

# **Asphalt Binder vs. Asphalt Mixtures**

**Investigation of Low Temperature Cracking in Asphalt Pavements - National Pooled Fund Study 776**

Mihai Marasteanu  
Adam Zofka  
Raul Velasquez

**Pavement Performance Prediction Symposium  
Laramie, July 2007**

# Background

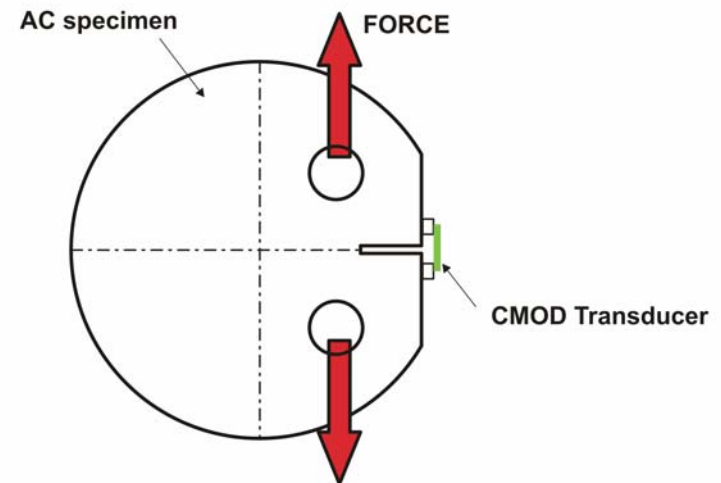
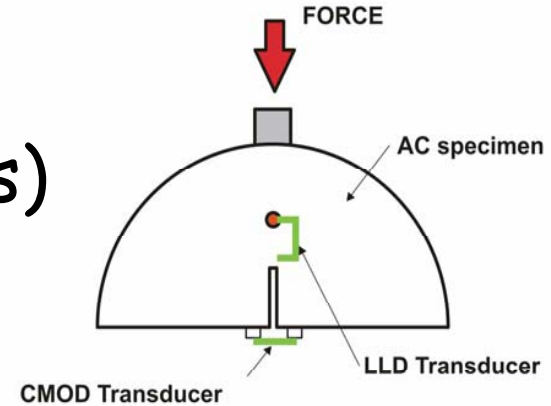
- Comprehensive project
  - Experimental investigation
    - Asphalt mixtures
      - Laboratory prepared
      - Cores and beams from selected pavements
    - Asphalt binders
      - Laboratory aged
      - Extracted from field cores
    - Experimental data analysis
  - Pavement system modeling

# 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

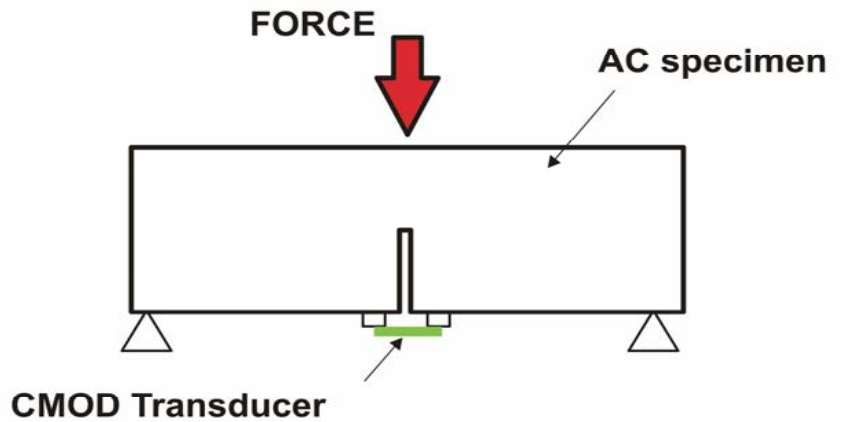
# Mixture tests performed

- IDT
  - Creep (multiple load levels)
  - Strength (multiple loading rates)
- Semi Circular Bending (SCB)
- Disc-Shaped Compact Tension DC(T)



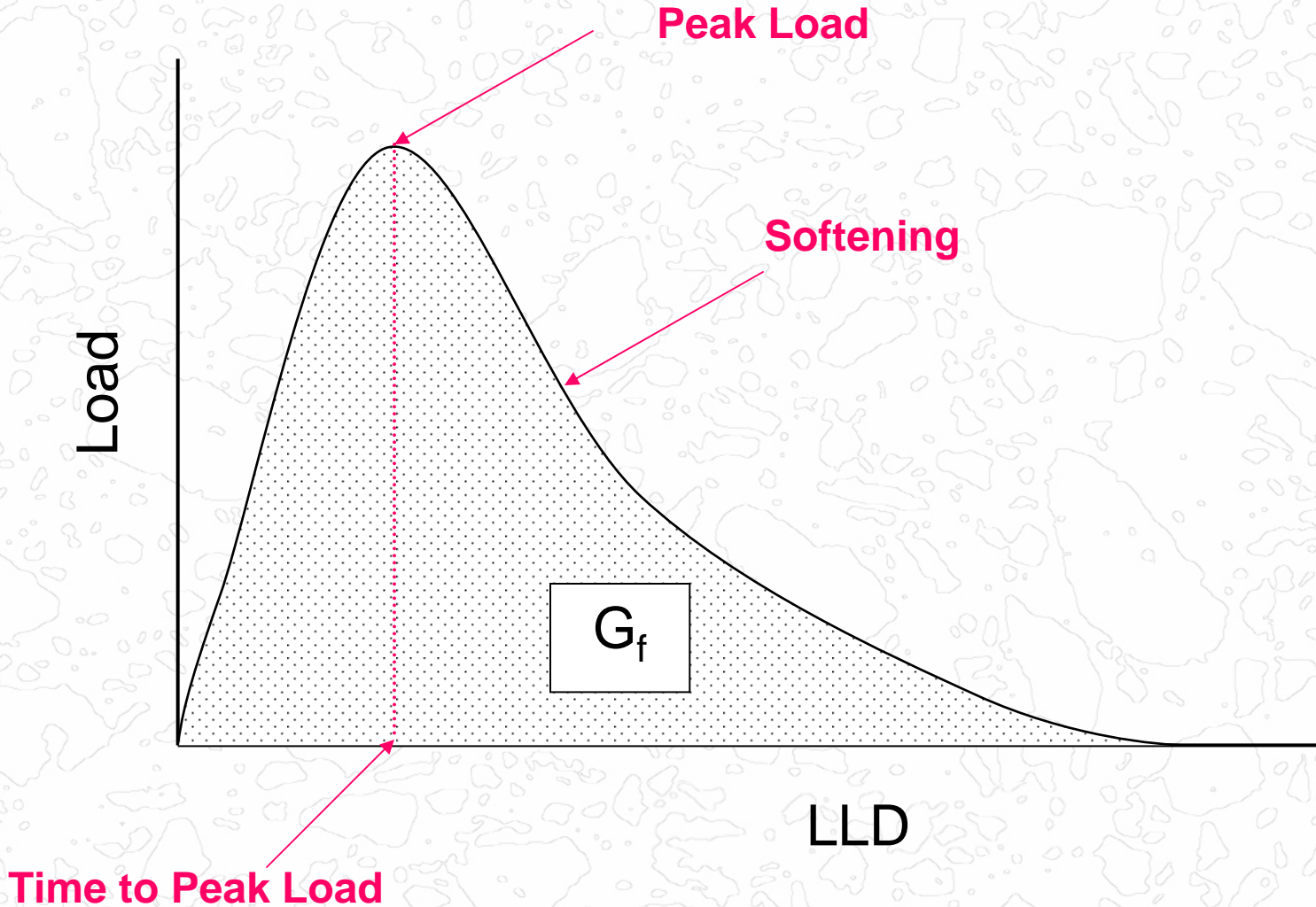
# Mixture tests performed

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



- Thermal Stress Restrained Specimen Test (TSRST)

# Fracture Energy – $G_f$ (J/m<sup>2</sup>)

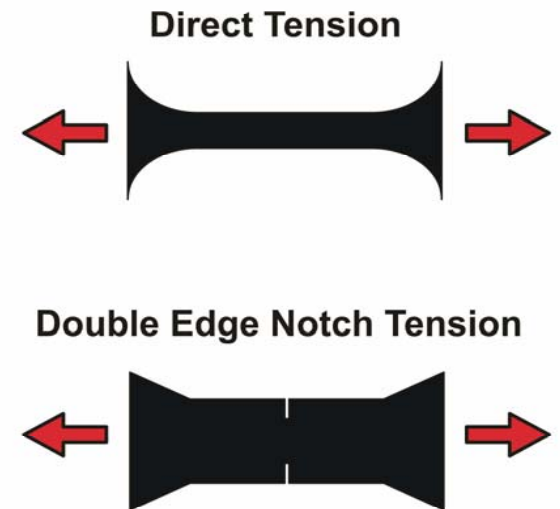


# Binder Testing

- Two sets of asphalt binders
  - Ten laboratory aged binders
    - Two conditions: RTFOT and PAV
  - Thirteen extracted binders
- Three test temperatures based on PG grade:
  - (PG+10) identified as High (H)
  - (PG+10)-6 identified as Intermediate (I)
  - (PG+10)-12 identified as Low (L)

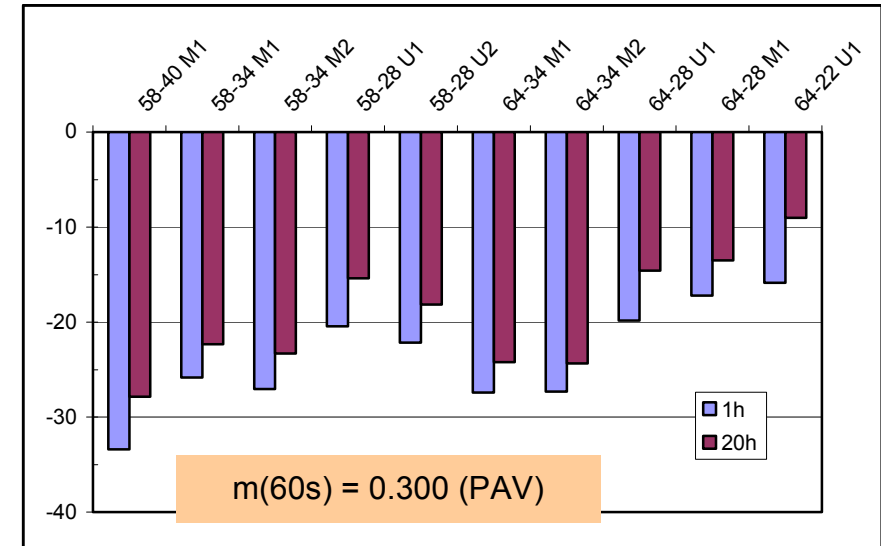
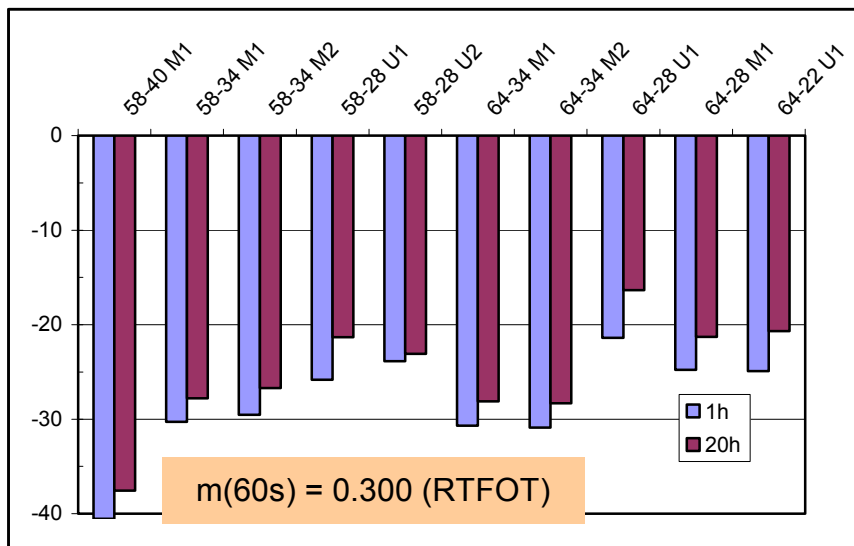
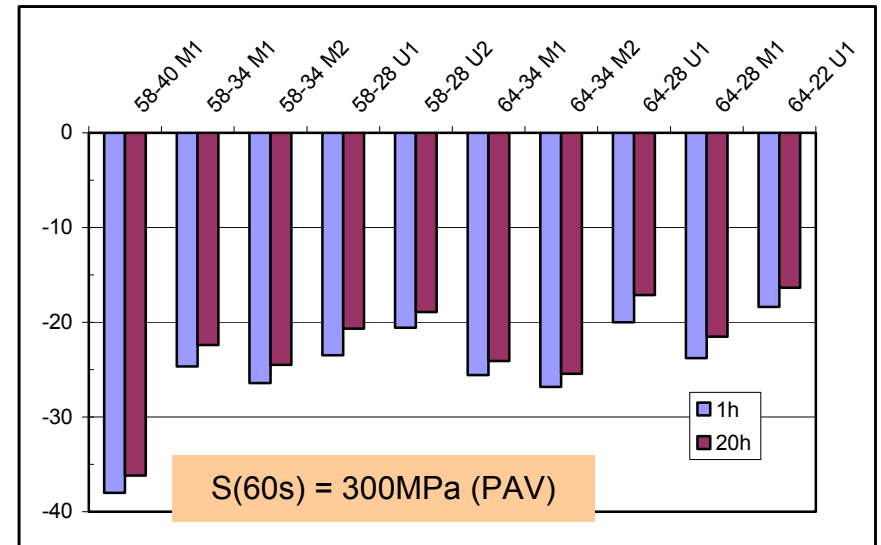
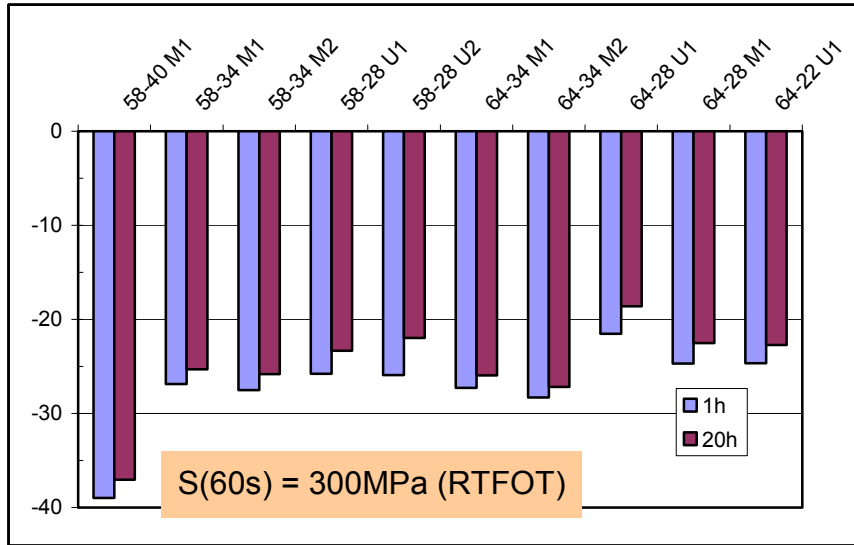
# Binder tests performed

- BBR
  - 1h conditioning
  - 20h conditioning
- Direct Tension
  - 3% per minute strain rate
  - 1% per minute strain rate
- Double Edge Notched Test
  - 1% per minute strain rate



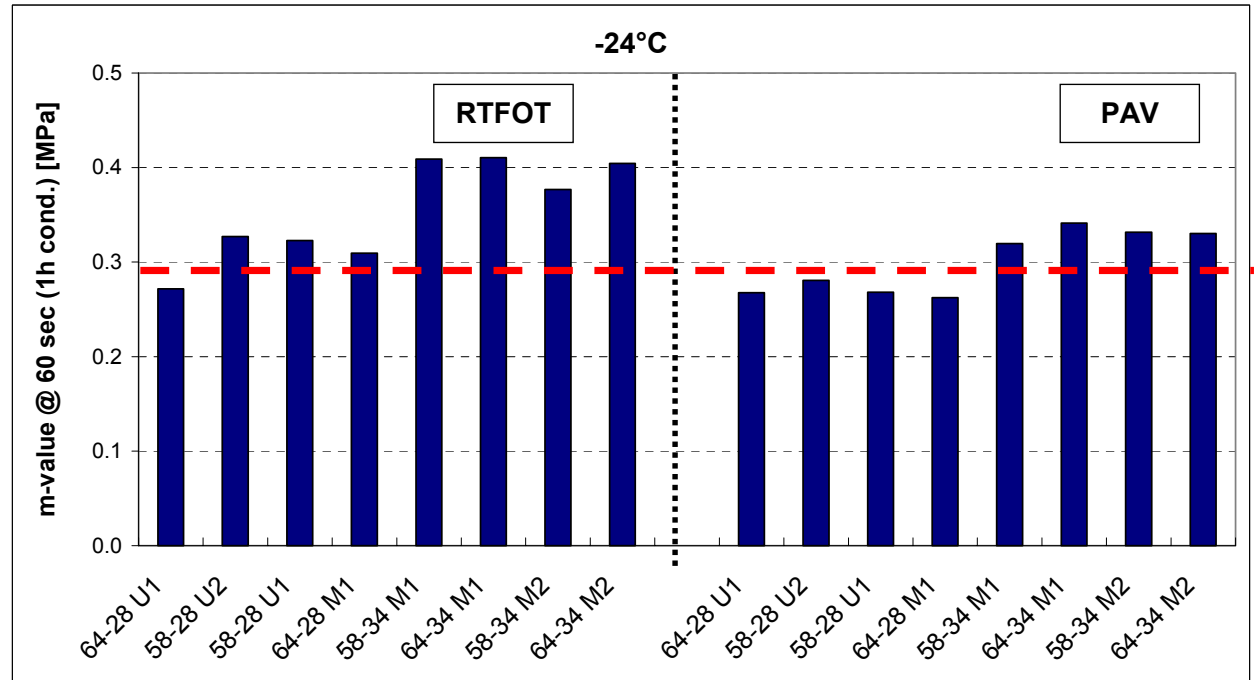
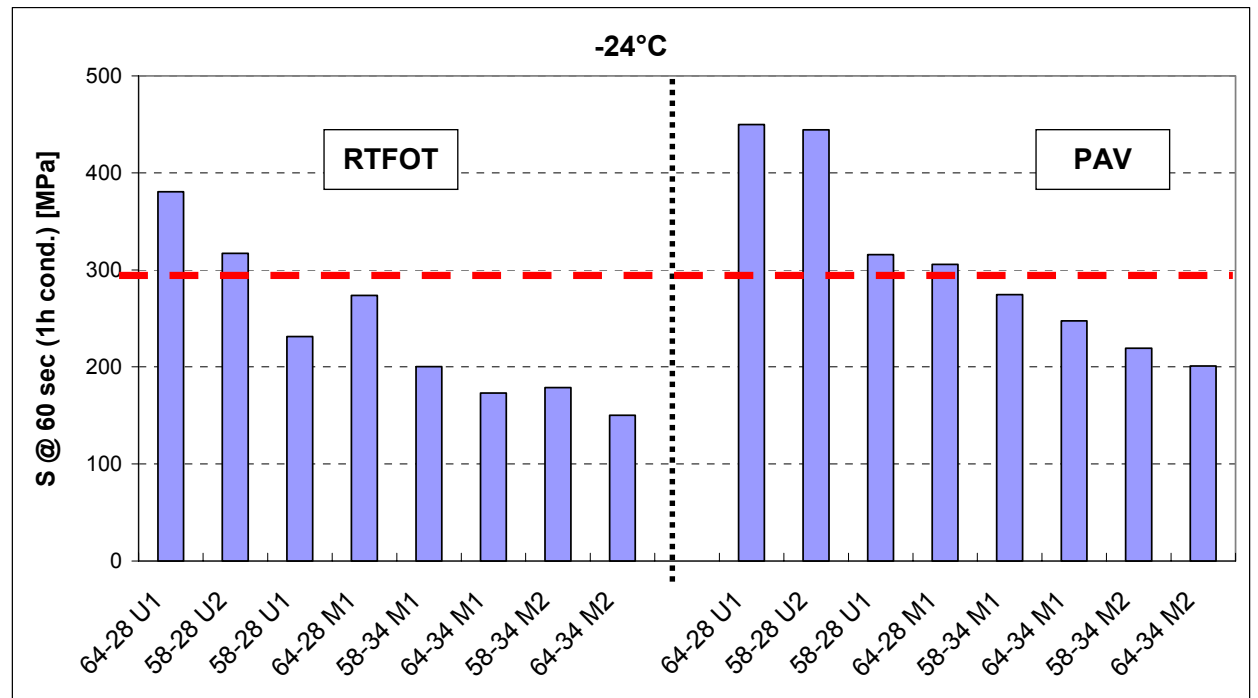
Binder details	Code name	Test temperatures		
		Binders		
	Temperature ->	H	I	L
PG58-40, modifier 1 - SBS (Flint Hills Res.)	58-40 M1	-30	-36	-42
PG58-34, modifier 1 - Elvaloy (Murphy)	58-34 M1	-24	-30	-36
PG58-34, modifier 2 - SBS (Flint Hills Res.)	58-34 M2	-24	-30	-36
PG58-28, plain 1 - (Seneca Petroleum)	58-28 U1	-18	-24	-30
PG58-28, plain 2 - (Payne and Dolan)	58-28U2	-18	-24	-30
PG64-34, modifier 1 - Elvaloy (Murphy)	64-34 M1	-24	-30	-36
PG64-34, modifier 2 - Black Max (Husky)	64-34 M2	-24	-30	-36
PG64-28, plain 1 - (Seneca)	64-28 U1	-18	-24	-30
PG64-28, modifier 1 - SBS (Seneca)	64-28 M1	-18	-24	-30
PG64-22, plain - (Seneca)	64-22 U1	-12	-18	-24

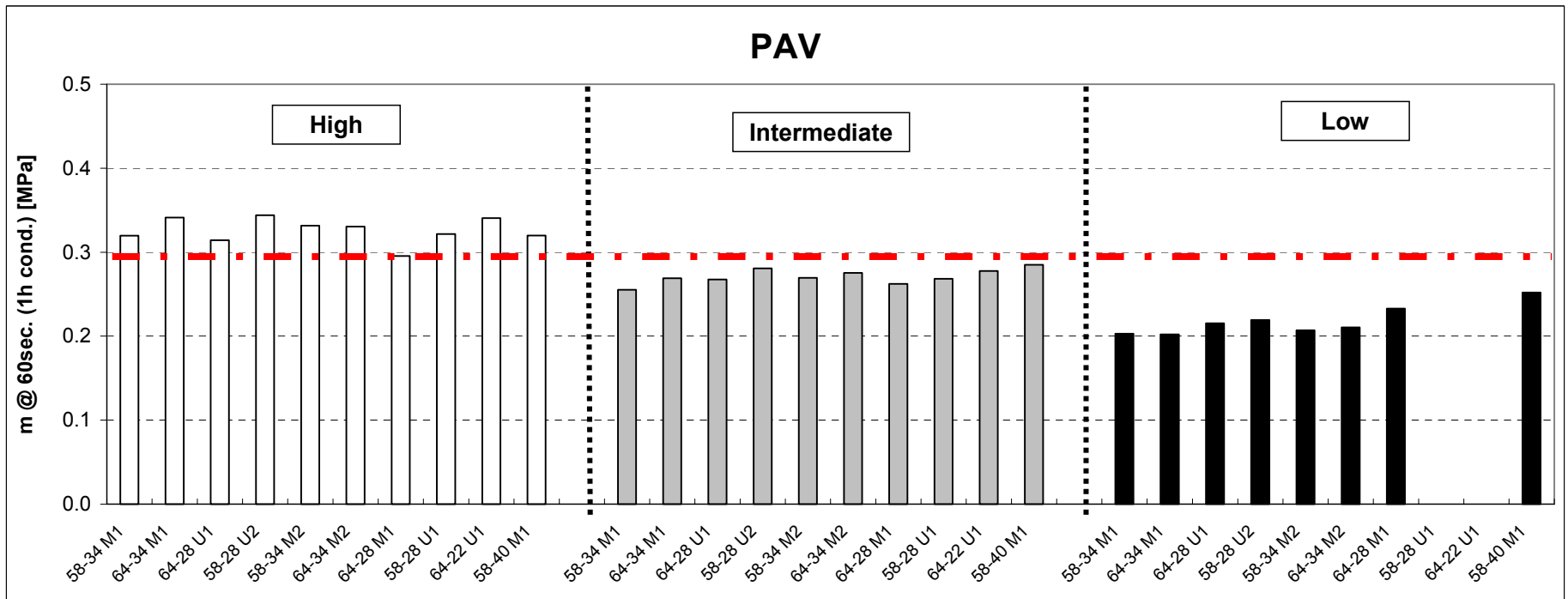
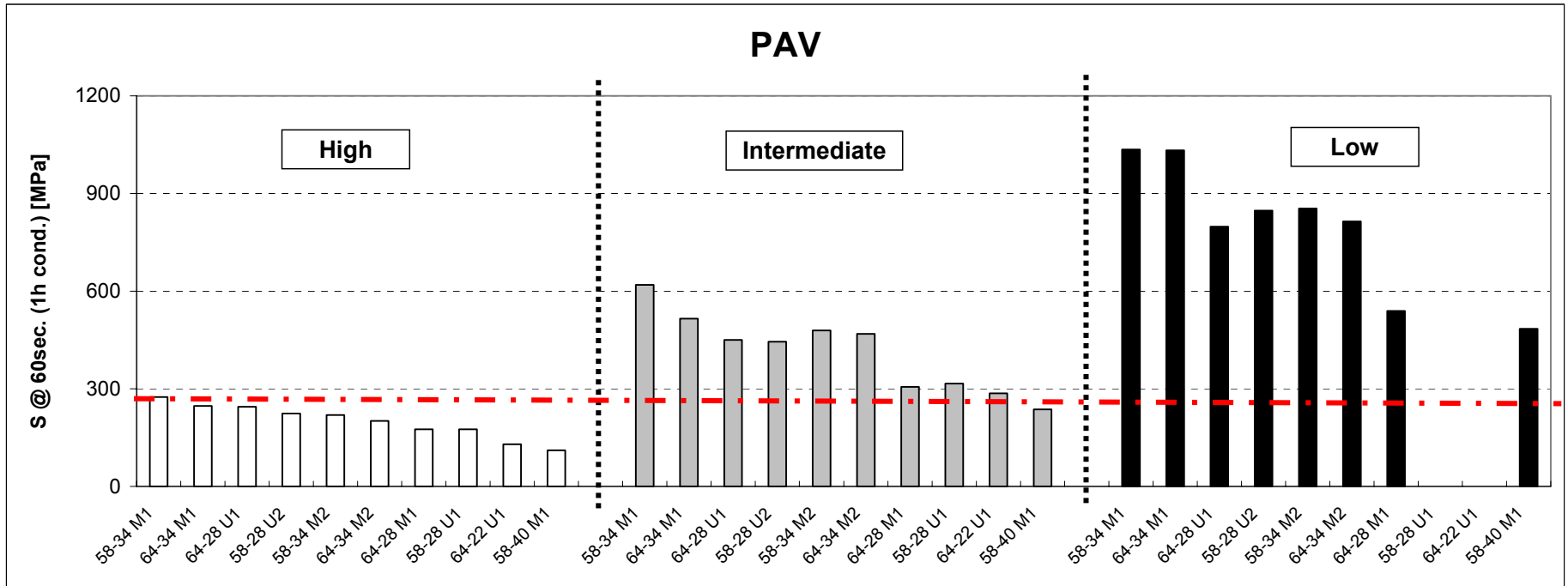
# Physical Hardening - BBR

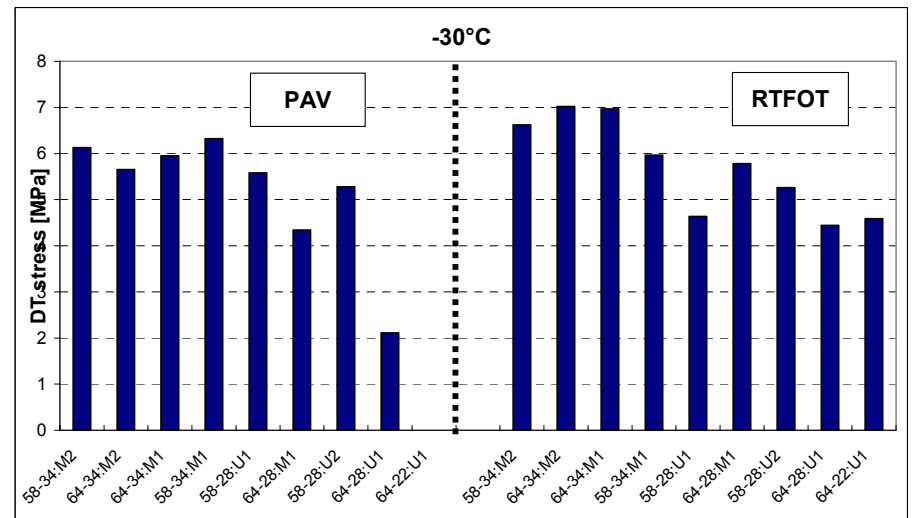
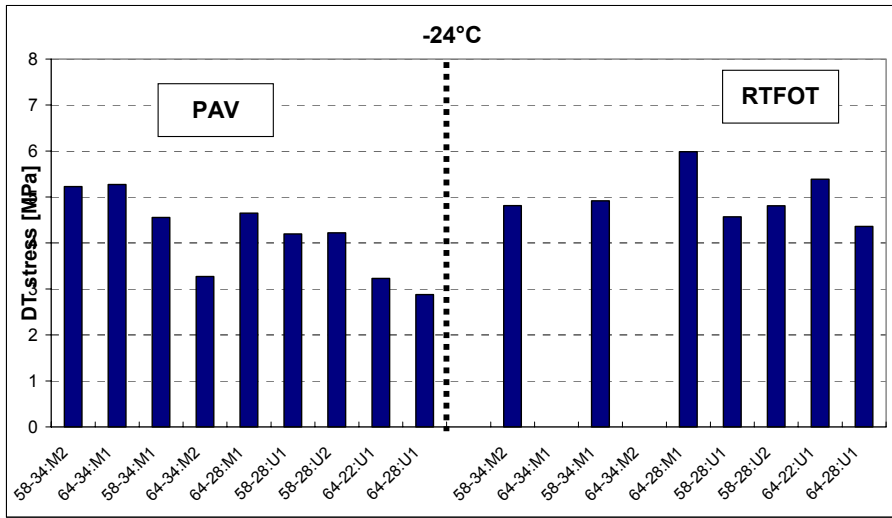
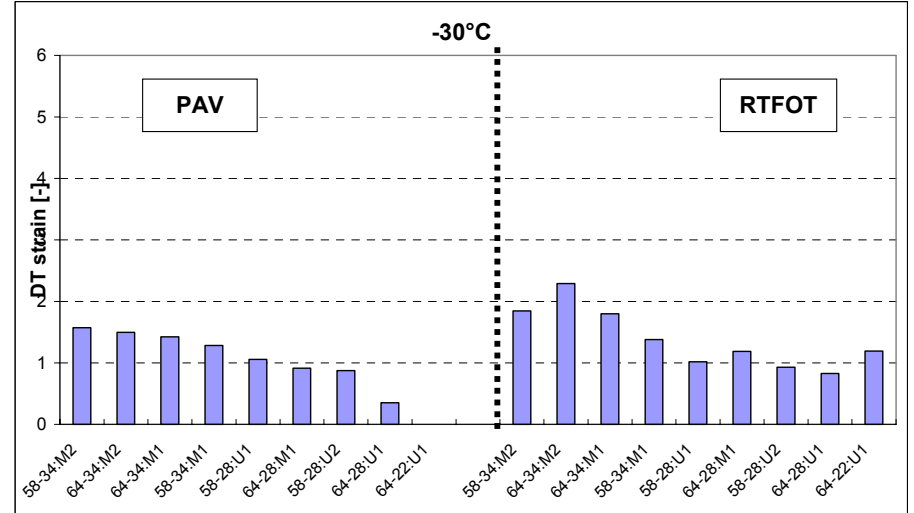
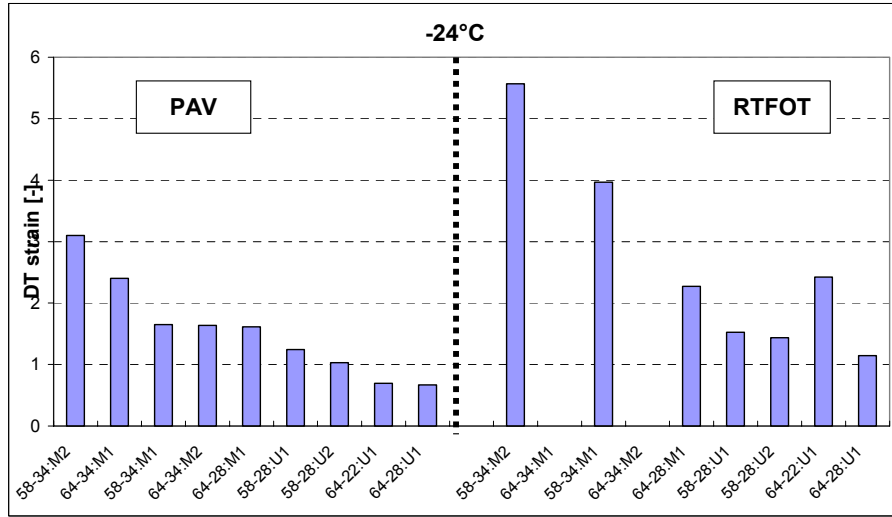


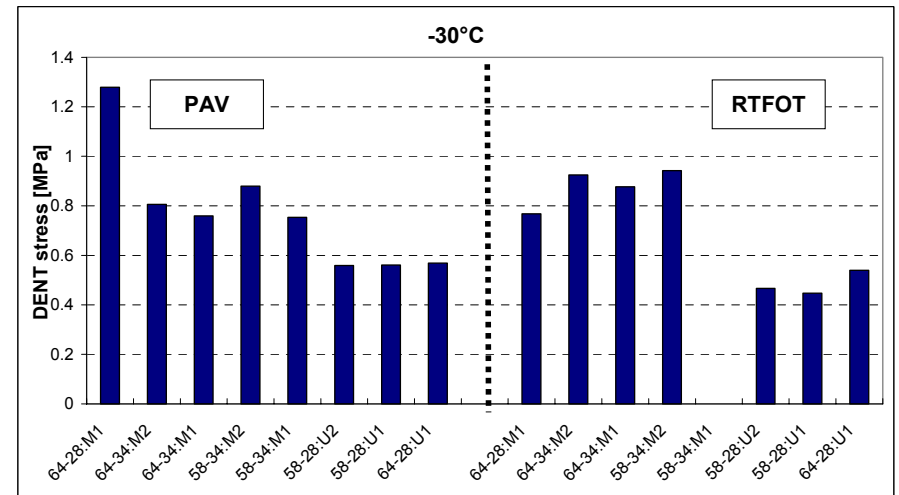
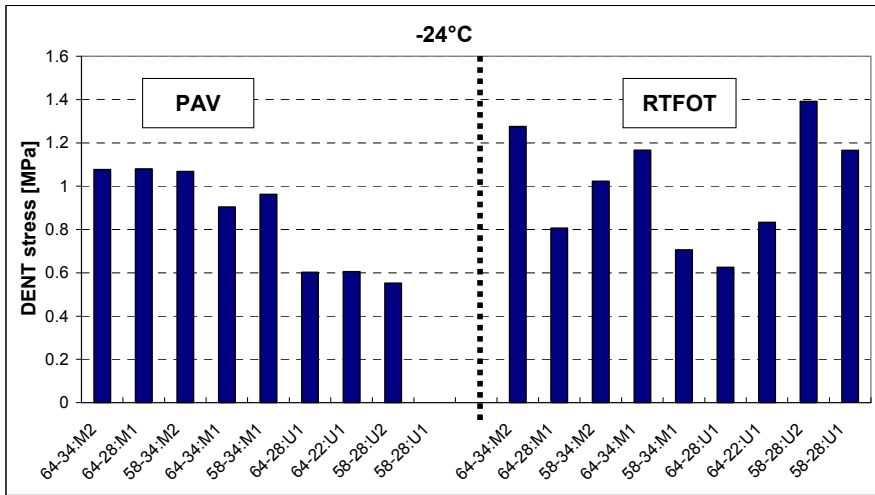
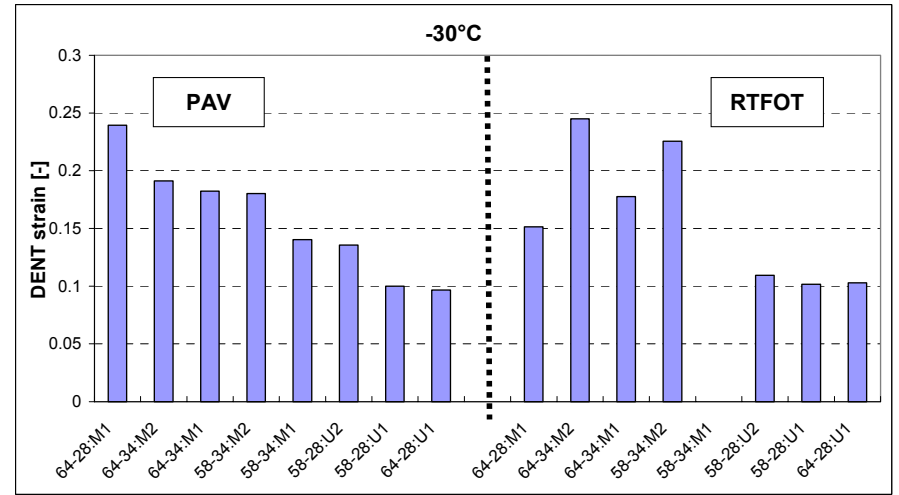
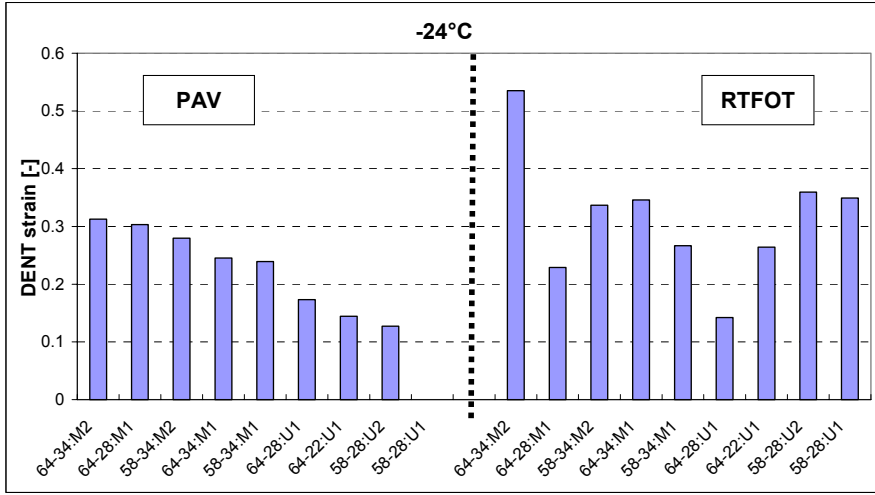
# Binder Ranking

## RTFOT vs. PAV

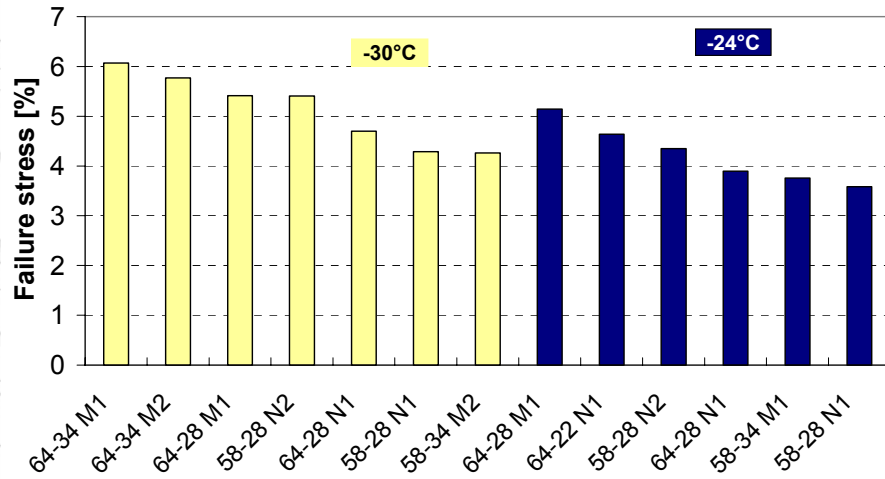




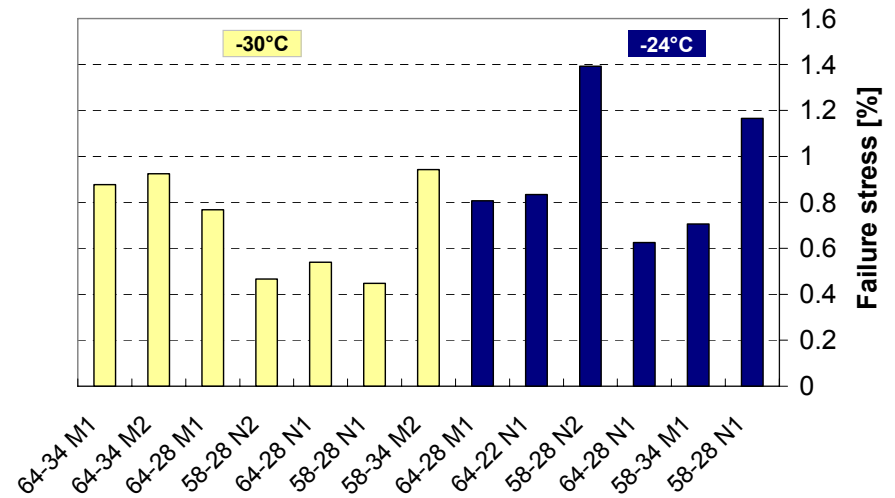




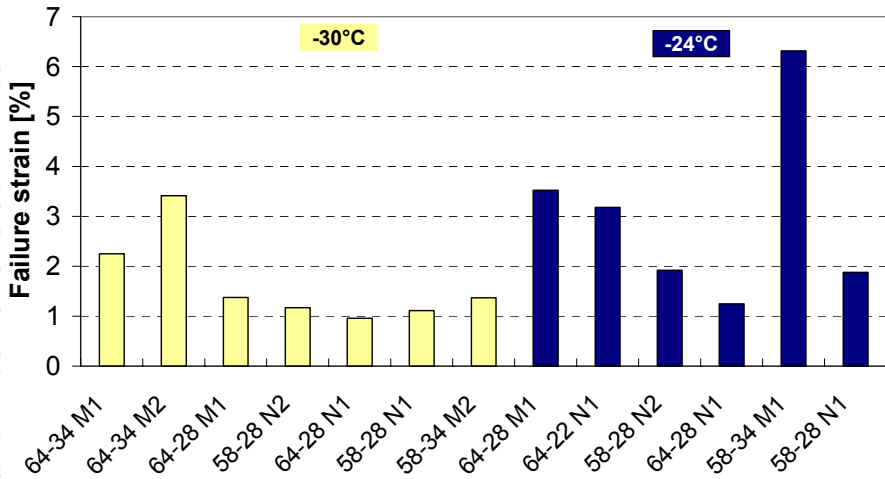
RTFOT, DT, 1%/min.



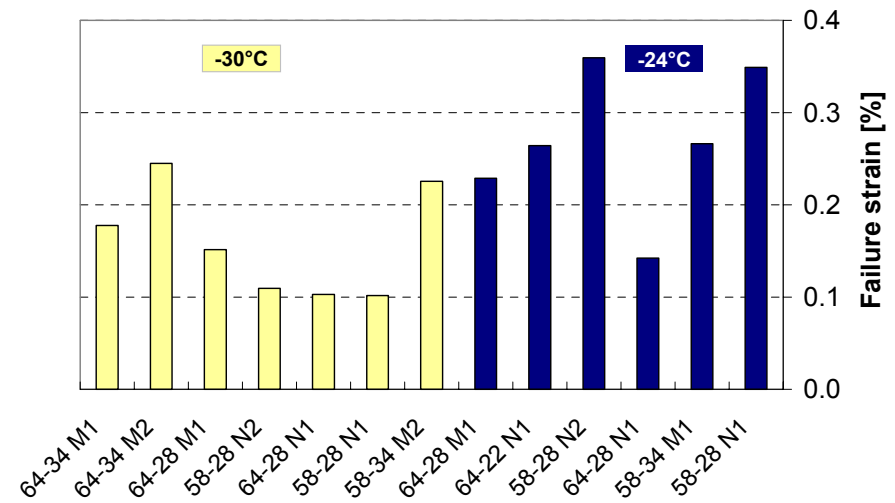
RTFOT, DENT, 1%/min.

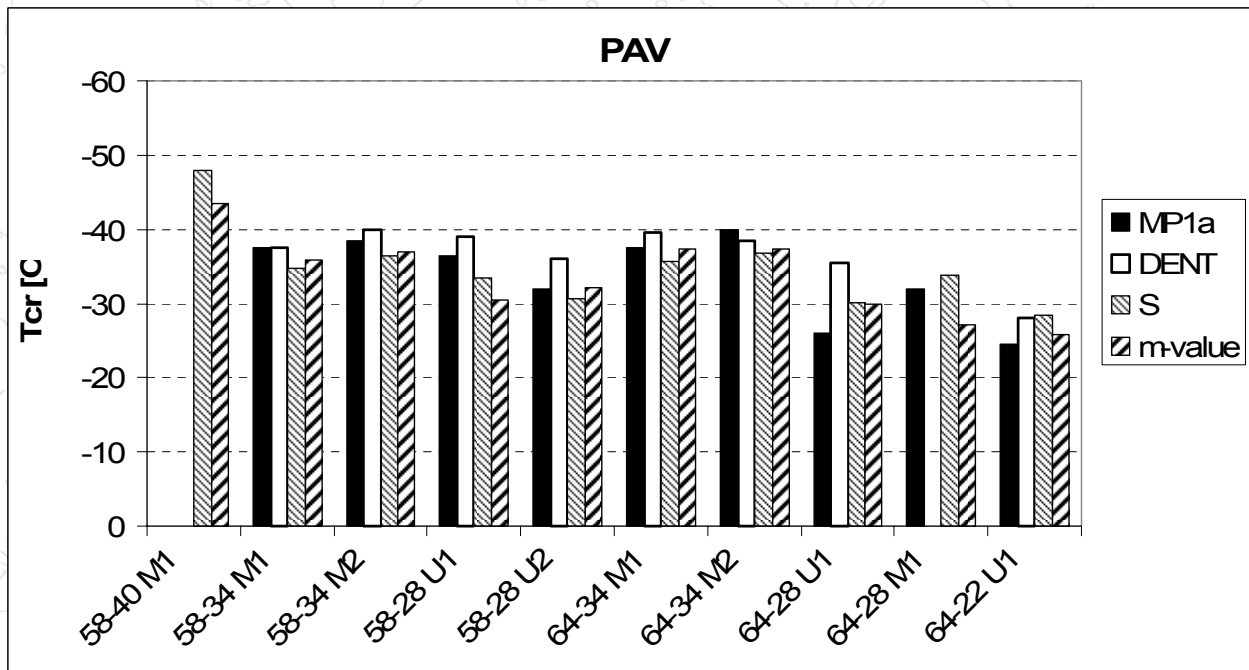
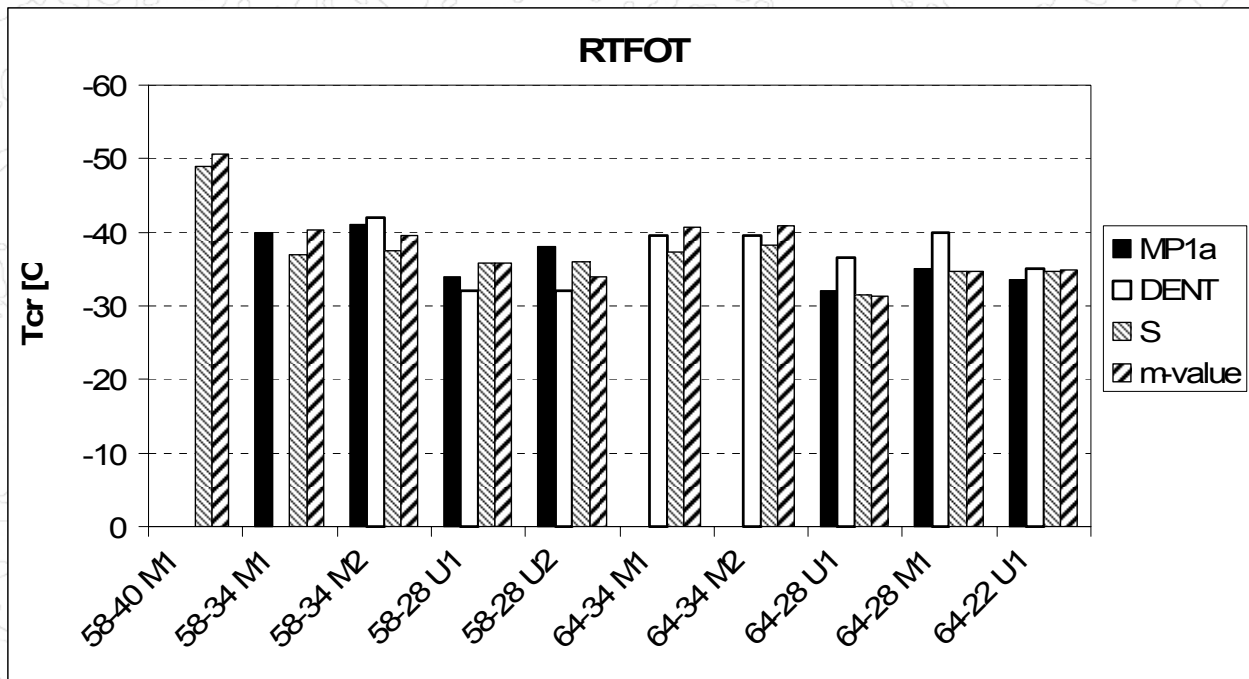


RTFOT, DT, 1%/min.



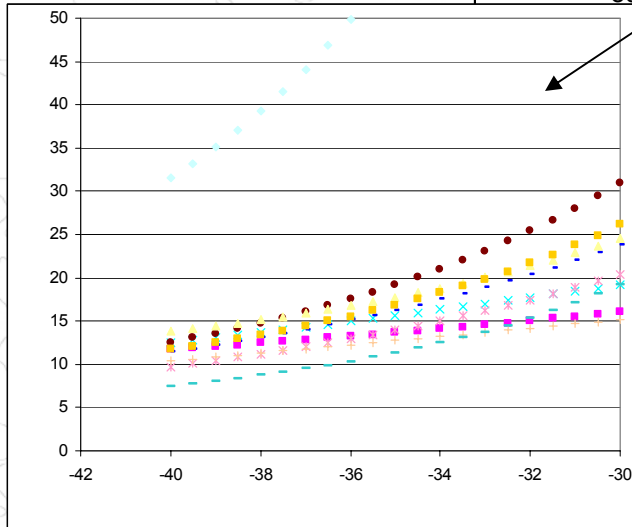
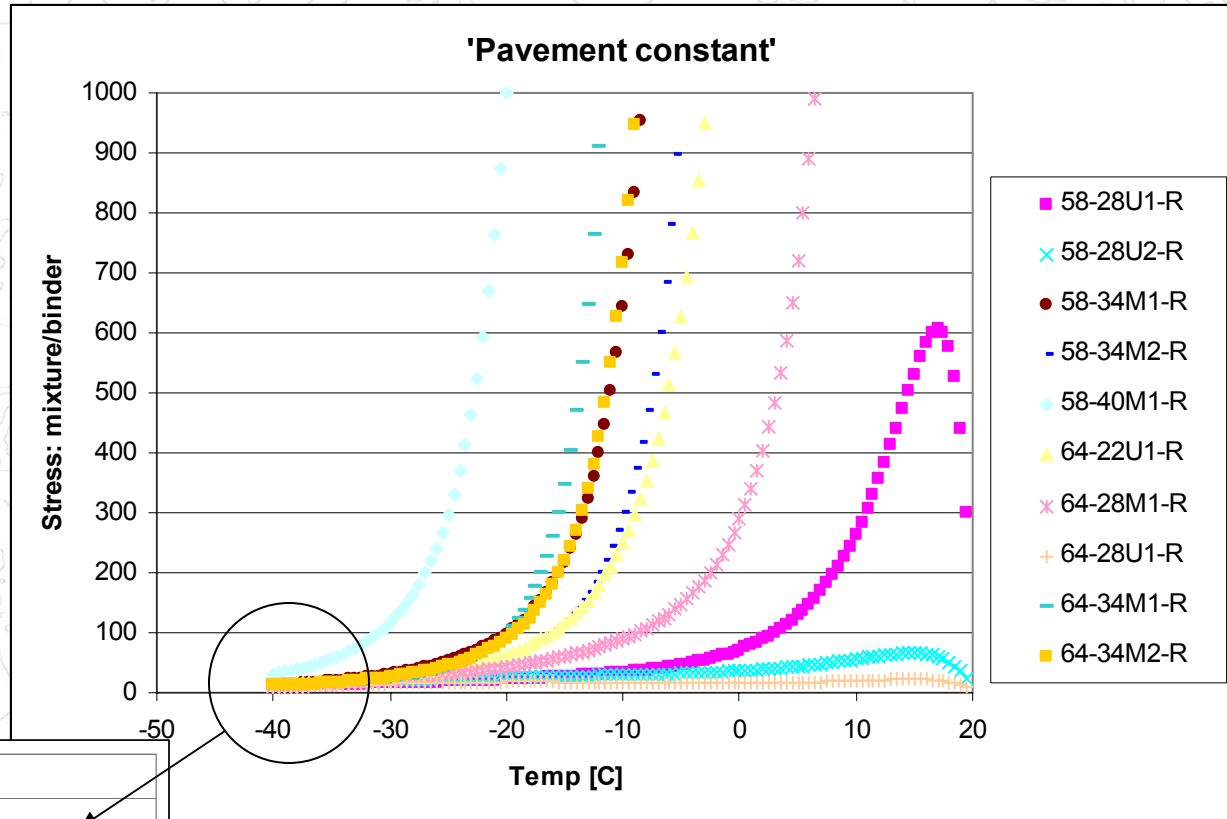
RTFOT, DENT, 1%/min.





# Pavement Constant

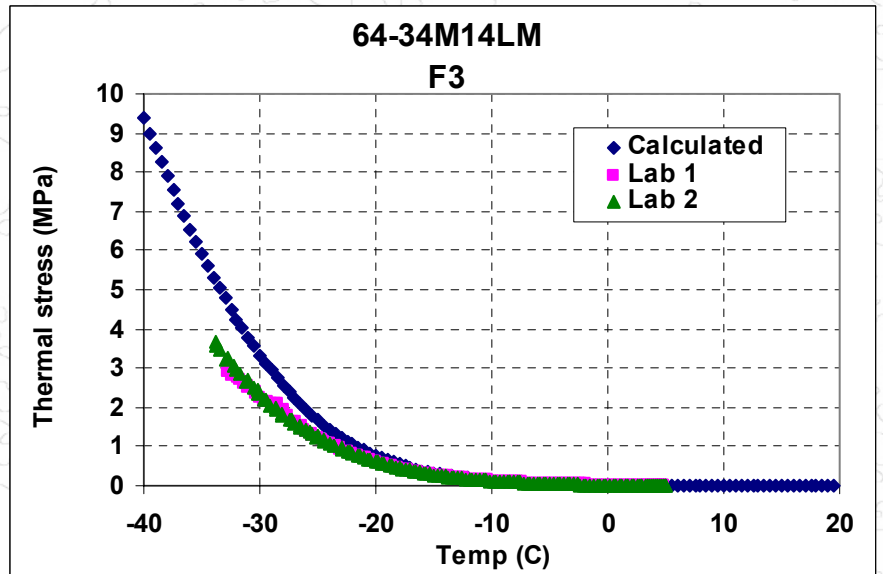
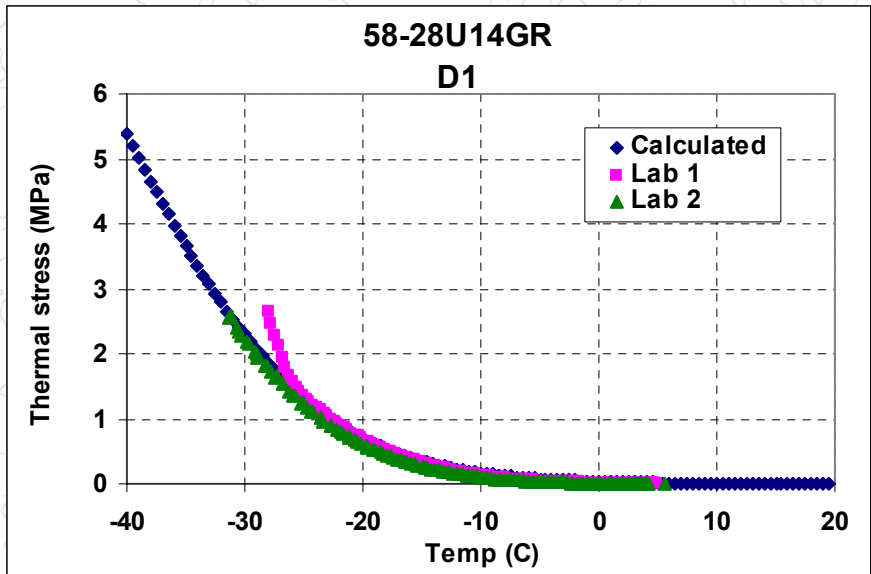
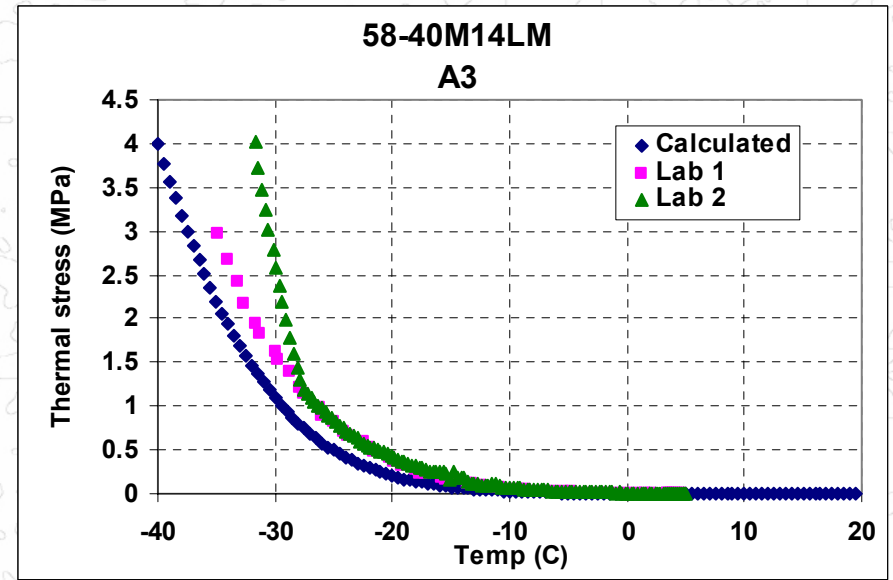
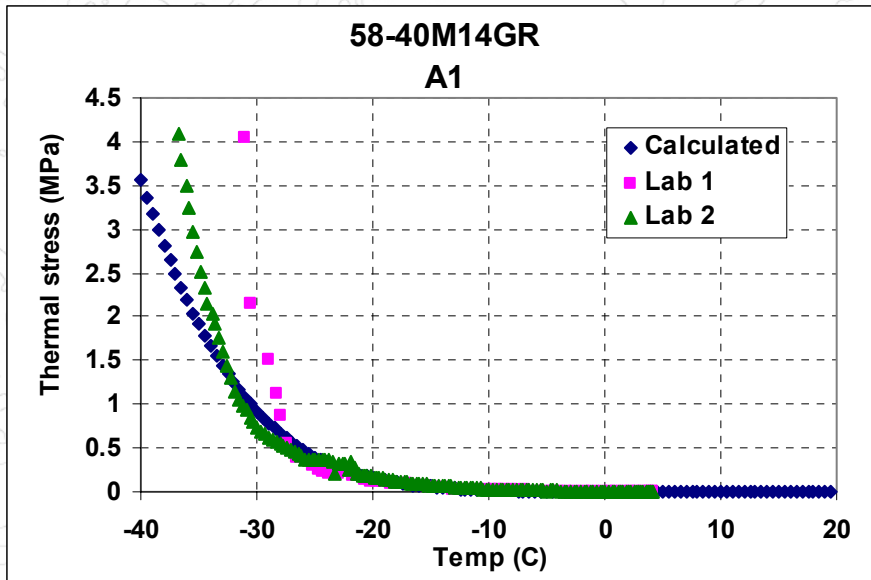
$$PC = \frac{\sigma_{mixture}}{\sigma_{binder}}$$



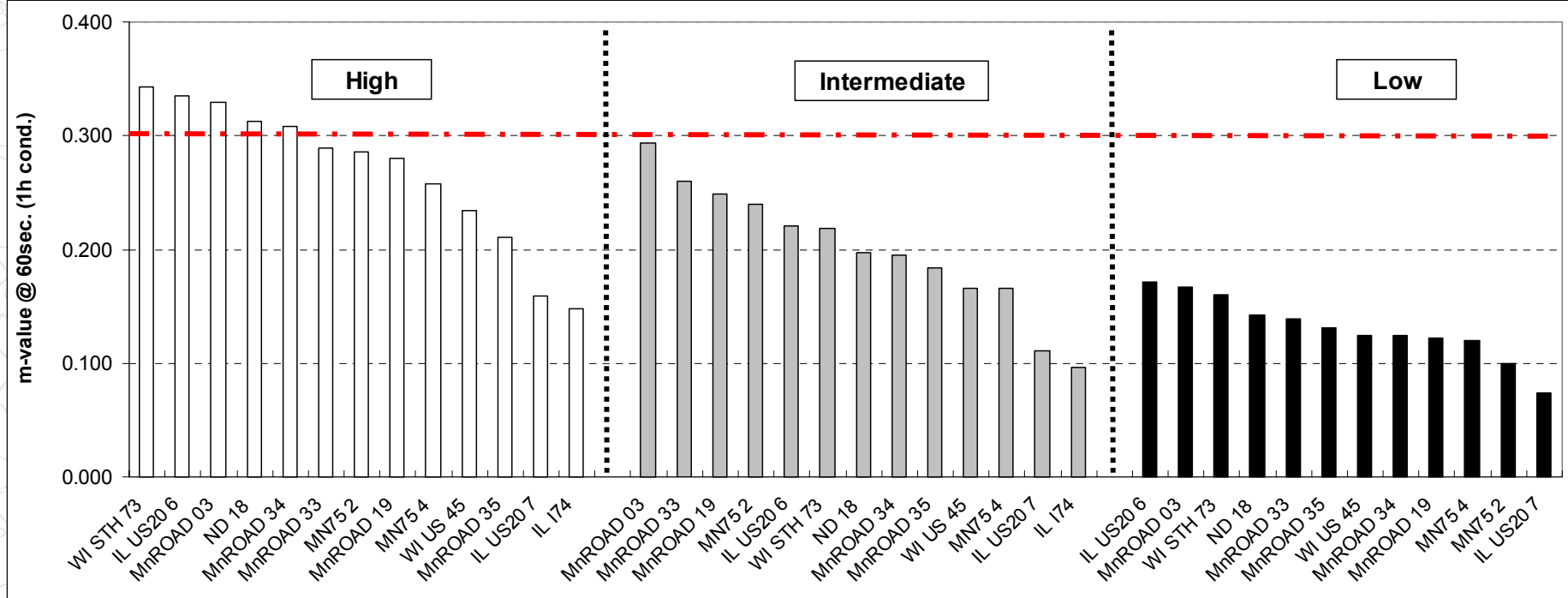
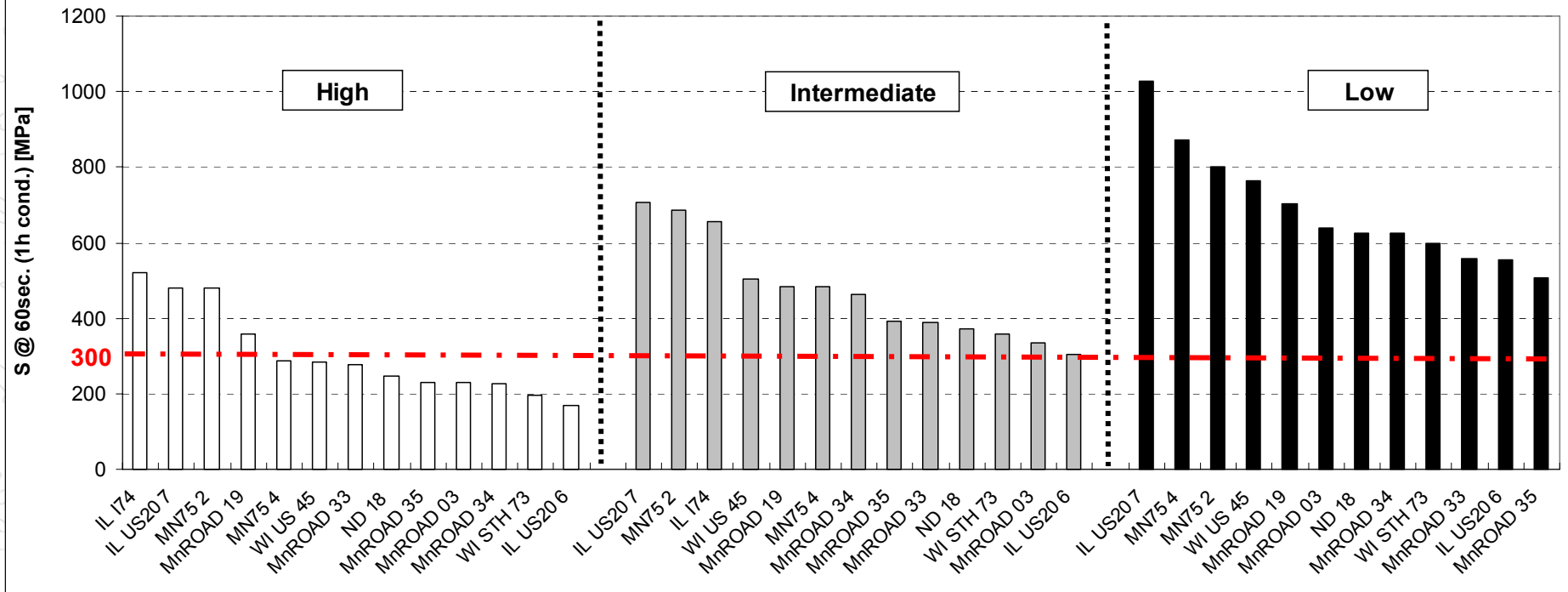
'Pavement constant' varies with temperature

At -40C almost all values merge and tend to  $PC = 10$

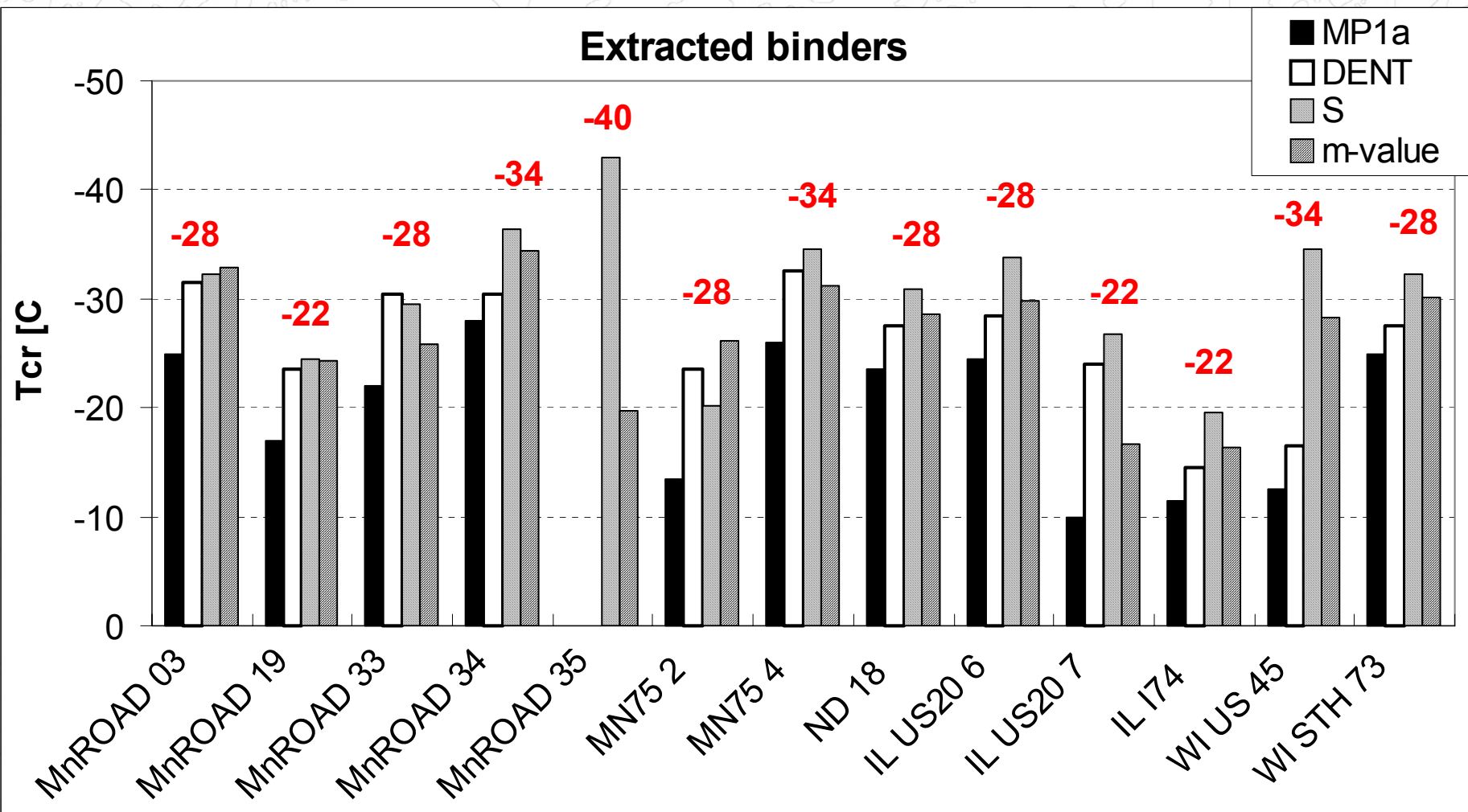
# Thermal Stresses vs. TSRST



Site	Code name	Original grade	Equivalent grade	Test temperatures (DT, DENT, BBR)		
				Temperature ->	H	I
MnROAD Cell 03	MnROAD 03	120/150	PG 58-28	-18	-24	-30
MnROAD Cell 19	MnROAD 19	AC-20	PG 64-22	-18	-24	-30
MnROAD Cell 33	MnROAD 33	PG 58-28	PG 58-28	-18	-24	-30
MnROAD Cell 34	MnROAD 34	PG 58-34	PG 58-34	-24	-30	-36
MnROAD Cell 35	MnROAD 35	PG 58-40	PG 58-40	-30	-36	-42
MN CSAH-75, section 2 EB	MN75 2	PG 58-28	PG 58-28	-18	-24	-30
MN CSAH-75, section 4 WB	MN75 4	PG 58-34	PG 58-34	-24	-30	-36
WI US-45	WI US 45	PG 58-34	PG 58-34	-24	-30	-36
WI STH-73	WI STH 73	PG 58-28	PG 58-28	-18	-24	-30
IL US-20, section 6	IL US20 6	AC-10	PG 58-28	-18	-24	-30
IL US-20, section 7	IL US20 7	AC-20	PG 64-22	-18	-24	-30
IL I-74	IL I74	AC-20	PG 64-22	-18	-24	-30
ND SH-18	ND 18	120/150	PG 58-28	-18	-24	-30

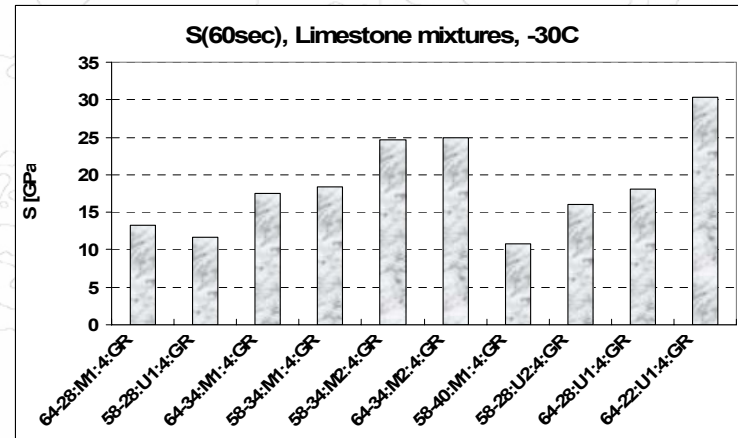
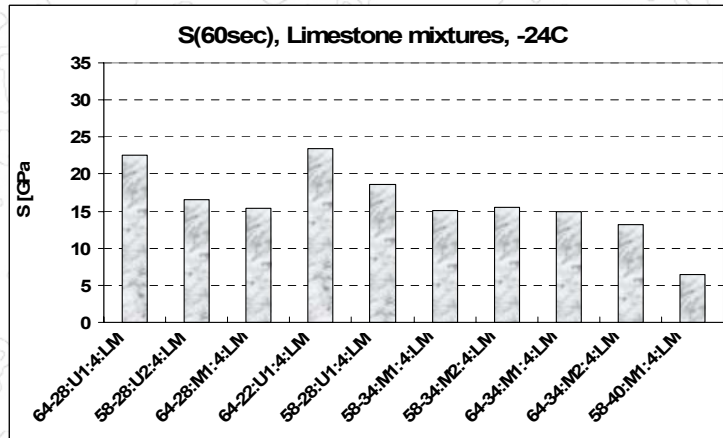
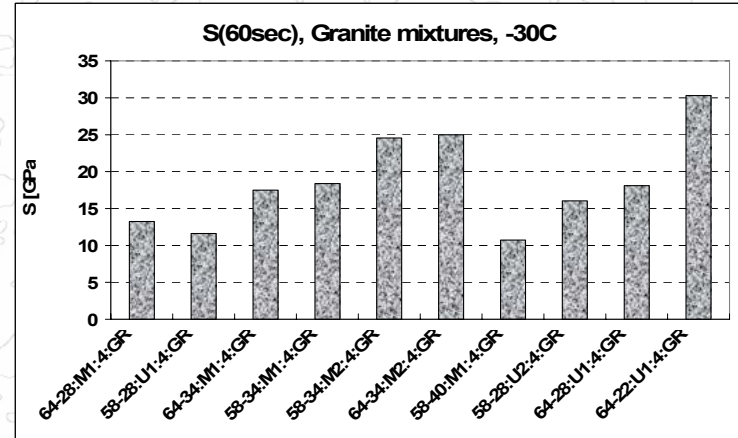
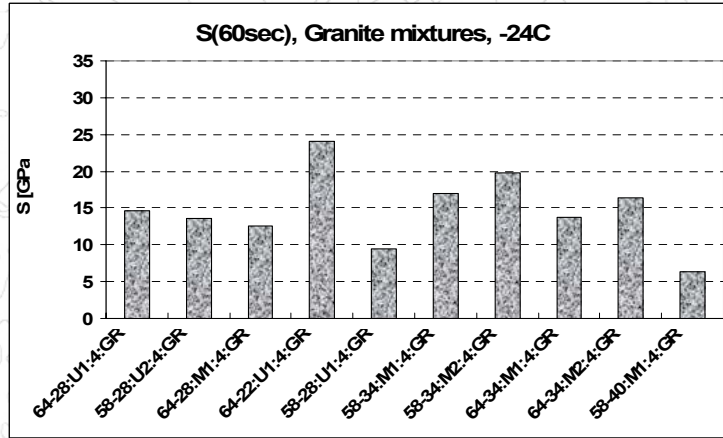
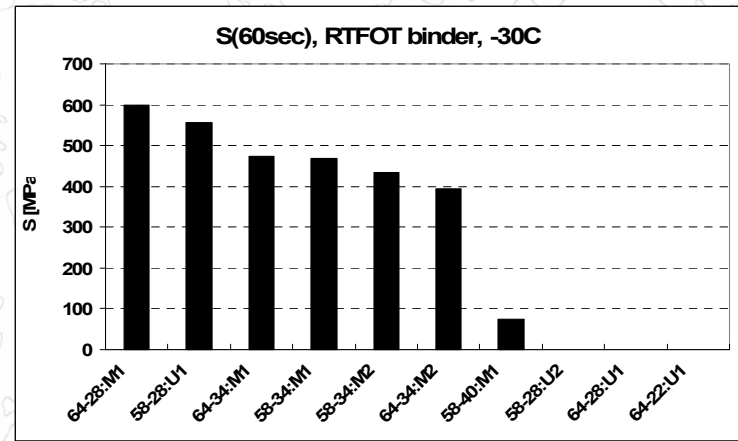
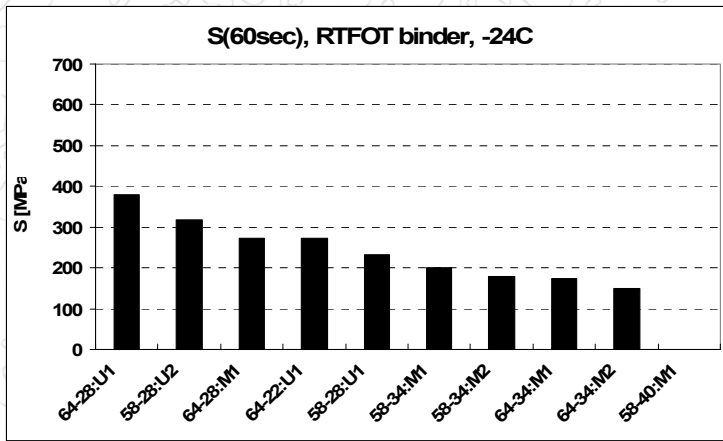


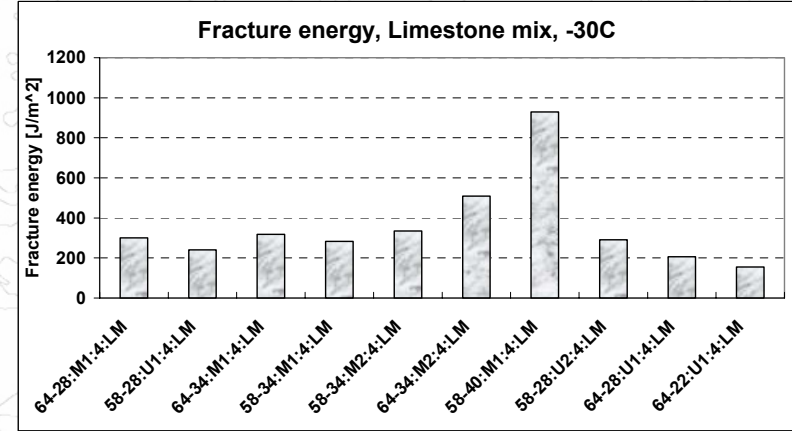
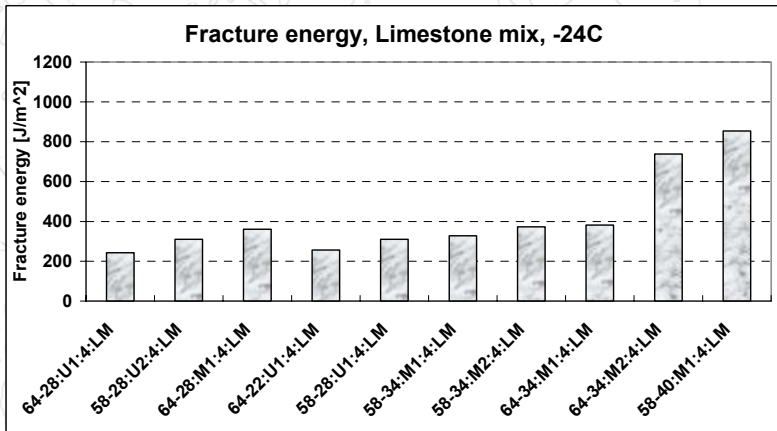
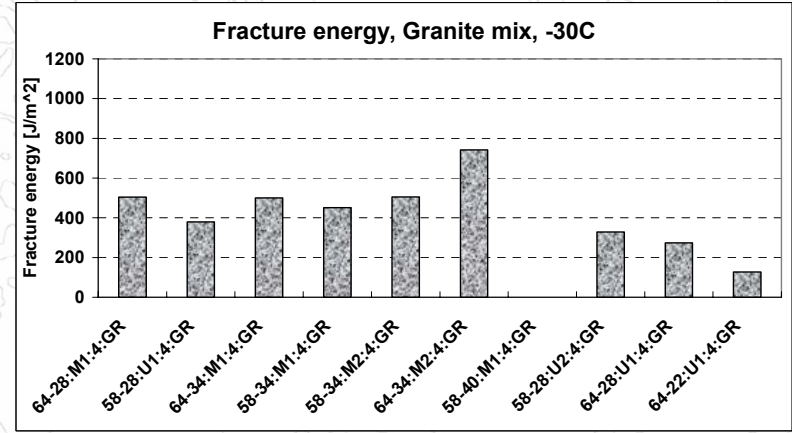
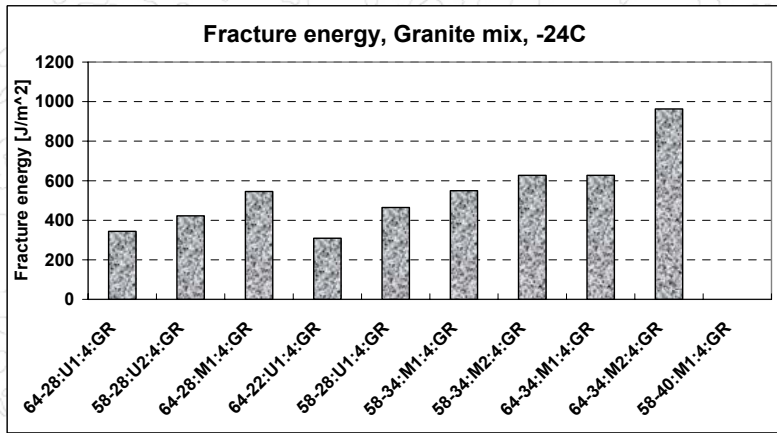
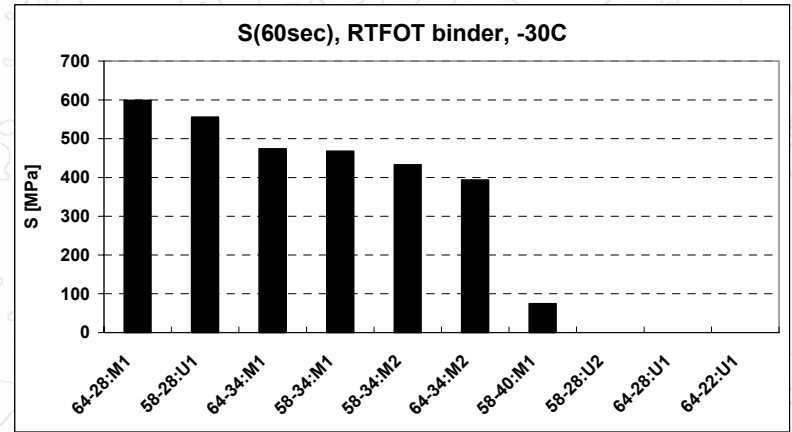
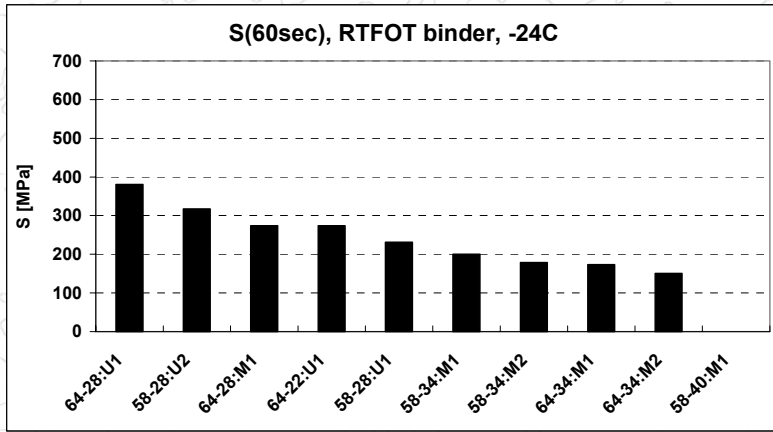
### Extracted binders

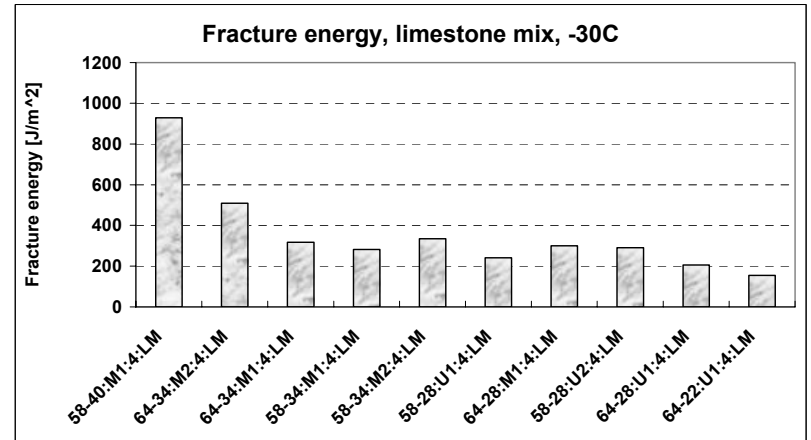
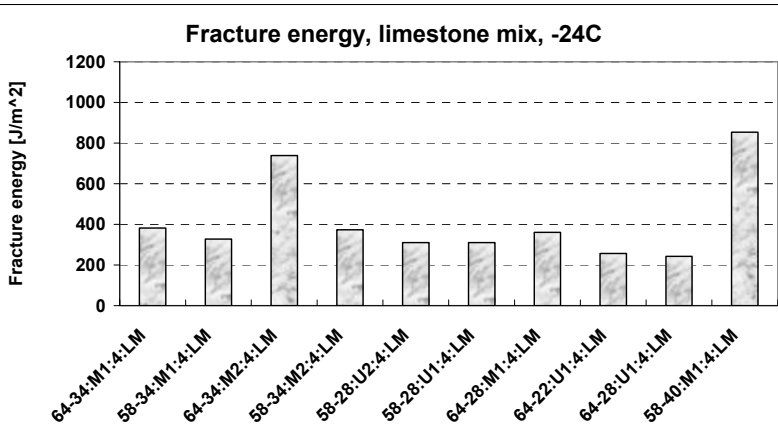
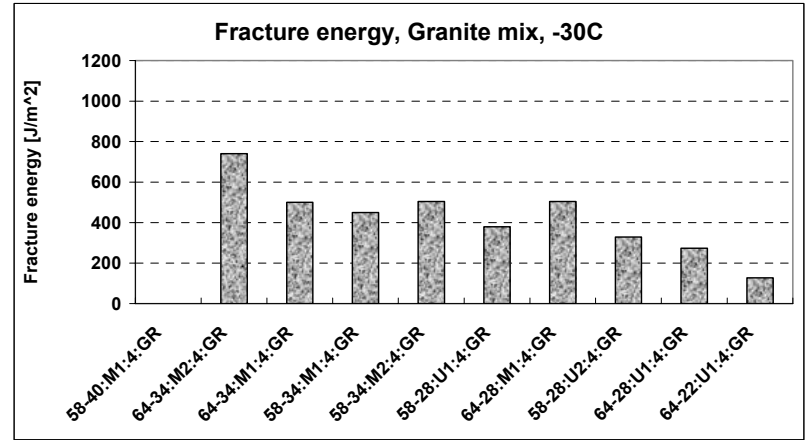
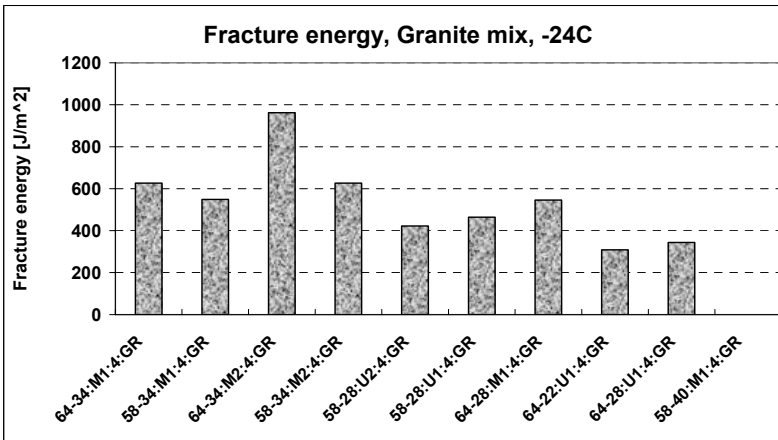
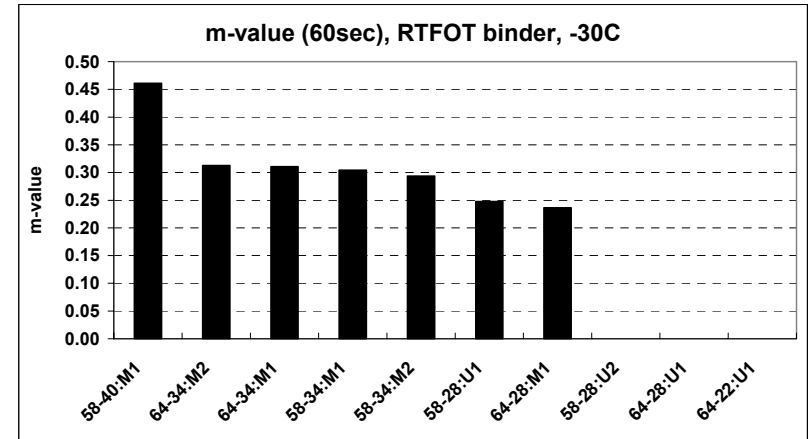
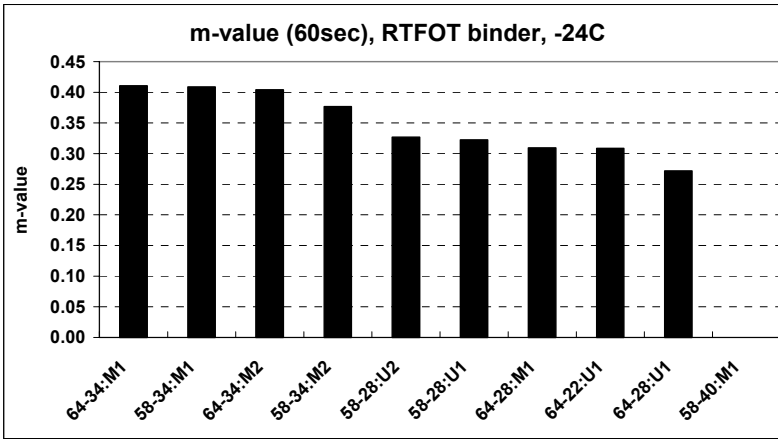


# Binder vs. Mixtures - laboratory specimens

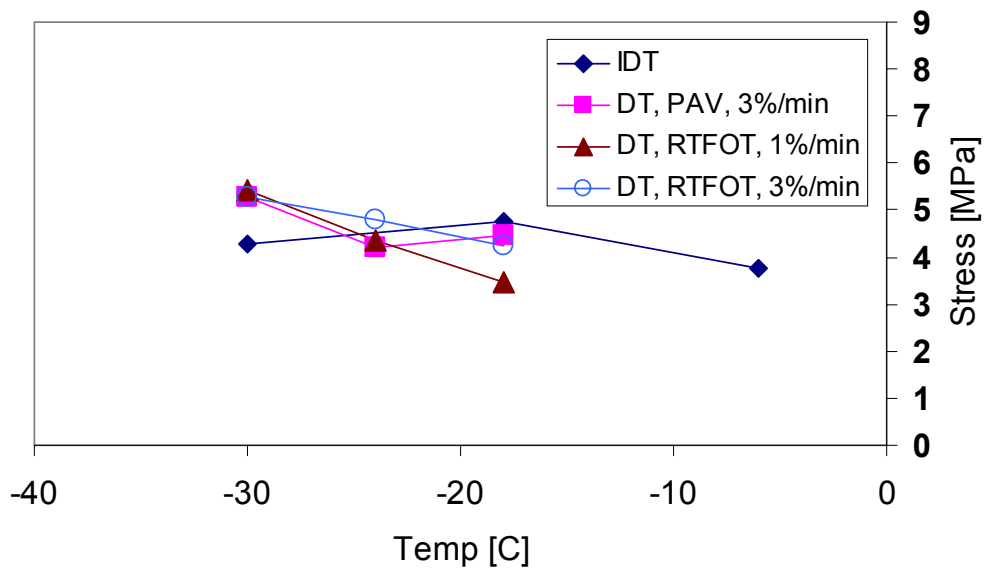
- Use binder experimental data to rank the set of binders investigated
- Does this ranking hold for asphalt mixtures (same mix design for all mixtures)
  - BBR vs. IDT creep
  - BBR vs. SCB
  - DTT vs. DT strength
  - DTT vs. SCB



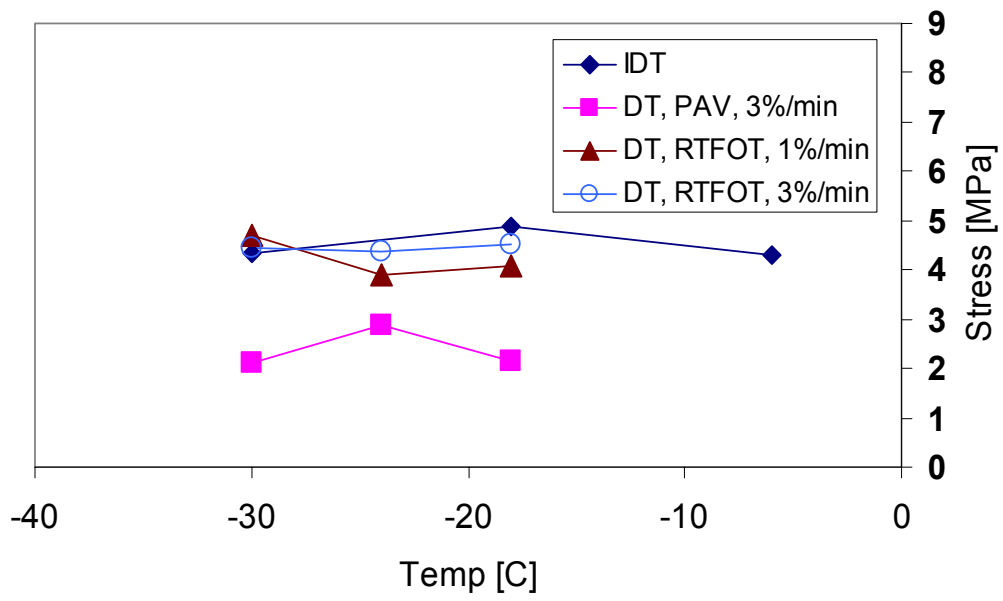


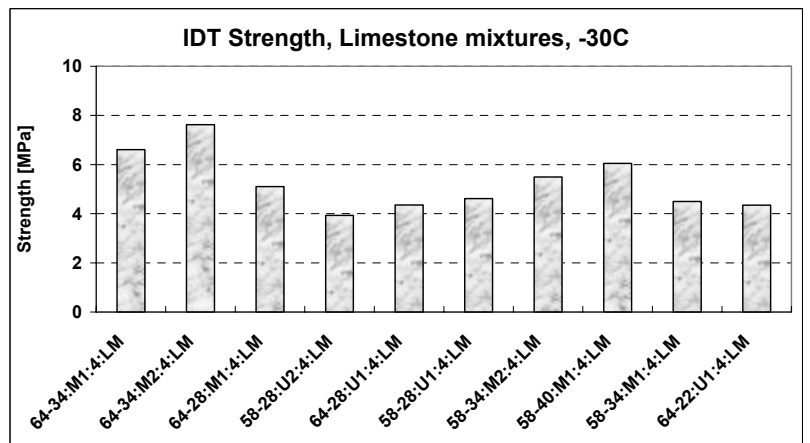
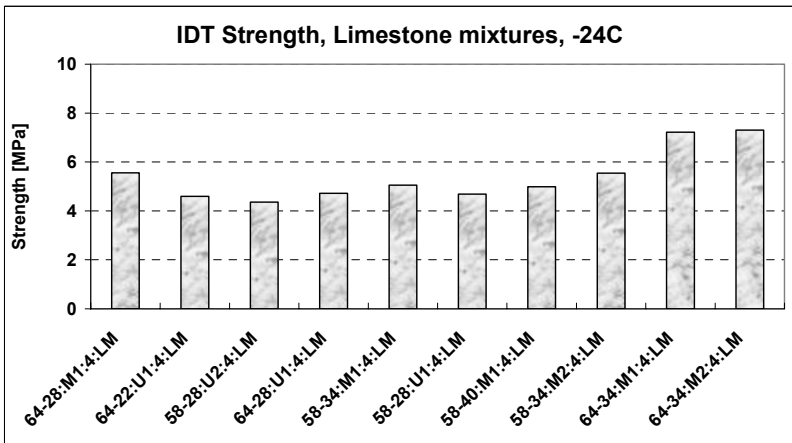
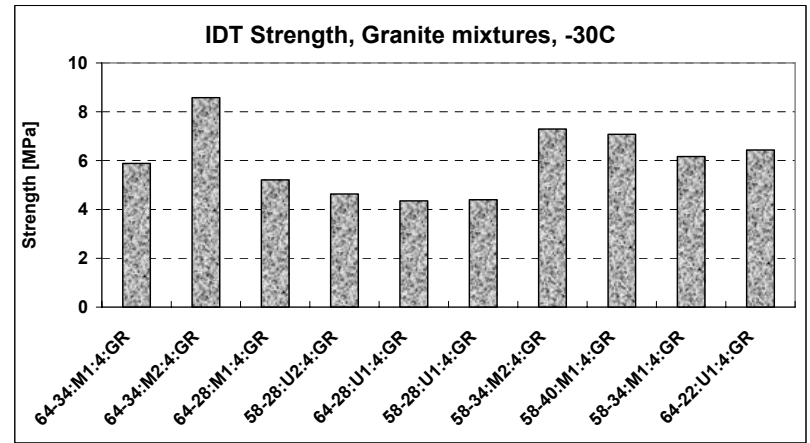
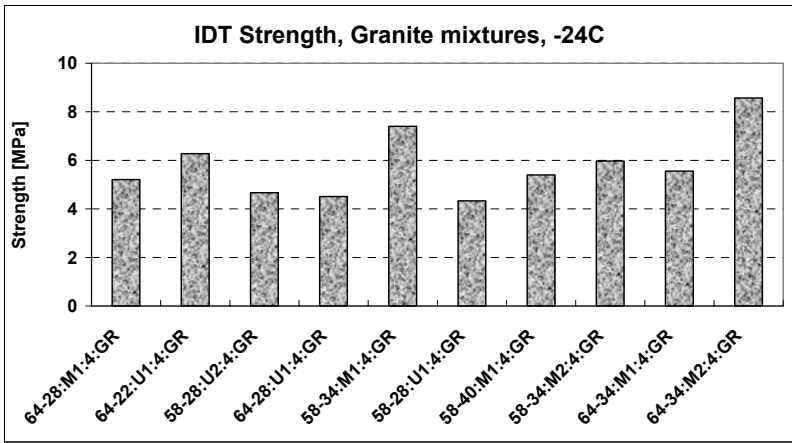
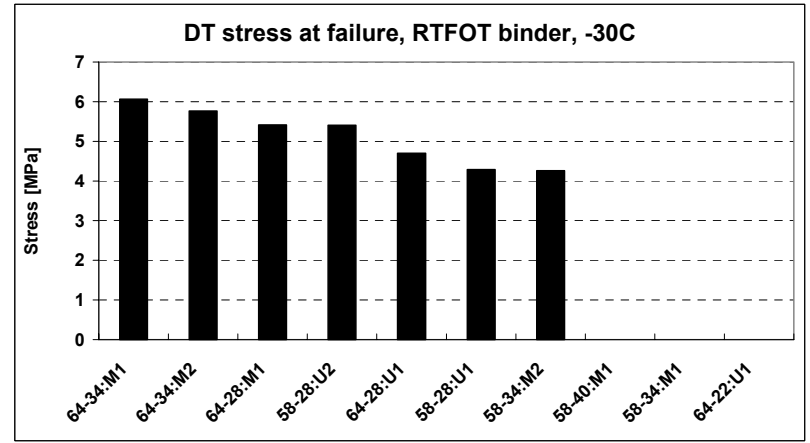
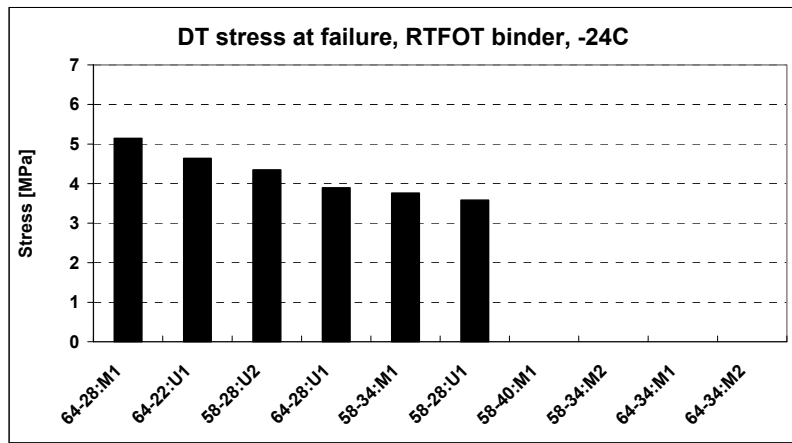


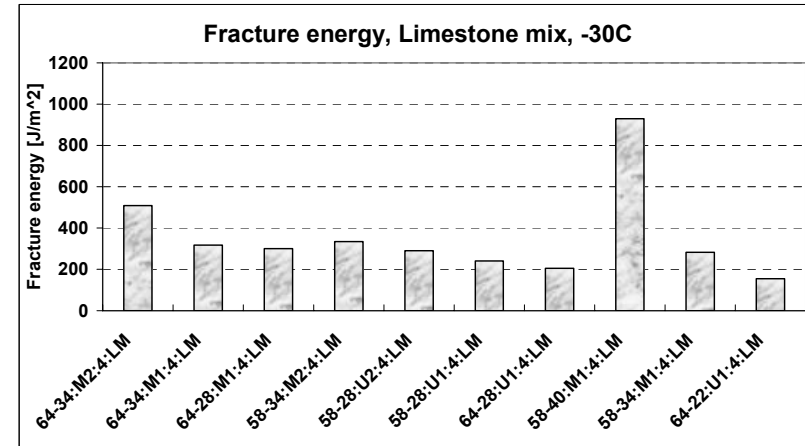
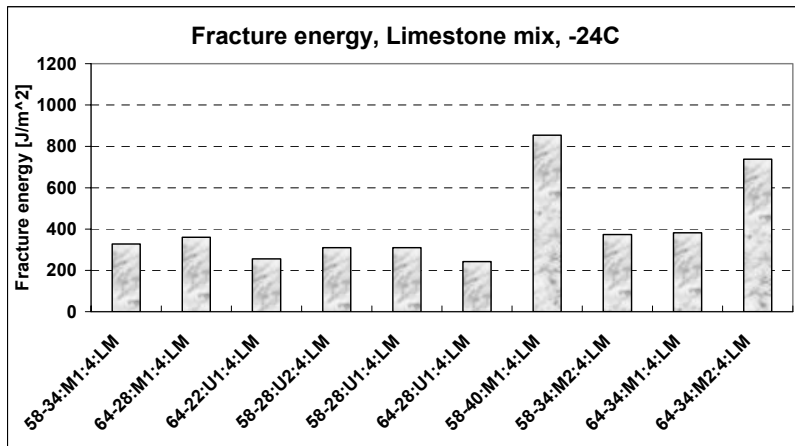
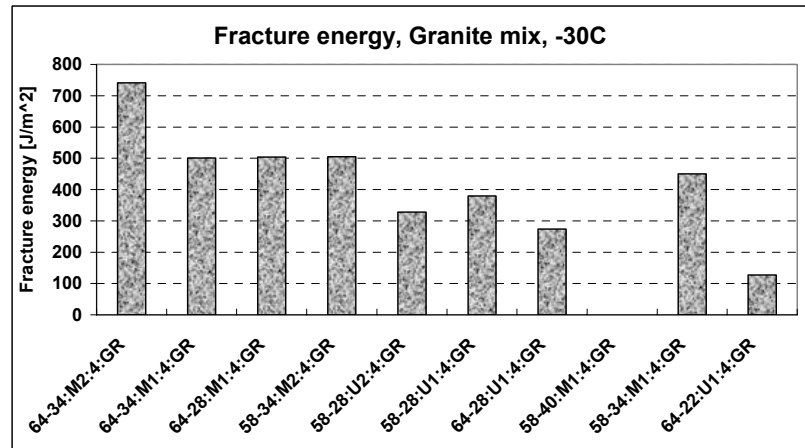
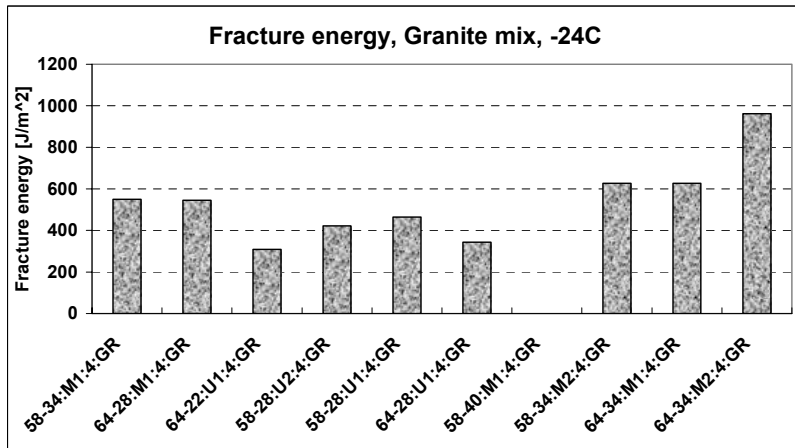
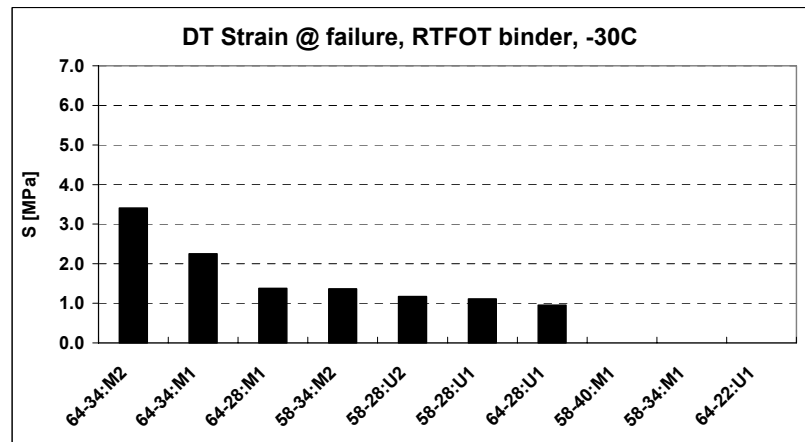
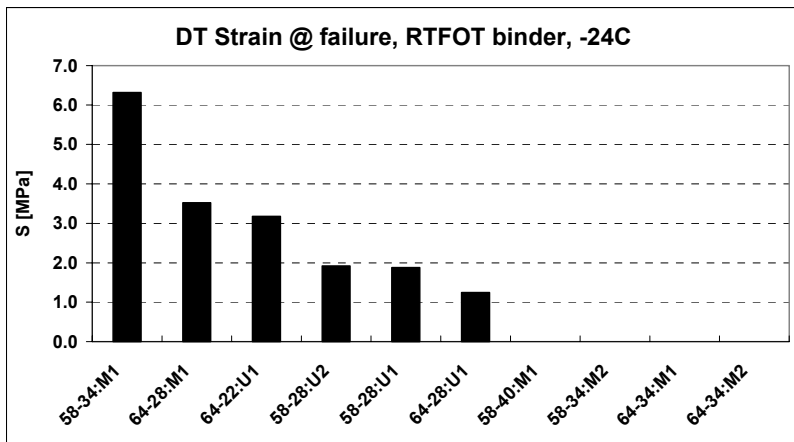
**58-28 U2**

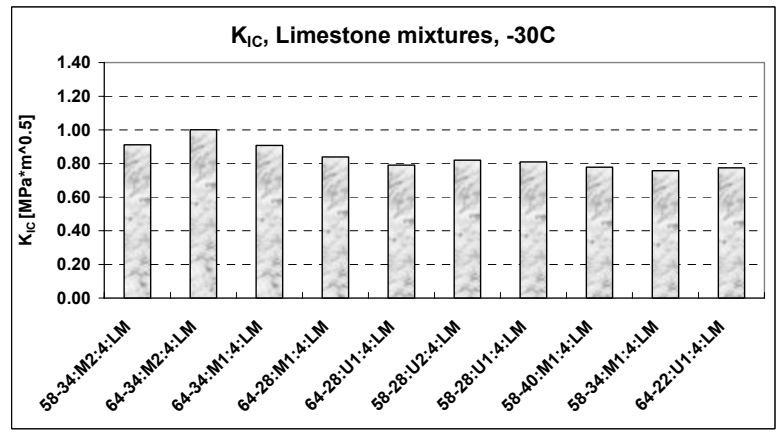
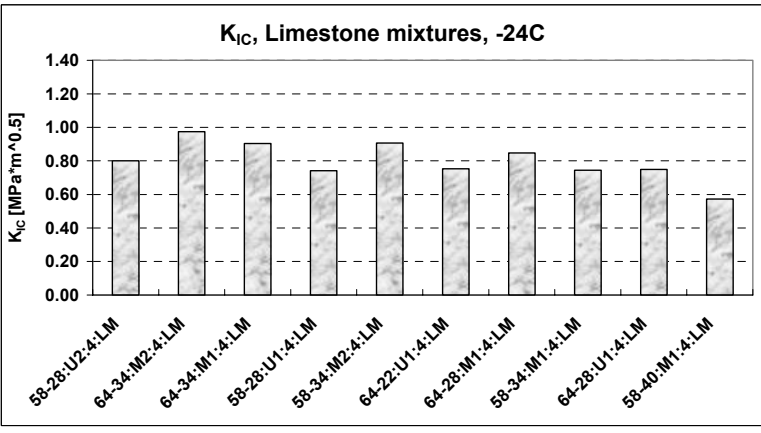
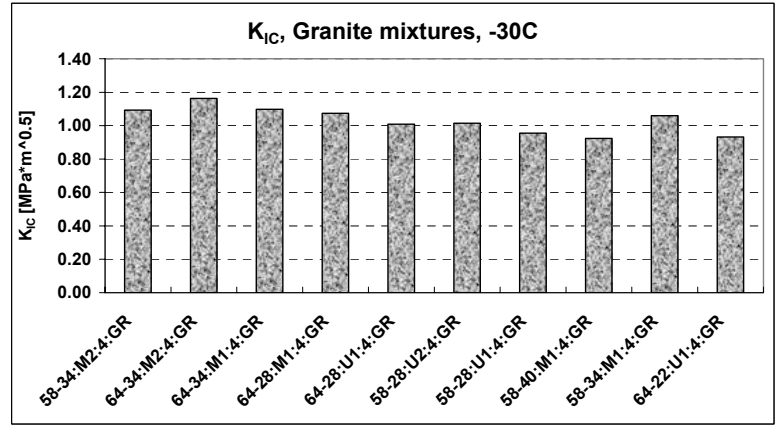
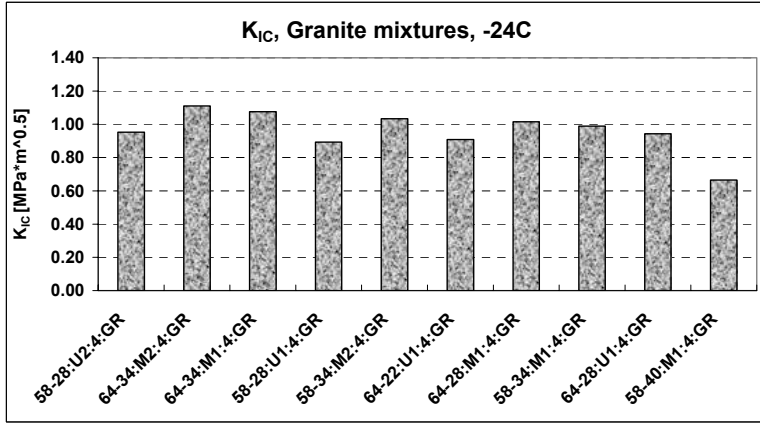
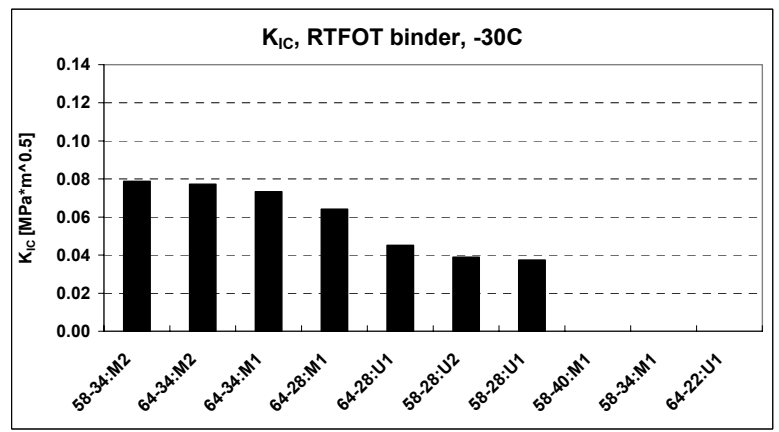
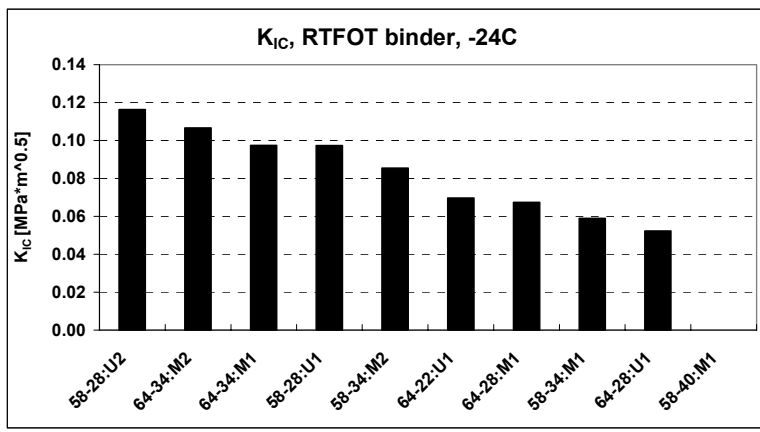


**64-28 U1**









# High binder temperature (PG + 10°C)

## Granite

	<i>S_BBR</i>	<i>m_BBR</i>	<i>DT_stress</i>	<i>DT_strain</i>	<i>DENT_stress</i>	<i>DENT_strain</i>	<i>SCB_K</i>	<i>SCB_F</i>	<i>DCT_F</i>	<i>IDT_60</i>	<i>IDT_500</i>	<i>IDT_Str</i>
<i>S_BBR</i>	1.00											
<i>m_BBR</i>	-0.62	1.00										
<i>DT_stress</i>	0.75	-0.04	1.00									
<i>DT_strain</i>	-0.42	0.17	0.20	1.00								
<i>DENT_stress</i>	-0.82	0.44	-0.70	0.42	1.00							
<i>DENT_strain</i>	-0.69	0.03	-0.93	-0.09	0.51	1.00						
<i>SCB_K</i>	0.34	0.08	0.86	0.66	0.16	-0.59	1.00					
<i>SCB_F</i>	-0.64	0.75	0.06	0.82	0.61	0.01	0.18	1.00				
<i>DCT_F</i>	-0.70	0.78	0.11	0.60	0.69	-0.15	0.16	0.91	1.00			
<i>IDT_60</i>	0.47	-0.03	0.87	0.37	-0.29	-0.55	0.61	0.08	0.07	1.00		
<i>IDT_500</i>	0.49	-0.08	0.88	0.43	-0.33	-0.58	0.66	0.06	0.02	0.98	1.00	
<i>IDT_Str</i>	-0.02	0.48	0.75	0.28	0.02	-0.34	0.58	0.68	0.52	0.68	0.68	1.00

# Low binder temperature (PG + 10°C - 12°C)

## Granite

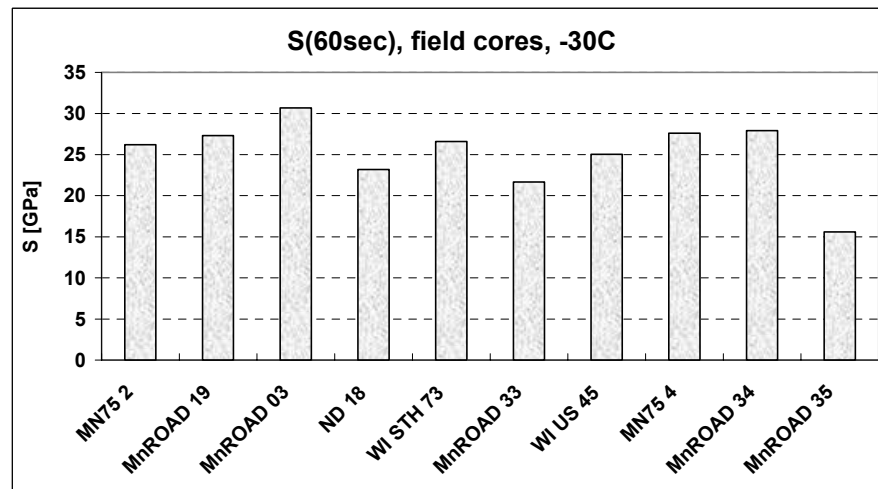
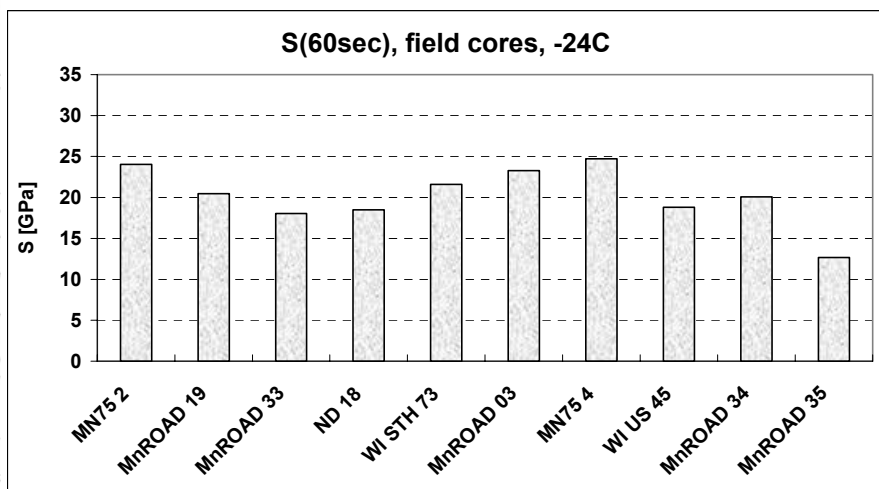
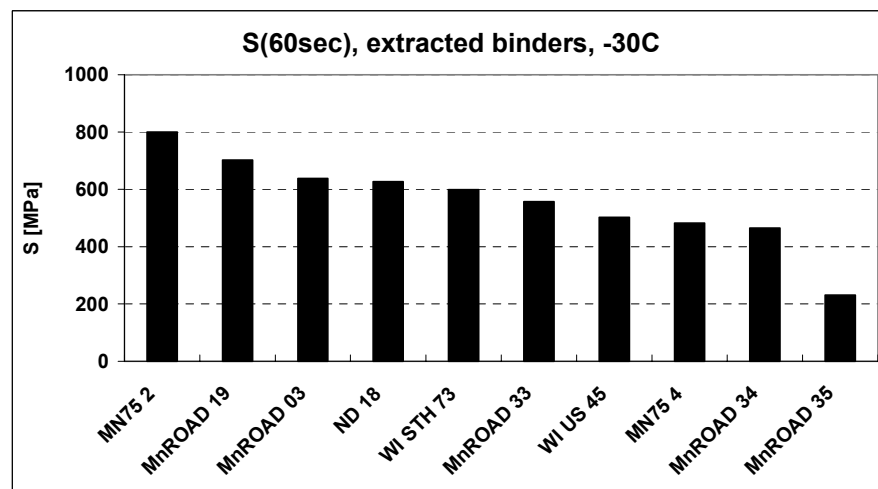
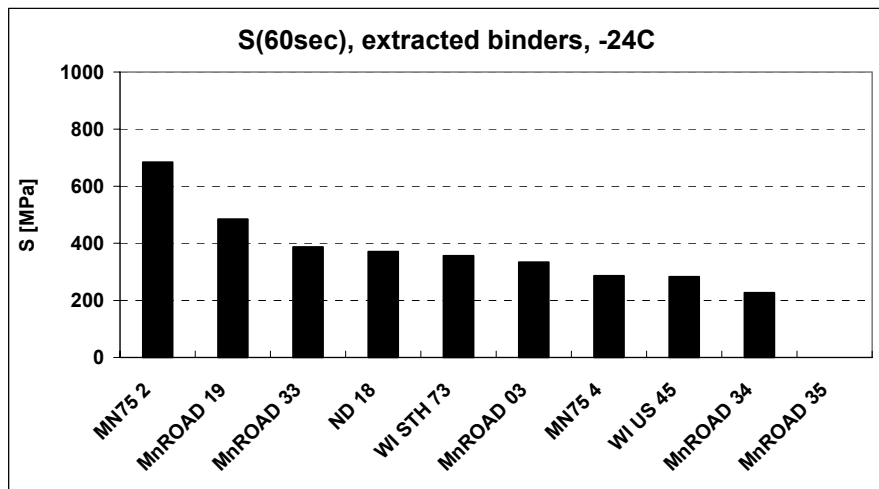
	<i>S_BBR</i>	<i>m_BBR</i>	<i>DT_stress</i>	<i>DT_strain</i>	<i>DENT_stress</i>	<i>DENT_strain</i>	<i>SCB_K</i>	<i>SCB_F</i>	<i>DCT_F</i>	<i>IDT_60</i>	<i>IDT_500</i>	<i>IDT_Str</i>
<i>S_BBR</i>	1.00											
<i>m_BBR</i>	-0.94	1.00										
<i>DT_stress</i>	-0.06	0.04	1.00									
<i>DT_strain</i>	-0.97	0.97	0.43	1.00								
<i>DENT_stress</i>	-0.53	0.52	0.68	0.79	1.00							
<i>DENT_strain</i>	-0.91	0.90	0.52	0.99	0.87	1.00						
<i>SCB_K</i>	0.54	-0.53	0.25	-0.67	-0.13	-0.58	1.00					
<i>SCB_F</i>	-0.13	0.08	0.63	-0.11	0.29	-0.05	0.73	1.00				
<i>DCT_F</i>	-0.22	0.31	0.17	-0.08	-0.43	-0.13	0.40	0.64	1.00			
<i>IDT_60</i>	0.24	-0.15	0.20	0.80	0.68	0.83	0.56	0.27	0.37	1.00		
<i>IDT_500</i>	0.43	-0.36	0.23	0.59	0.73	0.67	0.56	0.16	0.17	0.96	1.00	
<i>IDT_Str</i>	0.01	0.07	0.65	0.96	0.90	0.99	0.73	0.63	0.55	0.83	0.70	1.00

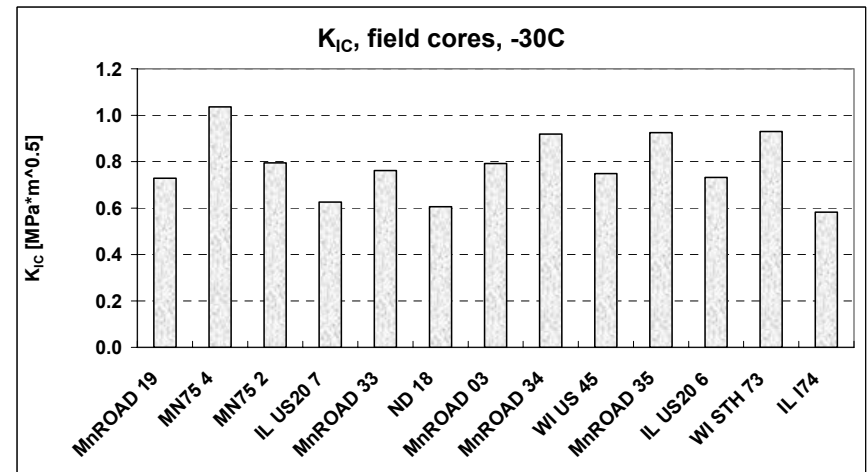
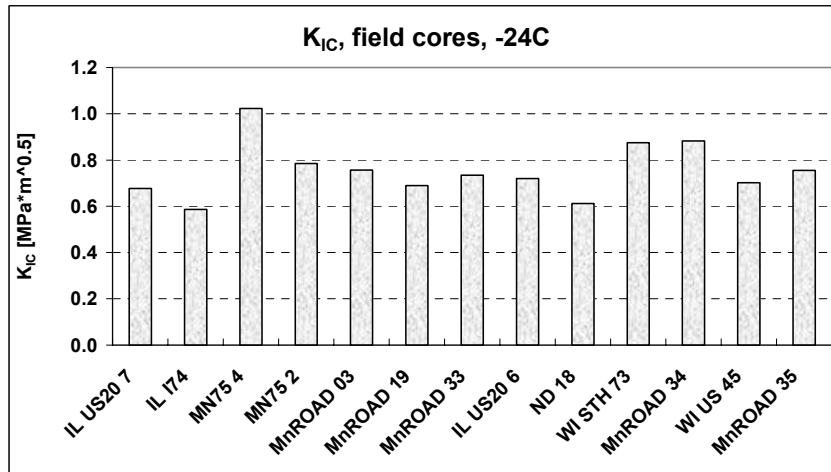
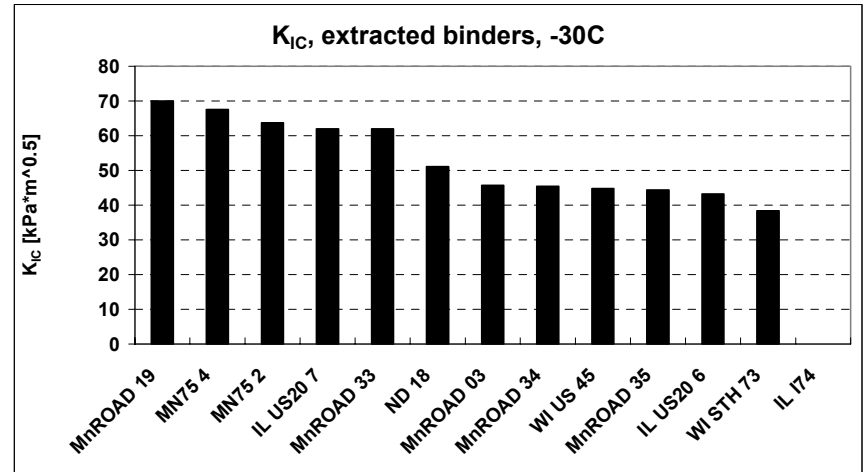
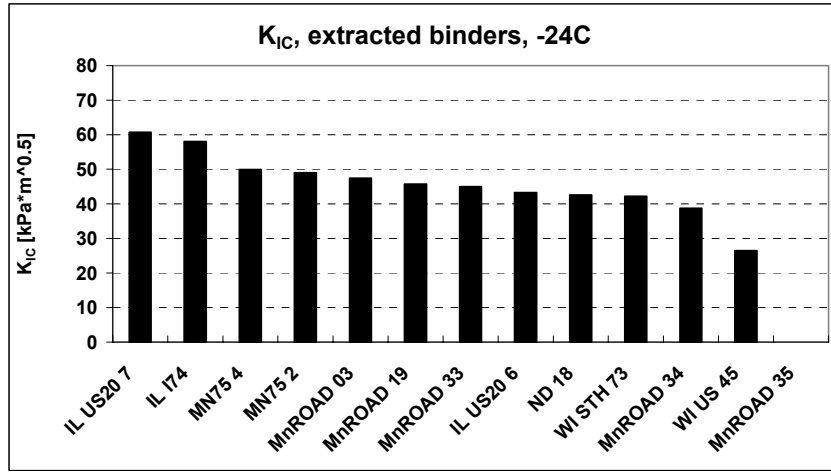
# High binder temperature (PG + 10°C)

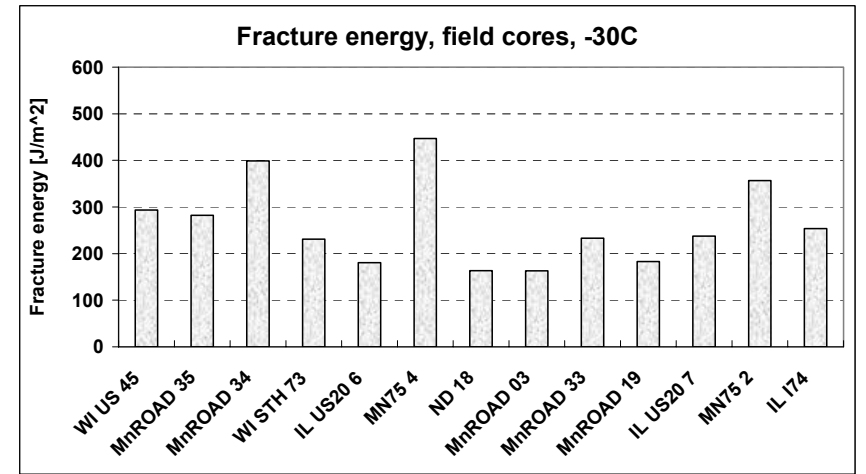
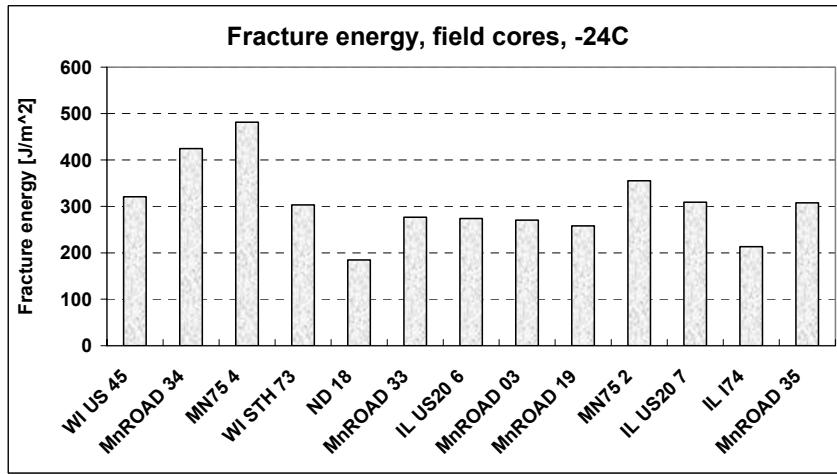
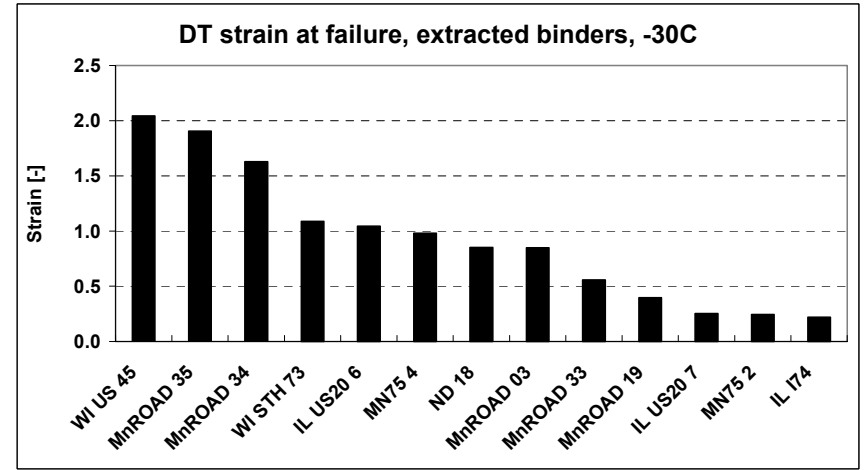
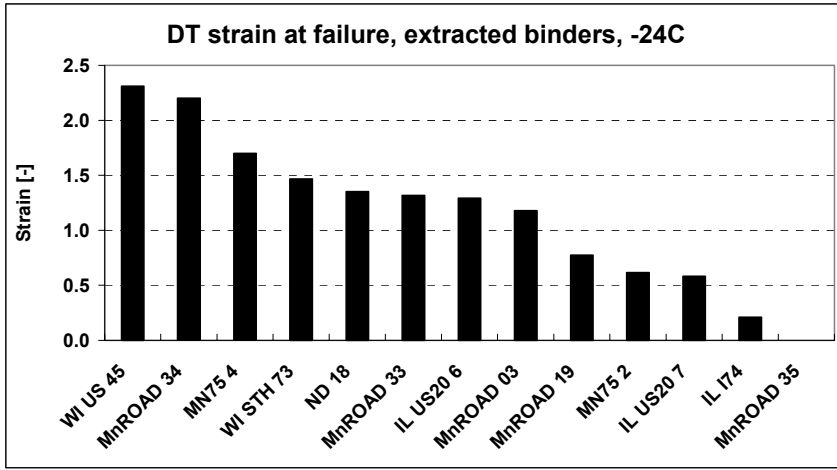
## Limestone

	<i>S_BBR</i>	<i>m_BBR</i>	<i>DT_stress</i>	<i>DT_strain</i>	<i>DENT_stress</i>	<i>DENT_strain</i>	<i>SCB_K</i>	<i>SCB_F</i>	<i>DCT_F</i>	<i>IDT_60</i>	<i>IDT_500</i>	<i>IDT_Str</i>
<i>S_BBR</i>	1.00											
<i>m_BBR</i>	-0.62	1.00										
<i>DT_stress</i>	0.75	-0.04	1.00									
<i>DT_strain</i>	-0.42	0.17	0.20	1.00								
<i>DENT_stress</i>	-0.82	0.44	-0.70	0.42	1.00							
<i>DENT_strain</i>	-0.69	0.03	-0.93	-0.09	0.51	1.00						
<i>SCB_K</i>	-0.15	0.15	0.27	0.85	0.63	-0.26	1.00					
<i>SCB_F</i>	-0.68	0.69	-0.32	0.85	0.61	0.10	0.36	1.00				
<i>DCT_F</i>	-0.24	0.71	0.62	0.19	0.14	-0.42	0.48	0.65	1.00			
<i>IDT_60</i>	0.87	-0.54	0.84	-0.16	-0.81	-0.80	0.11	-0.38	0.13	1.00		
<i>IDT_500</i>	0.80	-0.66	0.76	-0.06	-0.80	-0.72	0.07	-0.41	-0.03	0.97	1.00	
<i>IDT_Str</i>	-0.11	0.28	0.39	0.86	0.48	-0.26	0.82	0.50	0.41	0.11	0.06	1.00

# Binder vs. Mixtures - field samples







# High binder temperature (PG + 10°C)

	<i>S_BBR</i>	<i>m_BBR</i>	<i>DT_stress</i>	<i>DT_strain</i>	<i>DENT_stress</i>	<i>DENT_strain</i>	<i>SCB_K</i>	<i>SCB_F</i>	<i>DCT_F</i>	<i>SEB_F</i>	<i>IDT_60</i>	<i>IDT_500</i>	<i>IDT_Str</i>
<i>S_BBR</i>	1.00												
<i>m_BBR</i>	-0.72	1.00											
<i>DT_stress</i>	-0.47	0.23	1.00										
<i>DT_strain</i>	-0.81	0.53	0.74	1.00									
<i>DENT_stress</i>	0.24	-0.18	-0.45	-0.33	1.00								
<i>DENT_strain</i>	-0.67	0.17	0.28	0.65	0.07	1.00							
<i>SCB_K</i>	-0.11	0.17	0.30	0.13	-0.19	-0.07	1.00						
<i>SCB_F</i>	-0.16	0.39	0.31	0.19	-0.18	-0.15	0.80	1.00					
<i>DCT_F</i>	-0.17	-0.03	0.53	0.22	-0.13	-0.01	0.71	0.69	1.00				
<i>SEB_F</i>	-0.24	0.27	0.49	0.21	-0.56	-0.26	0.77	0.67	0.76	1.00			
<i>IDT_60</i>	0.66	-0.20	0.30	-0.25	-0.06	-0.51	0.71	0.74	0.57	0.61	1.00		
<i>IDT_500</i>	0.69	-0.32	0.20	-0.33	-0.08	-0.39	0.48	0.43	0.36	0.37	0.92	1.00	
<i>IDT_Str</i>	-0.24	0.04	0.48	0.61	-0.35	0.19	0.58	0.64	0.47	0.52	0.25	0.02	1.00

# Low binder temperature (PG + 10°C - 12°C)

	<i>S_BBR</i>	<i>m_BBR</i>	<i>DT_stress</i>	<i>DT_strain</i>	<i>DENT_stress</i>	<i>DENT_strain</i>	<i>SCB_K</i>	<i>SCB_F</i>	<i>DCT_F</i>	<i>SEB_F</i>	<i>IDT_60</i>	<i>IDT_500</i>	<i>IDT_Str</i>
<i>S_BBR</i>	1.00												
<i>m_BBR</i>	-0.79	1.00											
<i>DT_stress</i>	-0.74	0.90	1.00										
<i>DT_strain</i>	-0.75	0.91	0.99	1.00									
<i>DENT_stress</i>	0.50	-0.76	-0.91	-0.92	1.00								
<i>DENT_strain</i>	0.56	-0.72	-0.82	-0.83	0.71	1.00							
<i>SCB_K</i>	-0.06	0.00	0.17	0.15	-0.06	0.50	1.00						
<i>SCB_F</i>	0.38	-0.24	-0.40	-0.37	0.09	0.66	0.49	1.00					
<i>DCT_F</i>	0.15	-0.06	0.35	0.32	-0.32	0.07	0.65	0.39	1.00				
<i>SEB_F</i>	0.77	-0.41	-0.17	-0.16	-0.19	0.56	0.67	0.71	0.87	1.00			
<i>IDT_60</i>	0.33	-0.38	-0.37	-0.39	0.30	0.47	0.45	0.16	-0.02	0.12	1.00		
<i>IDT_500</i>	0.46	-0.45	-0.38	-0.41	0.32	0.52	0.44	0.18	0.04	0.20	0.98	1.00	
<i>IDT_Str</i>	-0.24	0.02	0.59	0.59	-0.73	-0.16	0.41	0.06	0.31	0.21	0.23	0.18	1.00

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

# Predicting performance

- Top “predictors” are fracture parameters
  - Mixture fracture toughness and energy
  - Binder strain at failure
- Need fracture test for both binders and mixtures
- Need to select fracture model
  - Develop specifications
- Validate with “good” field data
  - Statistically sound, long term, accurate data

# Predicting performance

- Need to address and clarify a number of issues
  - What is performance?
    - Frequent but hairline cracks
    - Rare but large cracks
    - No cracks
- Effect of aging on crack resistance
  - Aging penetration depth
  - Mixture test specimen size
    - BBR on thin beams?

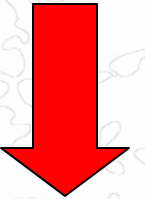
# Predicting performance

- Move to material properties limits?
  - At the temperature for the given location recommend values for material (binder and mixture) parameters
  - Slowly phase out PG limits?
    - Is 10°C relevant?
      - Developed for stiffness
      - What does it mean for  $m$  and  $DT$   $\sigma_f$  and  $\epsilon_f$ ?
  - Revisit physical hardening?

**Thank you!**



**Good bye low temperature cracks**



**MnROAD  
Feb. 2, 2016**

**Welcome to Tower, MN  
(-60F / Feb. 2, 1996)**

