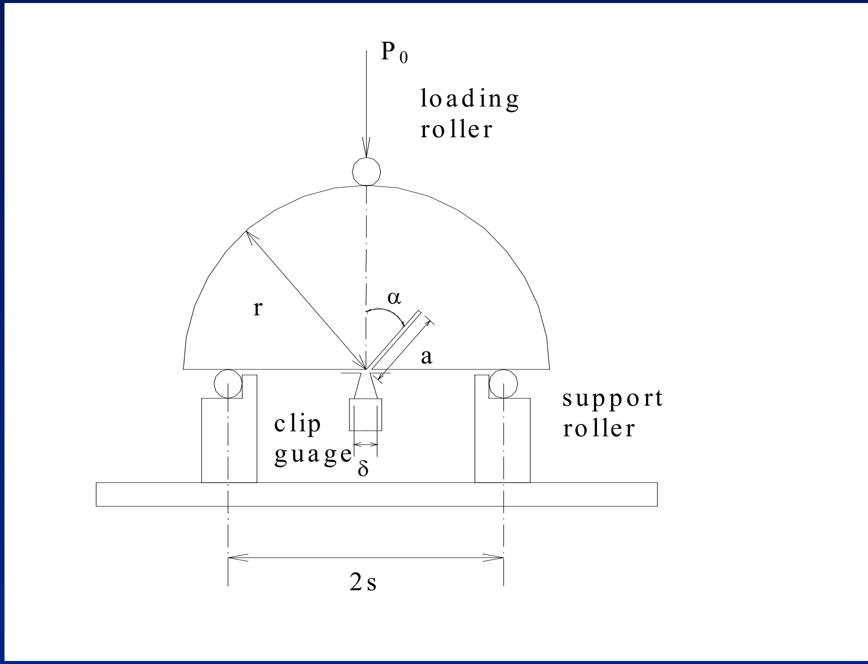


$$W_f = \int P du$$

$$G_f = \frac{W_f}{A_{lig}}$$

W_f: work of fracture
A_{lig}: area of the ligament

Stress Intensity Factor K_I



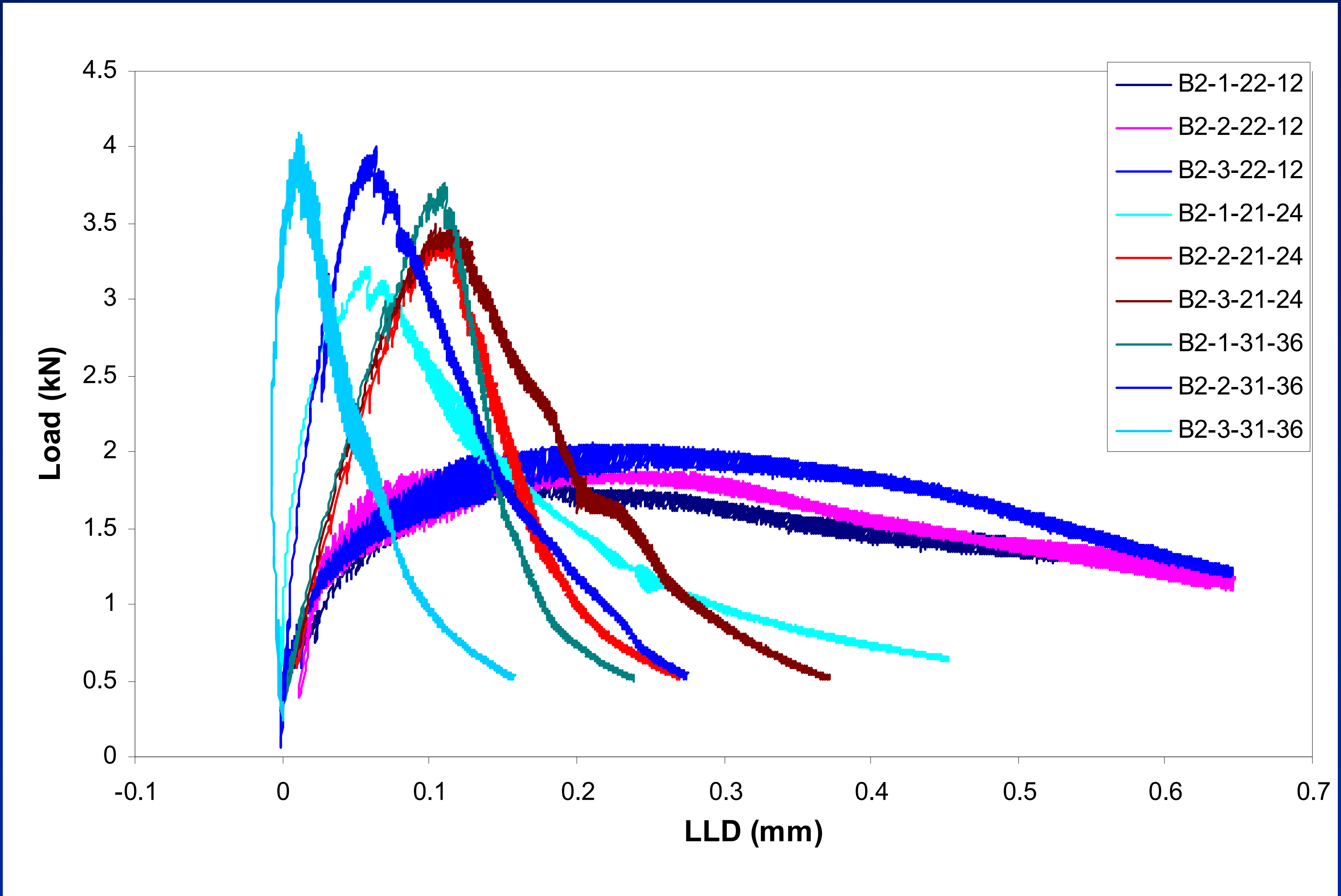
$$K_I = \sigma_0 \sqrt{\pi a} Y_I$$

$$\frac{K_I}{\sigma_0 \sqrt{\pi a}} = Y_{I(s_0/r)} + \frac{\Delta s_0}{r} B$$

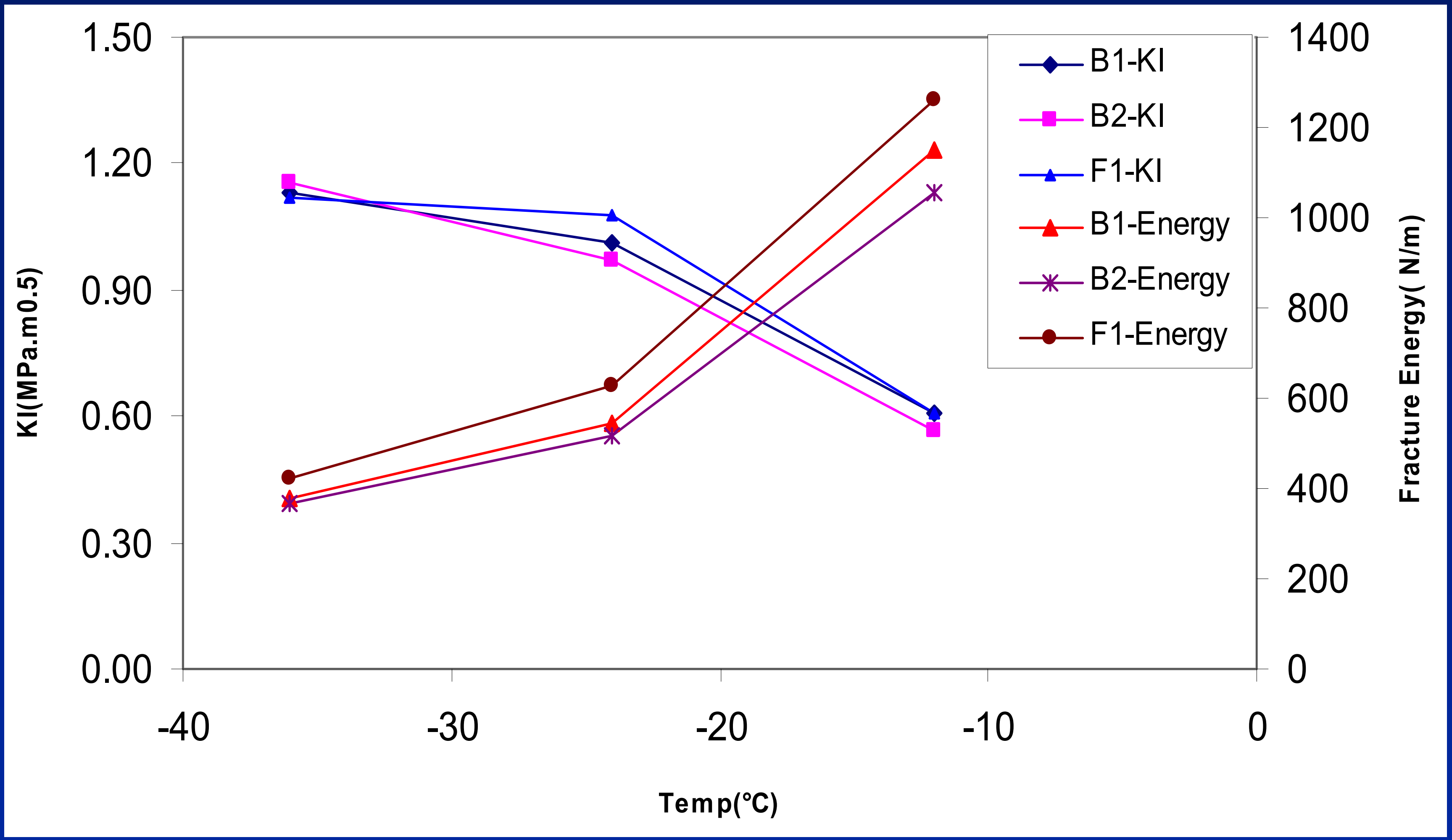
$$Y_{I(s_0/r)} = C_1 + C_2(a/r) + C_3 \exp(C_4(a/r))$$

$$B = 6.55676 + 16.64035\left(\frac{a}{r}\right)^{2.5} + 27.97042\left(\frac{a}{r}\right)^{6.5} + 215.0839\left(\frac{a}{r}\right)^{16}$$

SCB Test Plots



SCB - temperature effect on K_{IC} and G_f

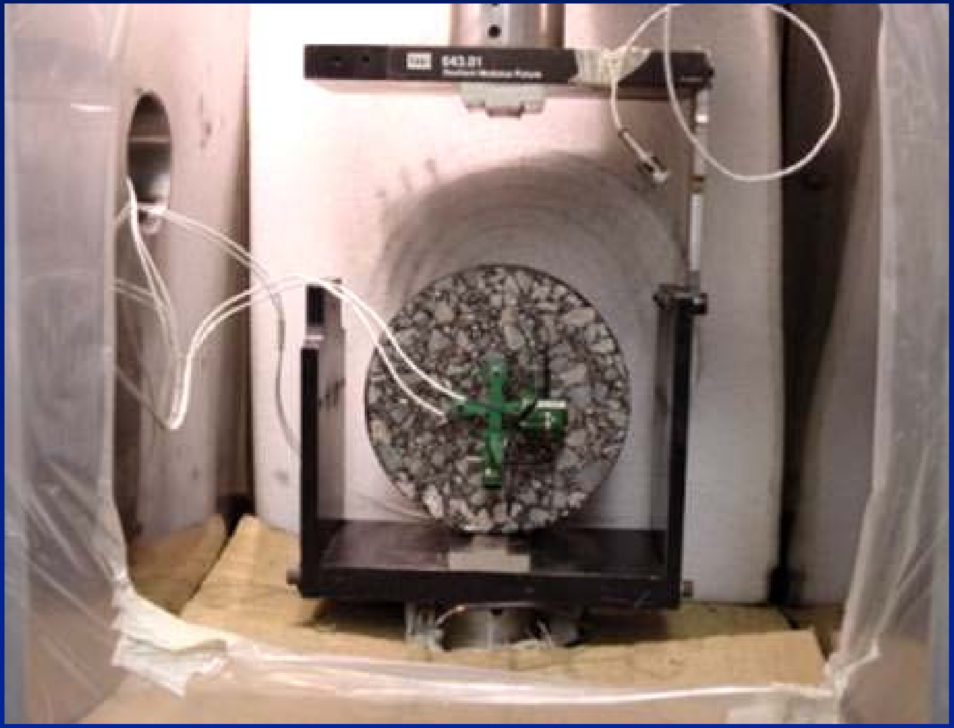



G3 -24 22
3 6 8

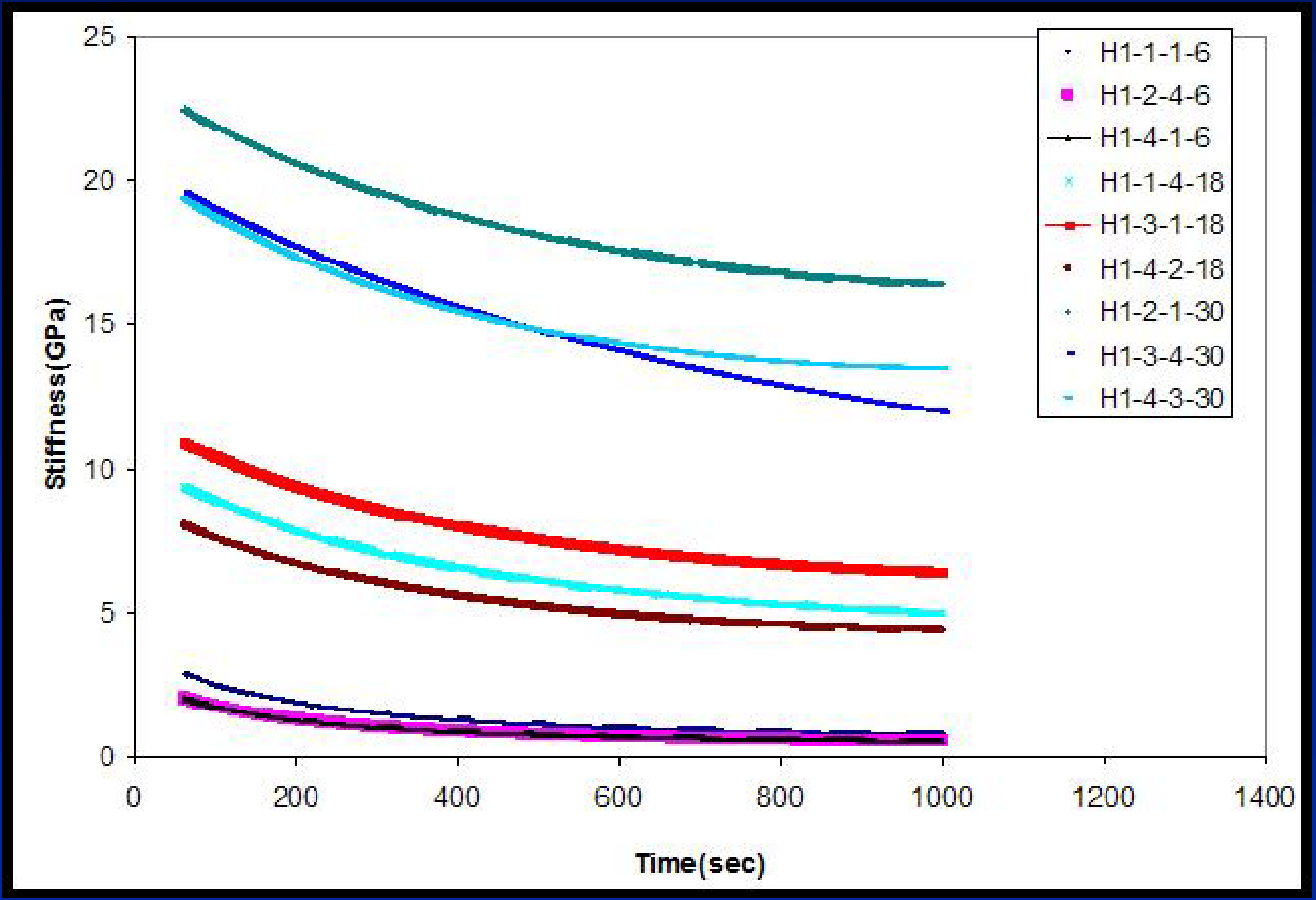
G1 -24 22
2 3 6

IDT - Creep and Strength

- Specification type tests
- In addition:
  - ✓Limited creep tests at different load levels
  - ✓Limited strength tests at different loading rates



IDT Creep Data

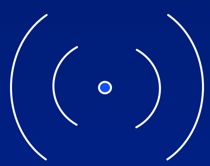


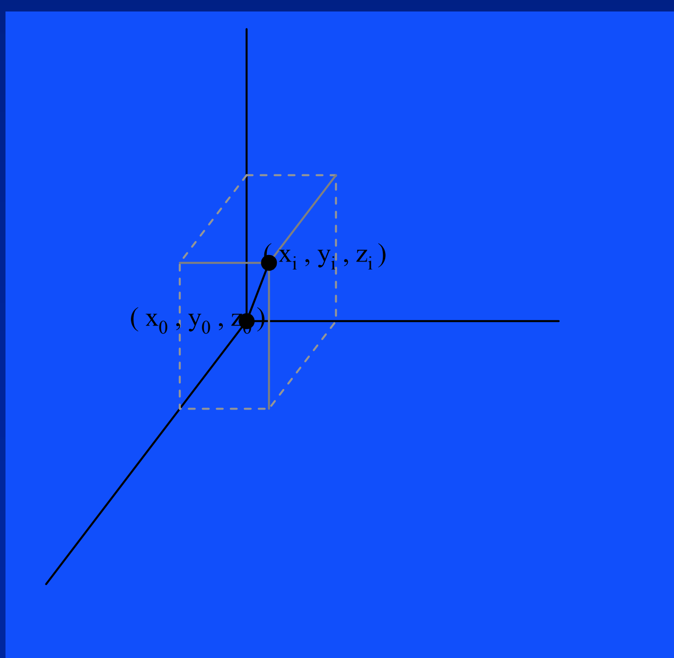
TSRST

- Tensile Strength Restrained Stress Test
  - ✓Lab prepared beams
  - ✓Field beams

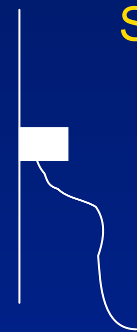
Acoustic Emission

Source





Sensor

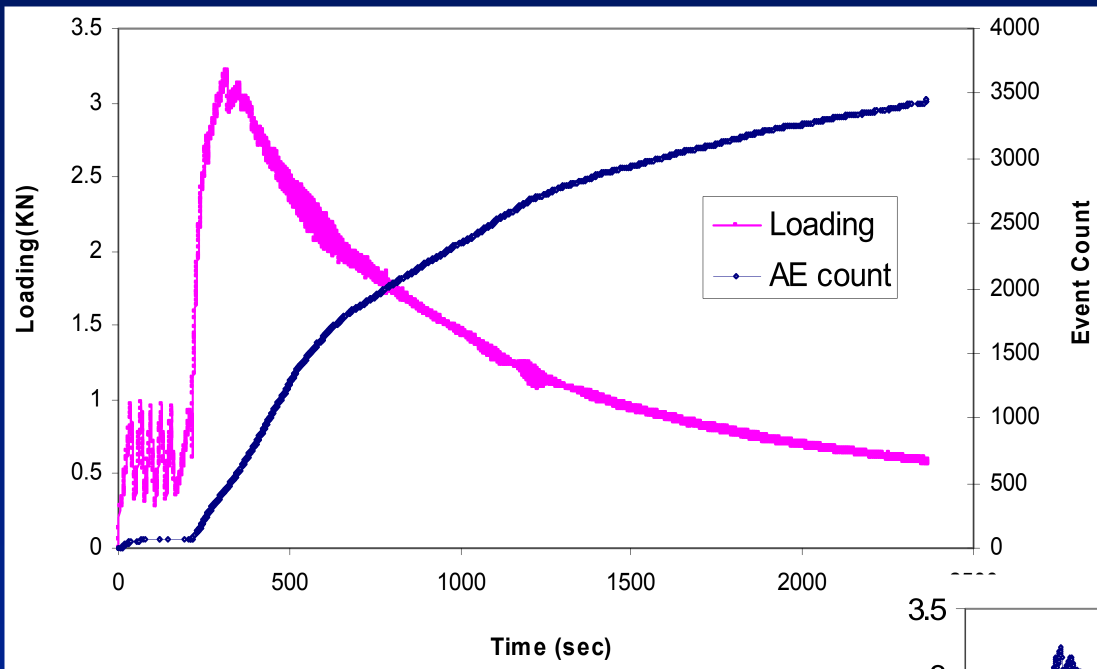


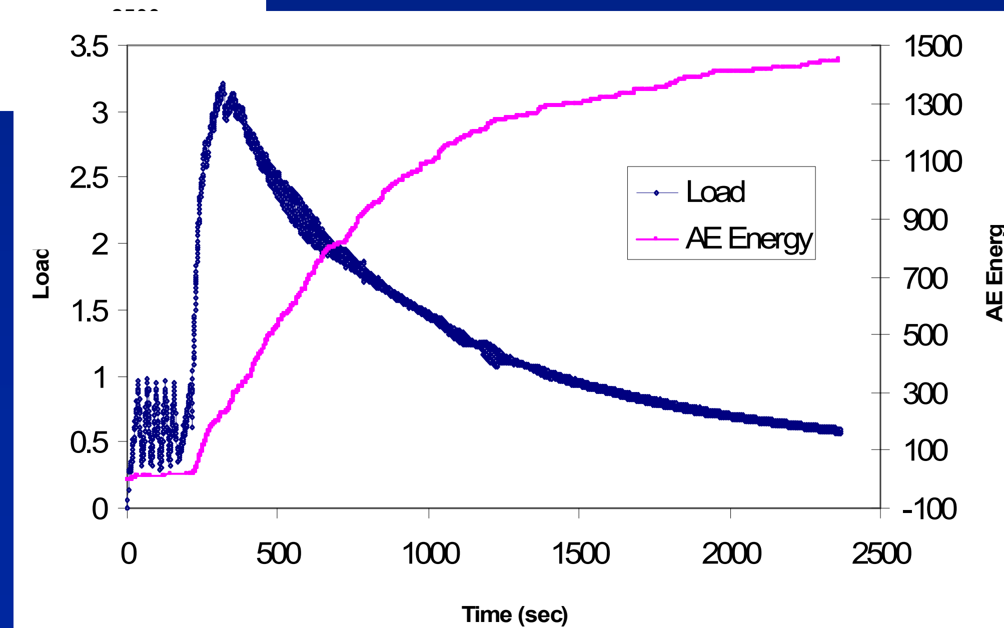
$$d_i = c_p (t_i - t_o) + \varepsilon_i$$

$$d_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2}$$

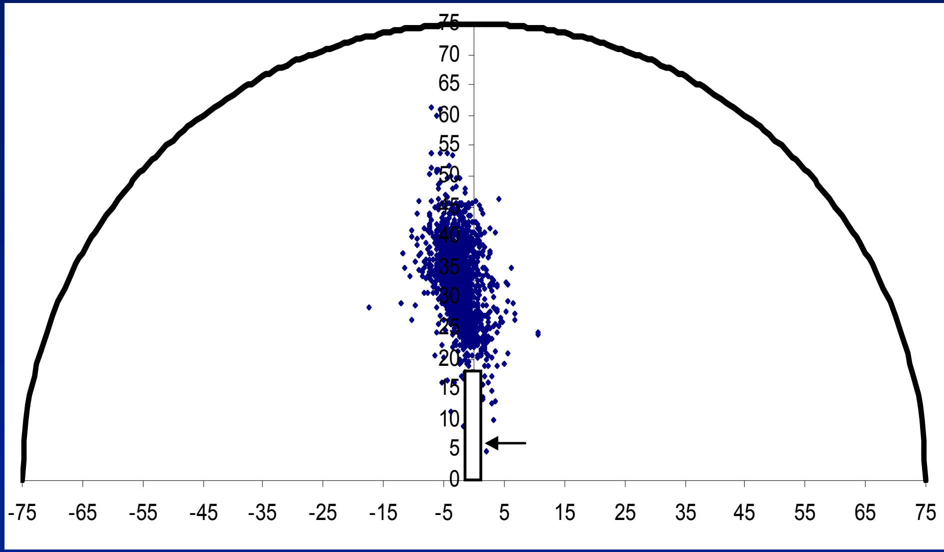
- C_p: Wave speed- from calibration
- T_i: Event Arrive time- from recording

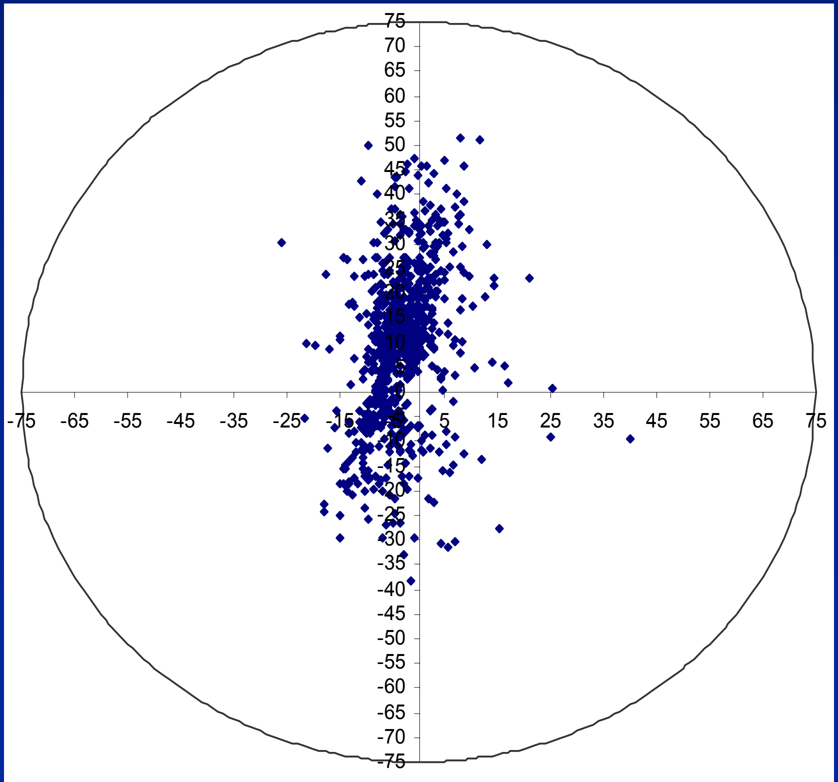
Acoustic Emission





Acoustic Emission Event Location

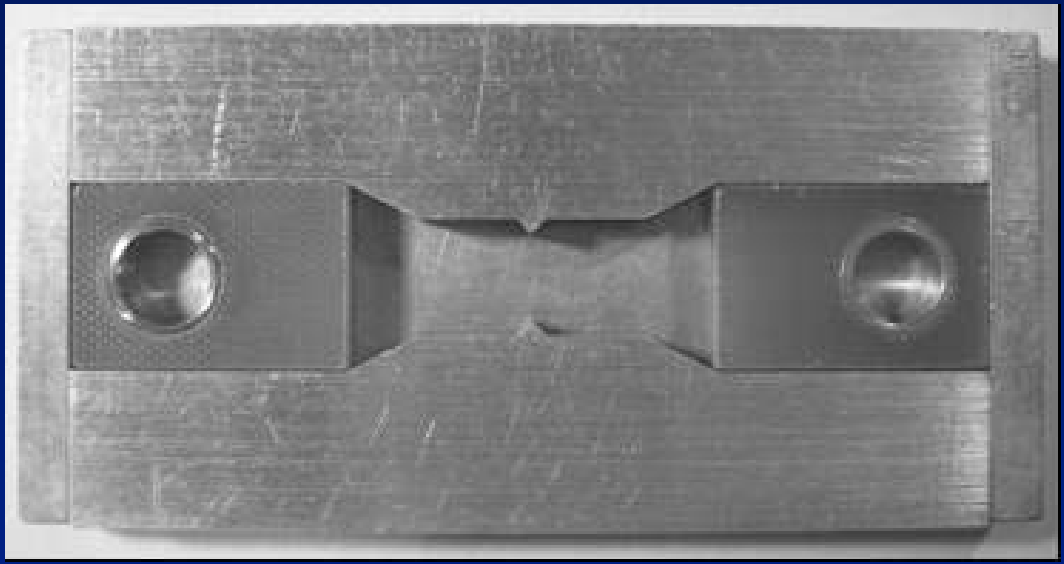


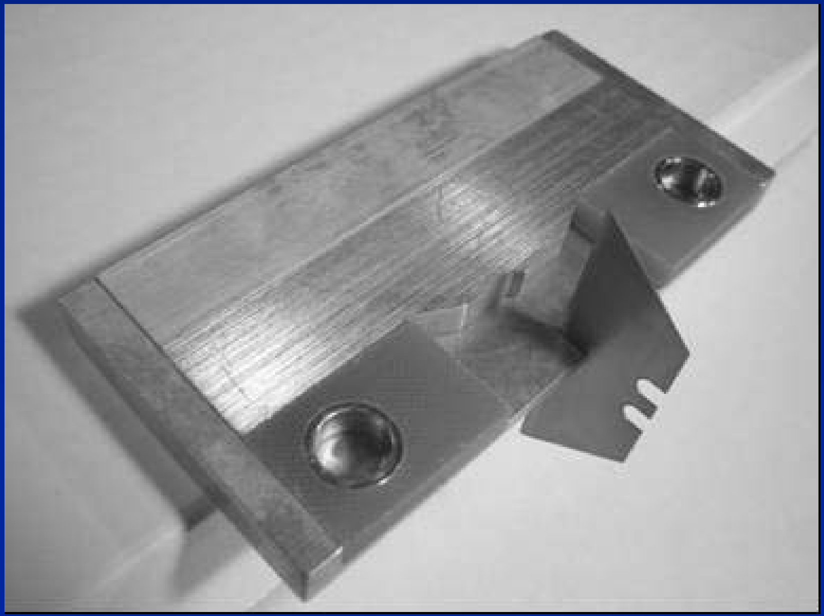


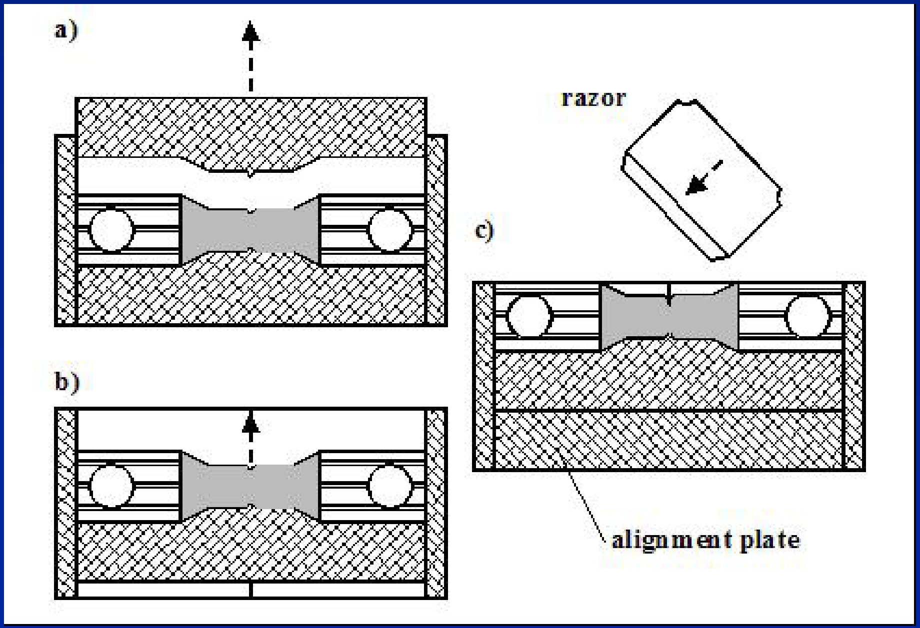
Binder Testing

- Binders used to prepare laboratory mixtures
- Binders recovered from top layer of field samples
- Test methods
  - ✓BBR – 1000s
  - ✓DT – 3%/min
  - ✓DENT – 1.8%/min
  - ✓All three after 1h and 20h conditioning

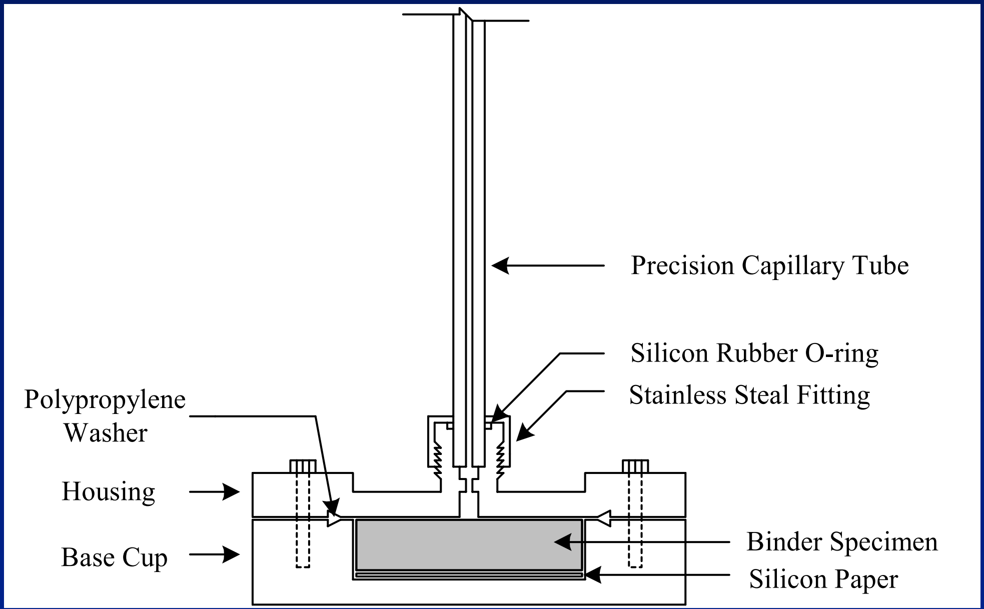
DENT

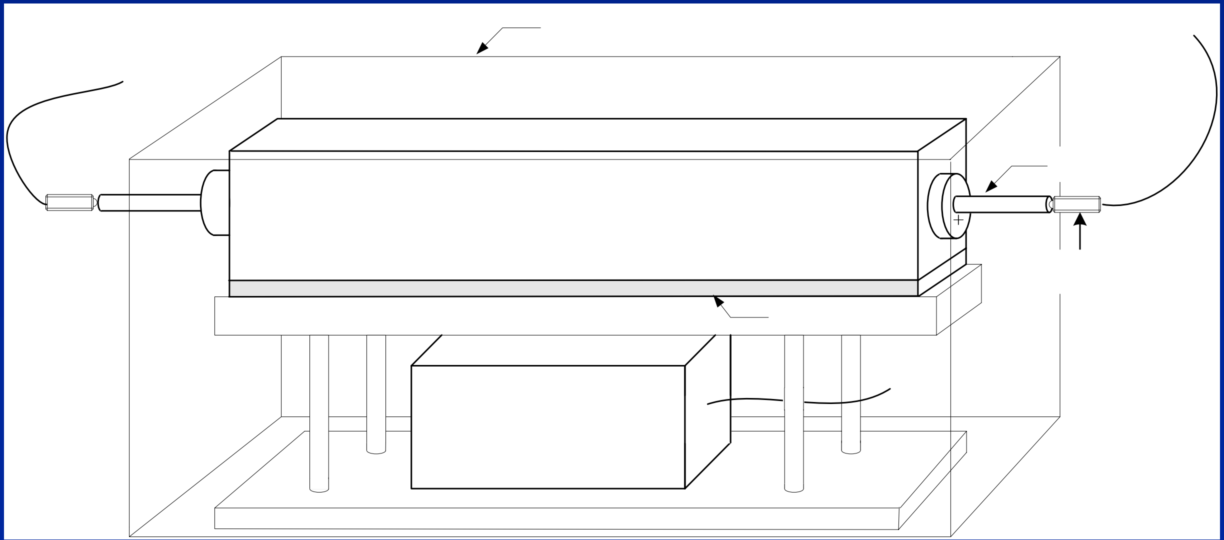




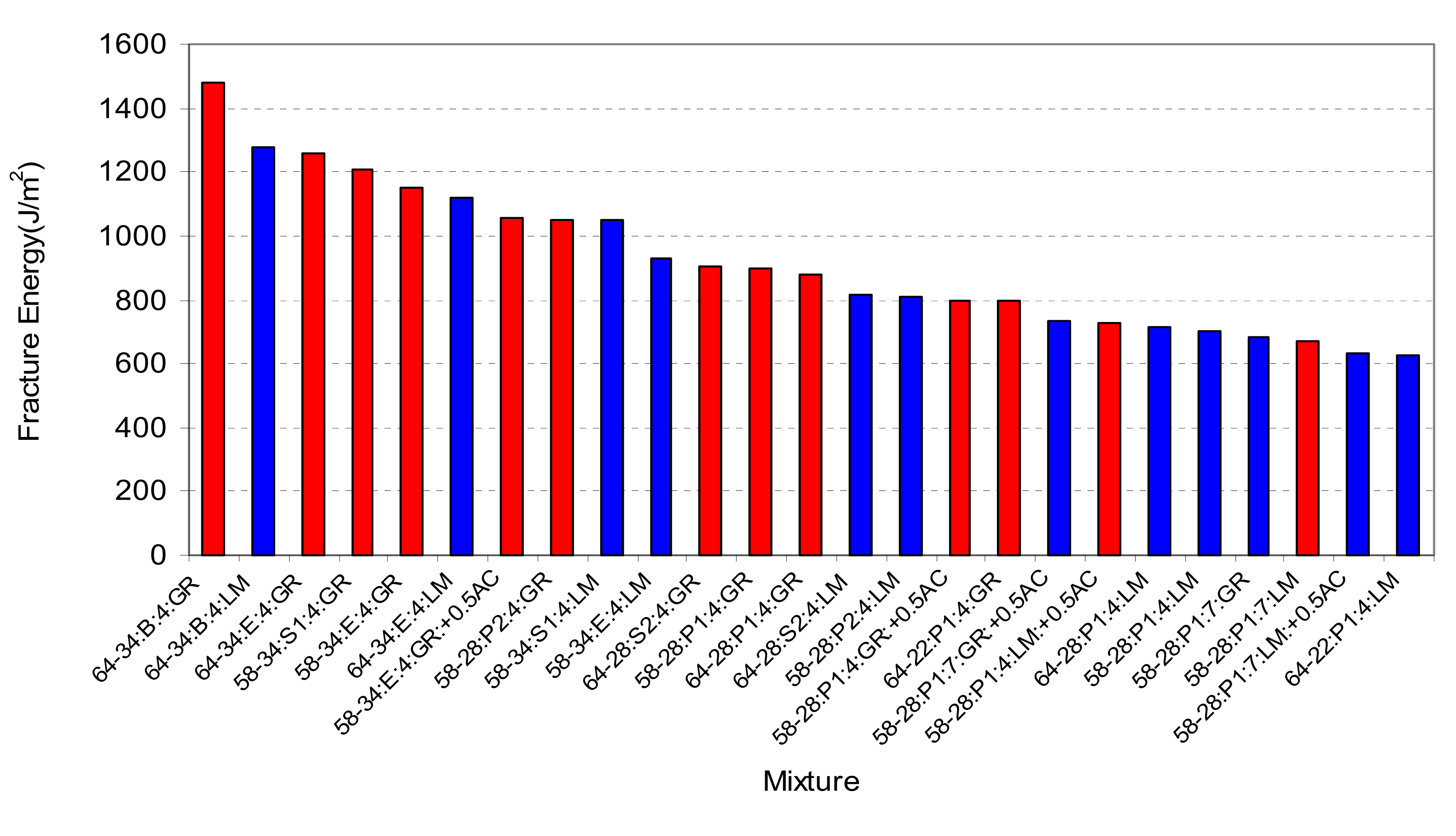


Dilatometric Measurements





Fracture Energy at T_H



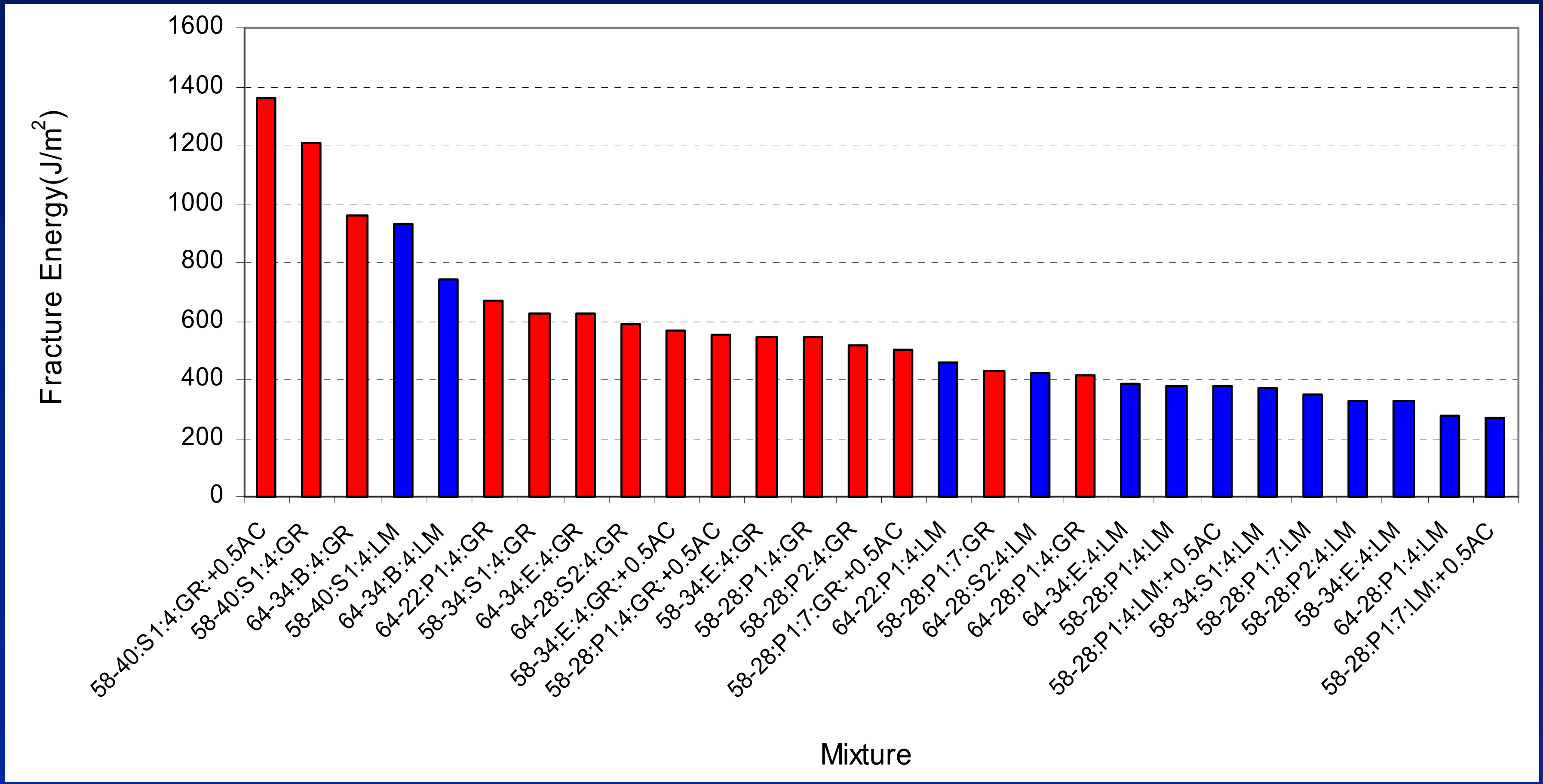
Fracture Energy Ranking at T_H

Highest: 64-34:B:4:GR

Not calculated: 58-40:M1

Lowest: 64-22:P1:4:LM

Fracture Energy at T_M

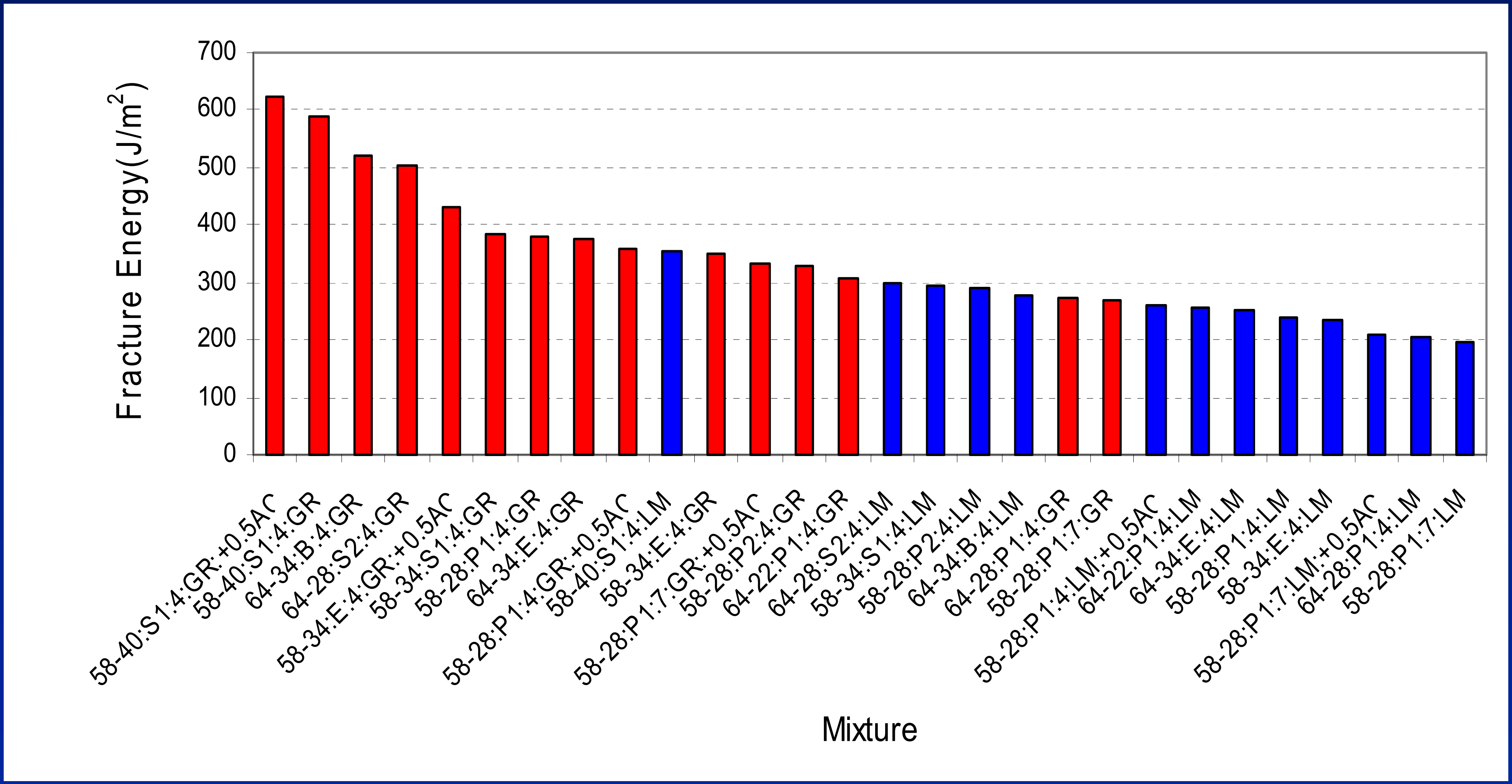


Fracture Energy Ranking at T_M

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

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

Fracture Energy at T_L

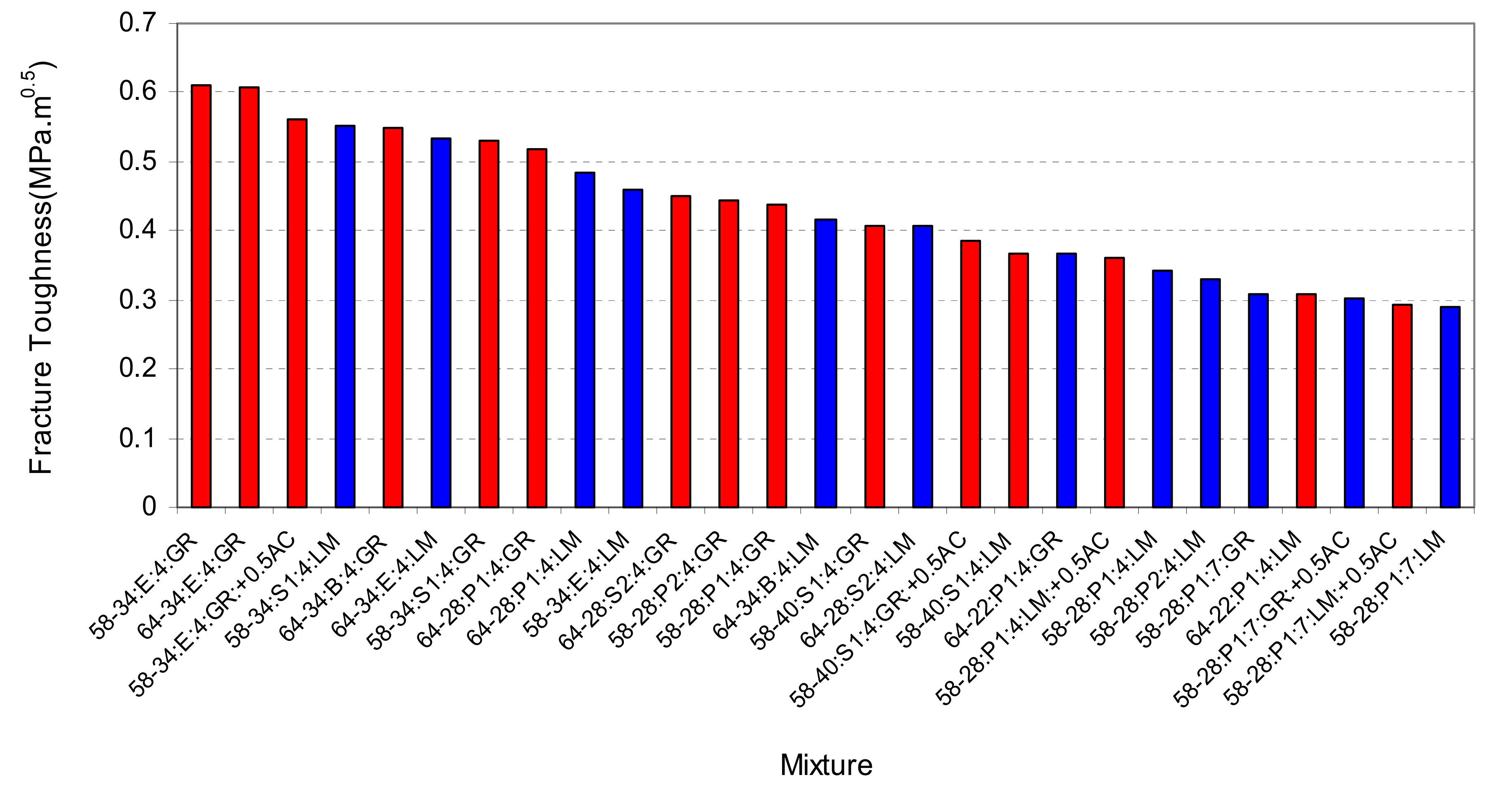


Fracture Energy Ranking at T_L

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

Lowest: 58-28:P1:7:LM

Fracture Toughness at T_H

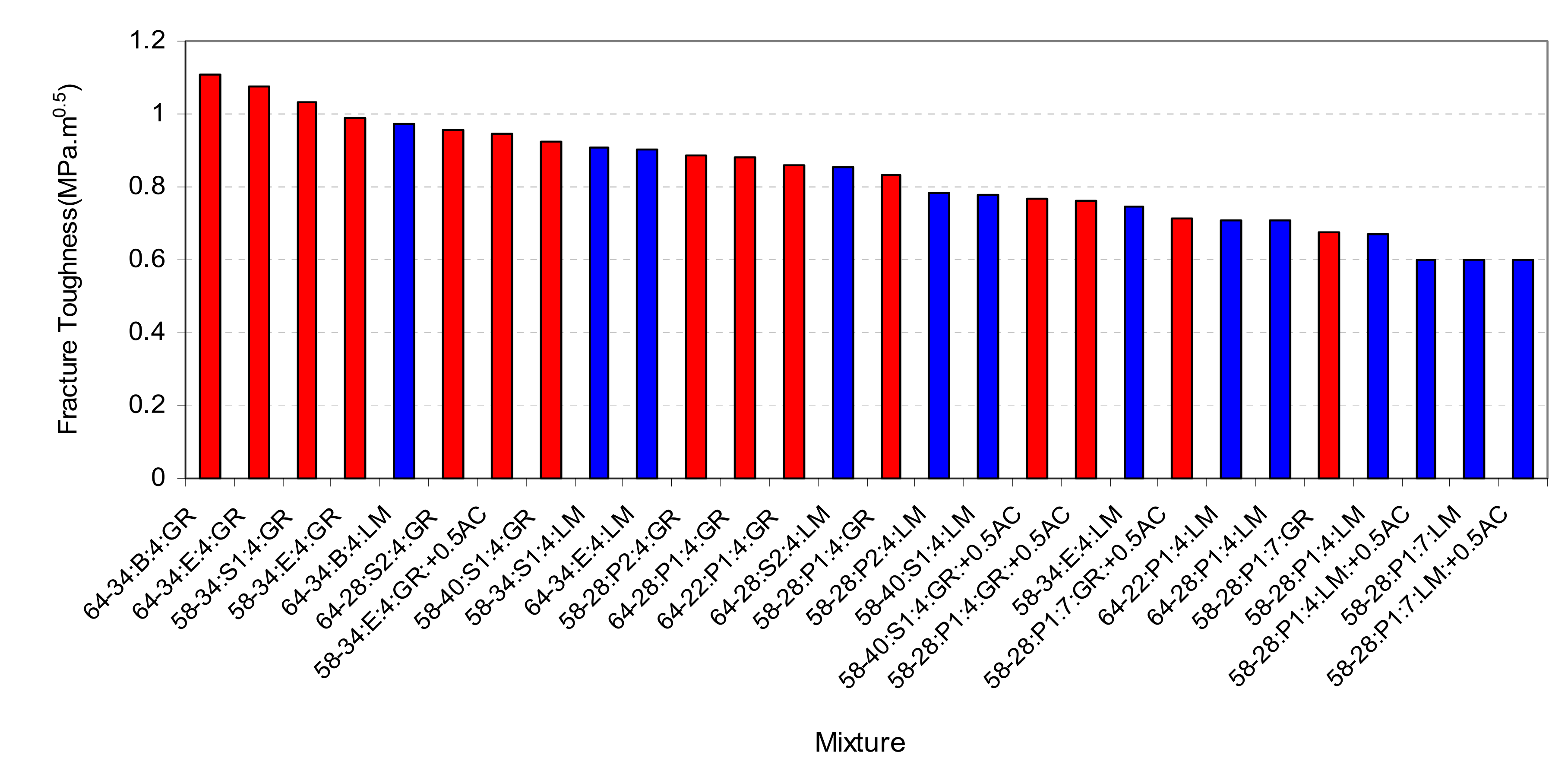


Fracture Toughness Ranking at T_H

Highest: 58-34:E:4:GR

Lowest: 58-28:P1:7:LM

Fracture Toughness at T_M

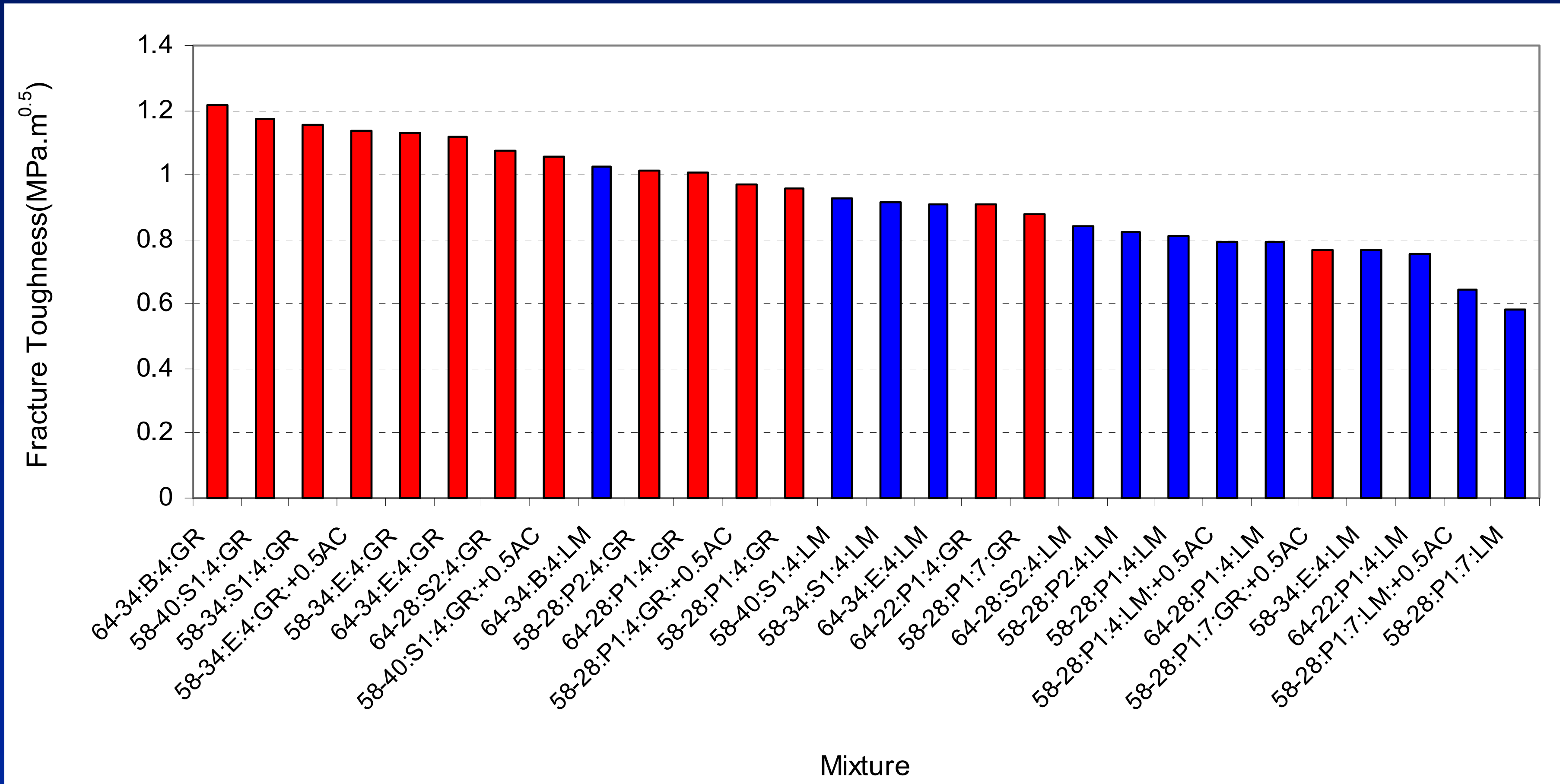


Fracture Toughness Ranking at T_M

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

Conclusions

- At low temperature, asphalt mixtures are complex viscoelastic composite materials that are significantly temperature and loading rate dependent
  - ✓ Testing temperatures should be established relative to expected low pavement temperature and relative to low temperature PG grade for location of interest
  - ✓ The effect of loading rate needs to be investigated to better match true field cooling rates
- Mixture and binder test temperatures should be matched as much as possible to better understand the contribution of the binder to the fracture properties of mixtures

Conclusions

- Asphalt binder testing alone does not provide sufficient reliability to predict low temperature cracking of asphalt pavements
  - ✓ The effect of aggregate type appears to have a significant effect for mixtures made with the same asphalt binder
- PG system provides a good starting point, however, further refinement of the current system.
  - ✓ Role of the BBR "m" value should be re-considered
  - ✓ Physical hardening has a significant effect on measured binder properties

Conclusions

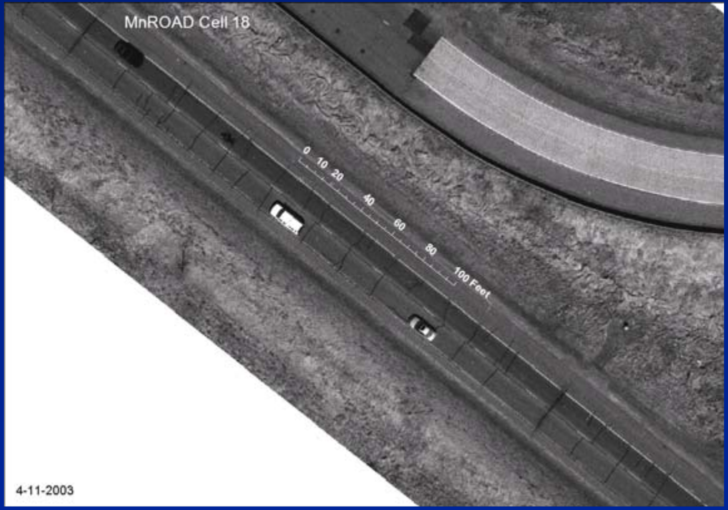
- The current specifications for low temperature cracking for both asphalt binders and mixtures do not include a fracture test
  - ✓Two simple mixture tests, the disk-shaped compact tension test and semi-circular bend test, were investigated and were successfully used
  - ✓The binder direct tension test protocol was modified to obtain binder characteristics needed for better ranking at low temperature
  - ✓However, need an improved binder test, that gives the same type of information as the mixture test, i.e. provide post-peak behavior

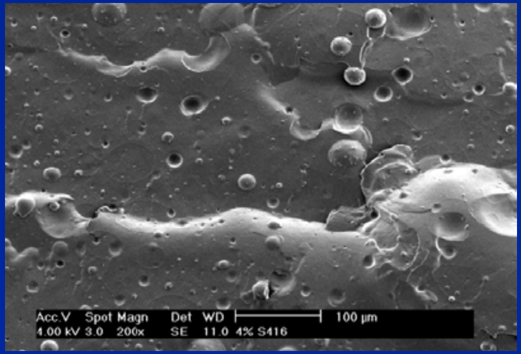
Conclusions

- The current indirect tensile test provides useful information for the complete evaluation of low temperature behavior of asphalt mixtures, but is not the best choice for a simple screening test
- The current thermal stress restrained specimen test can become a useful research tool to analyze the stress development and fracture mechanism in asphalt mixtures at low temperatures if further refined


Thank you!


NVIDIA.
Image © 2004 DigitalGlobe
©2004 keyhole.com
Pointer 45°15'22.01" N 93°42'07.23" W
Streaming |||||||||| 100%
Eye alt 428 ft


MnROAD Cell 18
0 10 20 40 60 80 100 Feet
4-11-2003


Acc.V Spot Magn Det WD 100 µm
4.00 kV 3.0 200x SE 11.0 4% S416