LOW TEMPERATURE PAVEMENT CRACKING CHALLENGE

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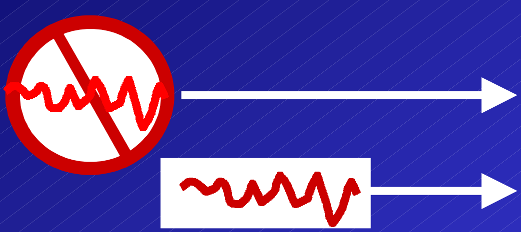
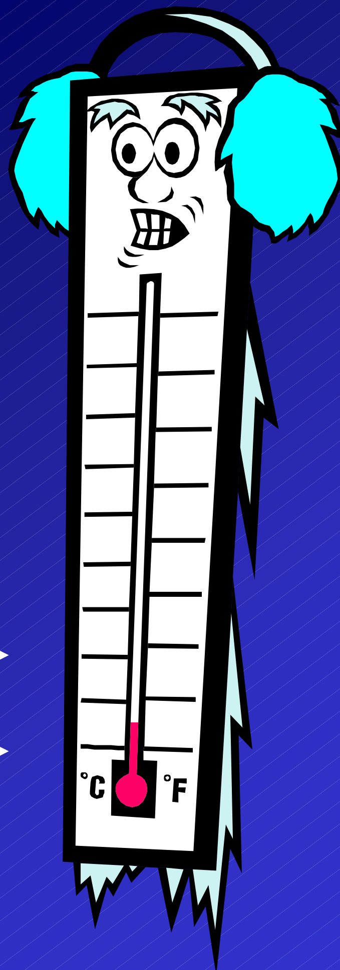
LOW TEMPERATURE PAVEMENT CRACKING CHALLENGE

FRACTURE – being a separation of molecules is governed by other rules than preceding deformation

The challenge **is not** to predict the temperature at which the binder will fracture due to thermal stress.

Design Criteria
(includes safety margin)





The challenge **is** to determine the critical temperature ABOVE which the probability of fracture is miniscule

Critical Temperature
= temperature at FRACTURE

Temperature at which thermal contraction exceeds viscous flow

Temperature where the critical stiffness of binder = 138 MPa, at 2.8 h loading time

(Fromm & Phang '70)

Critical Stiffness
= stiffness at FRACTURE

Stiffness of the binder = 240 MPa at 30 min loading time

(McLeod '68)

Stiffness of asphalt at –40°C < 200 MPa (Readshaw '72)

... Basis for the early SHRP low temperature specification criteria

Current low temperature binder specifications

AASHTO MP-1

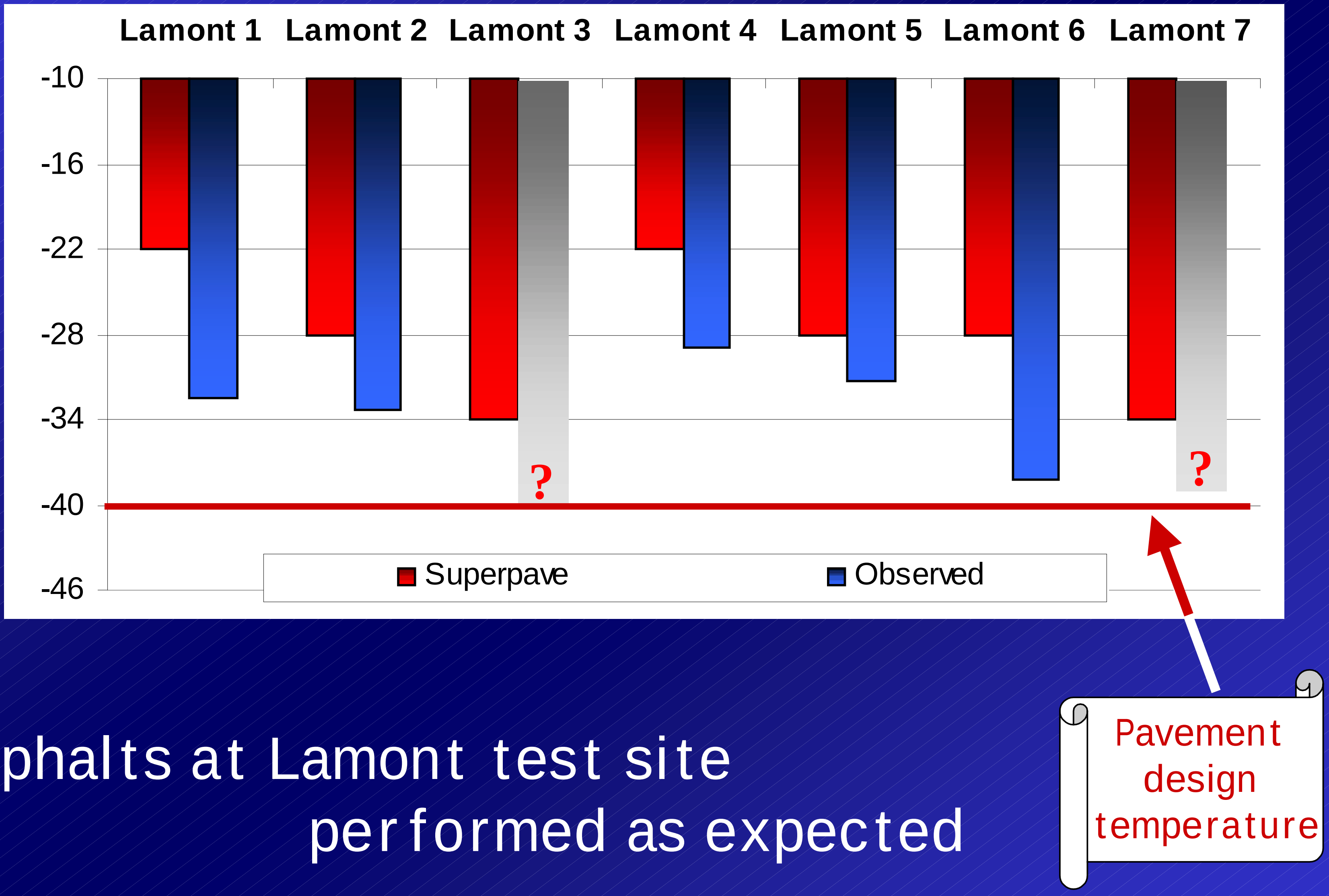
- *Maximum* creep stiffness **S** (60) = 300 MPa
- *Minimum* value for slope, **m**(60)➔log**(S)** vs log**(time**) = 0.300

S is a measure of thermal stress

m-value is a measure of the rate of stress relaxation

Is the low temperature Performance Grading performing?

Lamont Test Roads revisited



Asphalts at Lamont test site performed as expected

Similar results at other test sites...

Location	Test Section	Recommended Winter Grade	Grade Used PG	Cracks
Lamont, AB	1	PG xx-**40**	58-**22**	Yes
	2		52-**28**	Yes
	3		46-**34**	No
	4		58-**22**	Yes
	5		64-**28**	Yes
	6		52-**28**	Yes
	7		52-**34**	No
Hearst, ON	AA	PG xx-**40**	46-**34**	Yes
	A		52-**28**	Yes
	B		52-**28**	Yes
	BB		52-**28**	No
Sherbrooke, QC	A	PG xx-**34**	52-**34**	No
	B		58-**22**	Yes
	C		64-**28**	Yes
	D		52-**28**	No

Location	Test Section	Recommended Winter Grade	Grade Used PG	Cracks
Sturgeon Falls, ON	North	PG xx-**34**	52-**28**	Yes
	Centre		52-**34**	No
	South		52-**28**	Yes
Wilcox, PA	T-1	PG xx-**28**	64-**16**	Yes
	T-2		64-**16**	Yes
	T-3		64-**22***	No
	T-4		64-**22**	Yes
	T-5		58-**22**	Yes
	T-6		64-**28***	Yes

Several binders show
better performance than Superpave grading

So, what's wrong with MP-1?

AASHTO **MP-1** (Low Temperature) Specification

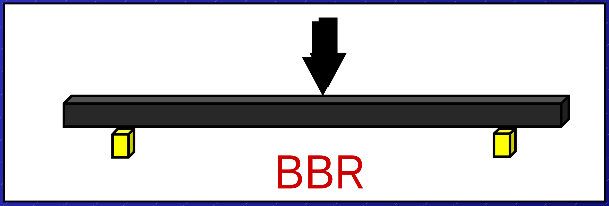
- Based on limiting creep stiffness
- Does not consider binder strength

Alternative:

Specification based on
a thermal stress and binder strength

... Basis for MP-1A specification development

MP-1A: Critical Cracking Temperature



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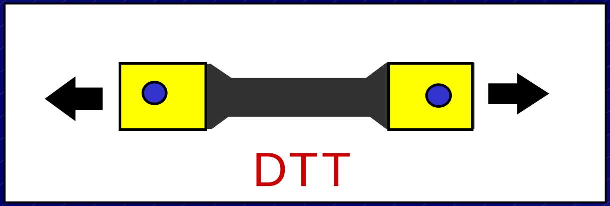
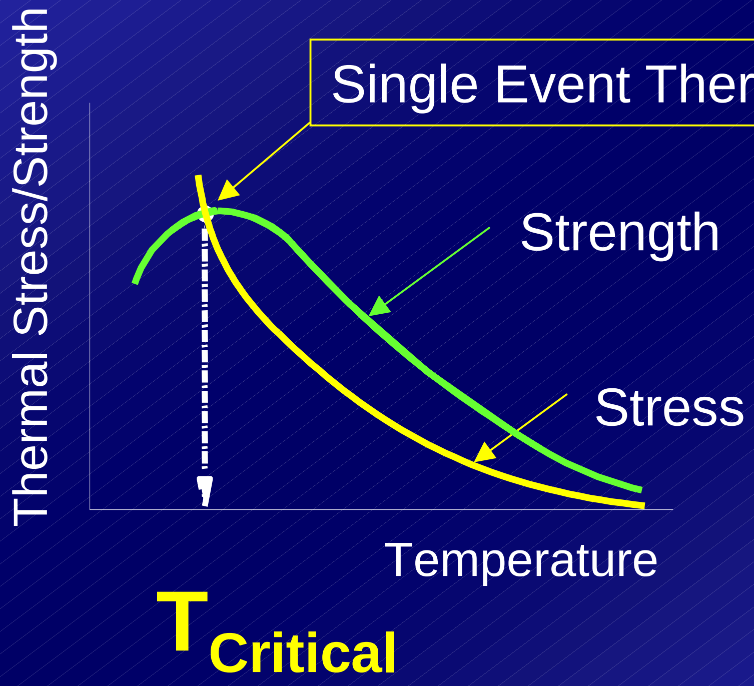
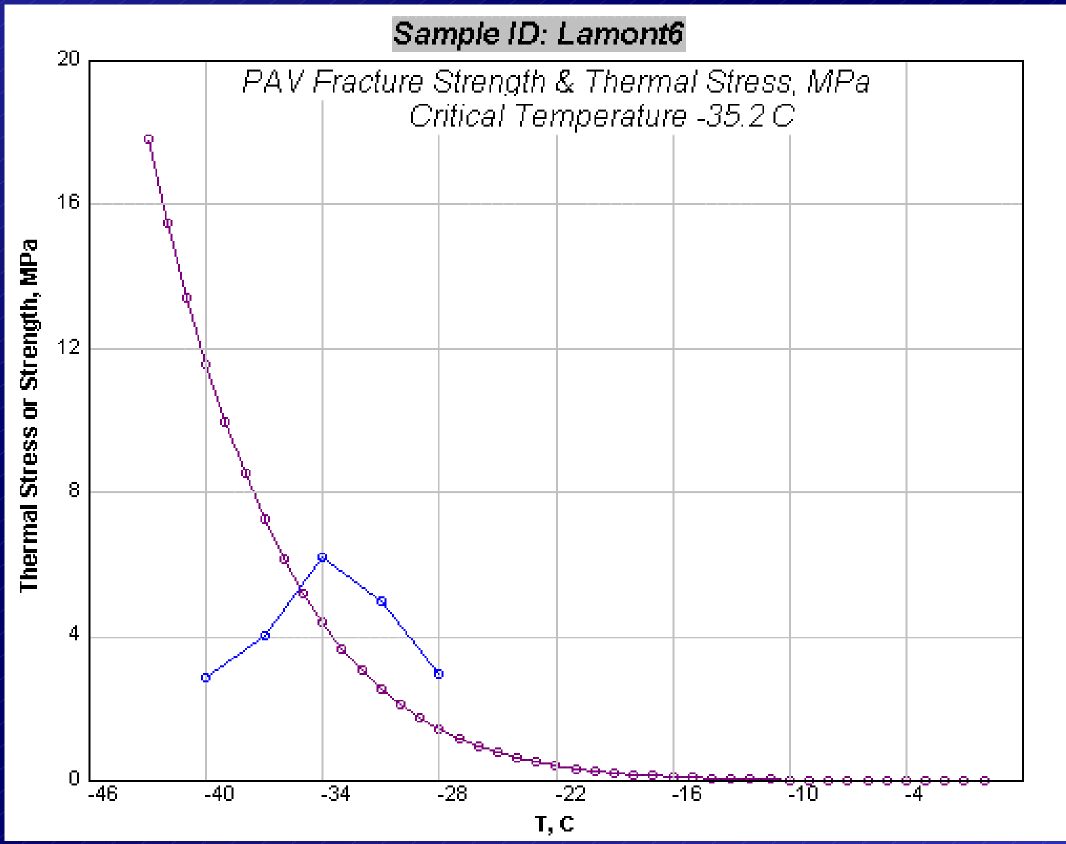




Failure is predicted at the temperature where the thermal stress exceeds the binder's 'strength'

Thermal Stress Analysis Routine (TSAR™)

$$\sigma = -\int_{T_0}^{T} \alpha_T \, E\,(t,T)\, dT$$



Problem

BBR stiffness and DTT strength inputs are not realistic relative to field conditions

- Calculated thermal stress is lower than field thermal stress
- Measured fracture stress is different from field

Therefore, need for a correction factor (PC)

BBR and DTT measurement conditions

Different from field conditions

- Test temperature - above critical temperature
- Loading time - longer than critical loading time range
- Conditioning time - short, relative to field cooling time
- Cooling rate - fast, relative to field cooling rate
- Failure stress measured at strain rate of 3%/min ...too high

Conclusion

T_{cr} (MP-1A) is as arbitrary as using the S(60) and m(60)

The Challenge continues

- Can the pavement fracture temperature be predicted from binder measurements alone?
- How to estimate thermal stress?
- What is the Critical Thermal Stress?
- Design Criteria - including safety margin?

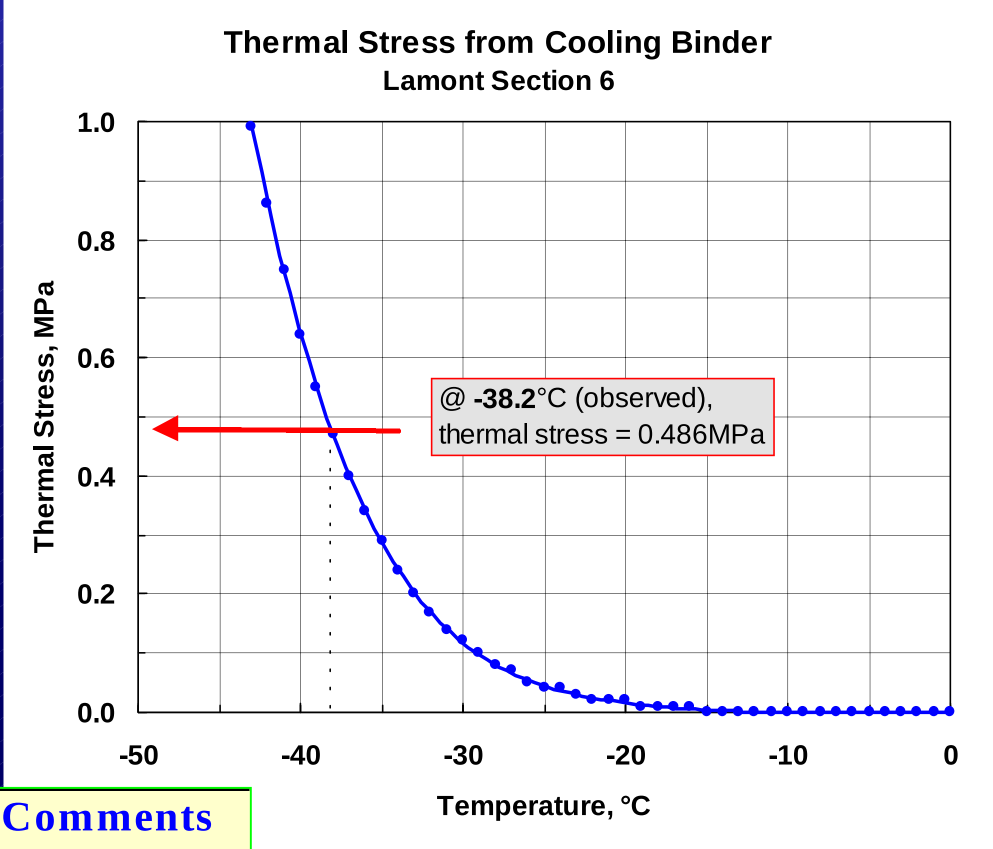
In designing for thermal cracking resistance the BINDER should be 100% reliable

Then, the only unreliable factor is the WEATHER

... However, we can choose the level of risk

Critical Binder Thermal Stress

For Lamont Test roads, the binder Critical Thermal Stress is the stress at the observed cracking temperatures



Test Section	Observed fracture T, °C	Est. binder thermal stress @ fracture, MPa	Comments
Lamont 1	-32.4	0.104	Air blown
Lamont 2	-33.3	0.464	
Lamont 3	-40.0	0.350	estimate
Lamont 4	-28.9	0.404	
Lamont 5	-31.3	0.156	Air blown
Lamont 6	-38.2	0.486	
Lamont 7	-37	0.350	estimate

Average binder Critical Thermal Stress = 0.331 MPa

w/o air blown asphalts = 0.411 MPa

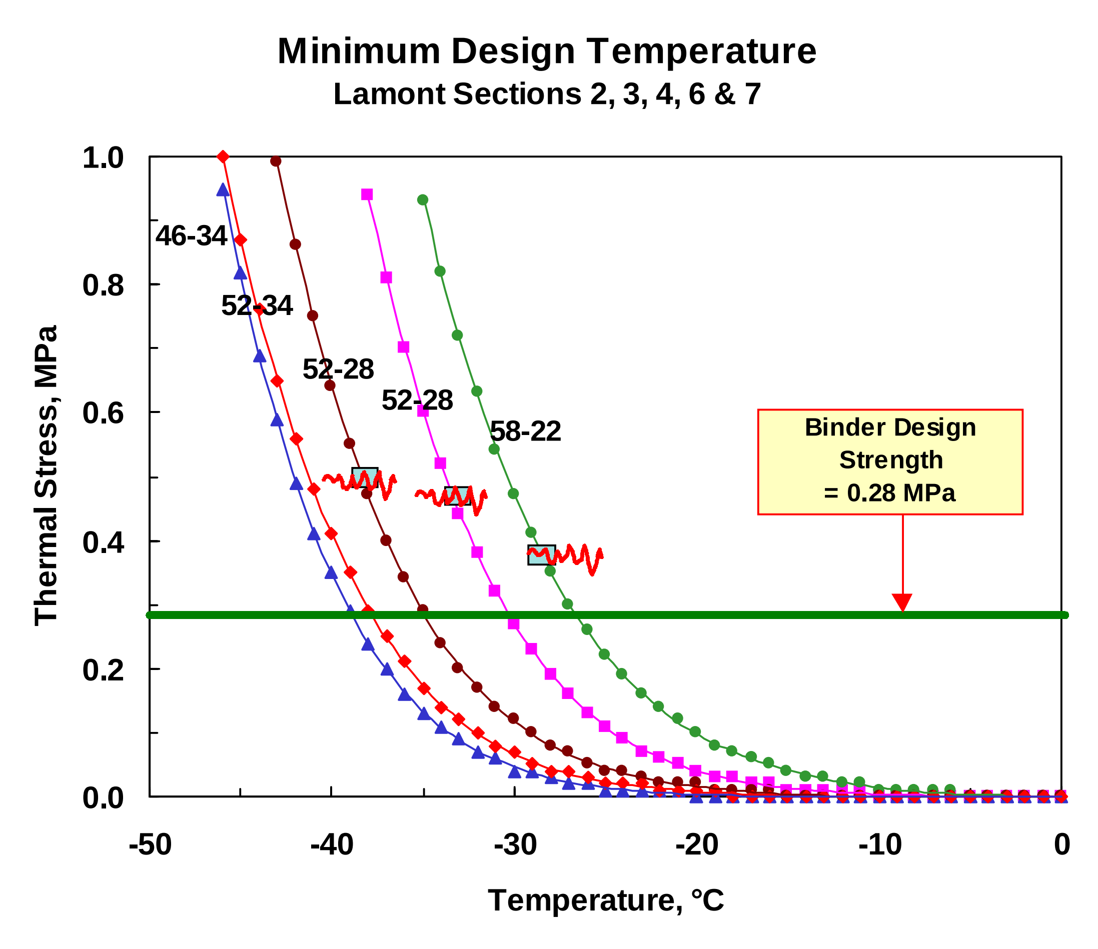
Pavement Design Criteria

Binder Design Strength

< binder strength at fracture

Design Temperature corresponds to **Binder Design Strength**

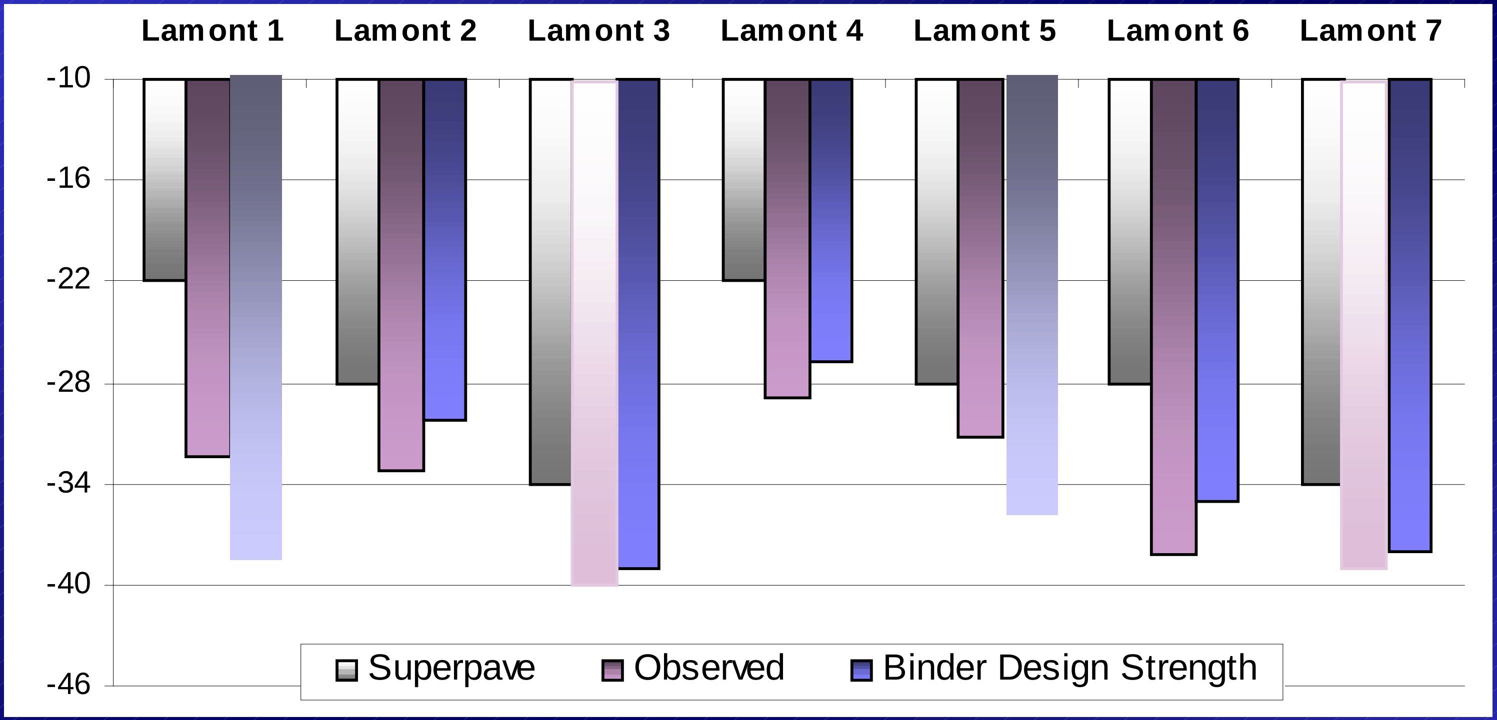
Excluding air blown asphalts the binder Design Strength at 99.5% confidence level = (0.411- 0.130) = 0.280 MPa



Summary Statistics	*Est binder failure stress, MPa*	*Est binder failure stress (w/o OX), MPa*
Mean	**0.331**	**0.411**
Standard Deviation	0.147	0.063
Confidence Level (99.0%)	**0.206**	**0.130**
Design Strength, MPa	**0.280**	**0.125**

Including air blown asphalts binder Design Strength = 0.125 MPa

Design Temperature @ Binder Design Strength



Binder Design Strength criteria shows promise for conventional, not oxidized asphalts...

Binder Design Strength

does not protect against failure

better than Superpave

Binder	Superpave	Actual	Binder Design Strength	MP-1A
Lamont 1	-22	-32.4	**-38.8***	**-38.2***
Lamont 2	-28	-33.3	-30.2	-29.0
Lamont 3	-34	na	-39	-38.1
Lamont 4	-22	-28.9	-26.8	-24.9
Lamont 5	-28	-31.3	**-35.5***	**-37.2***
Lamont 6	-28	-38.2	-35	-35.2
Lamont 7	-34	na	-38	-36.6

... Same conclusion for MP-1A

Conclusions

- In the current (AASHTO MP-1) binder low temperature grading system asphalts at Lamont and other test sites performed as expected.
- MP-1 testing conditions are arbitrary
- MP-1A is as arbitrary as the input data
- Fracture strength depends on binder type:

  Oxidized asphalt < Conventional < Polymer Modified
- Binder Design Strength criteria shows promise

In closing...

In the fracture-free world,

binder thermal strength is IMPORTANT

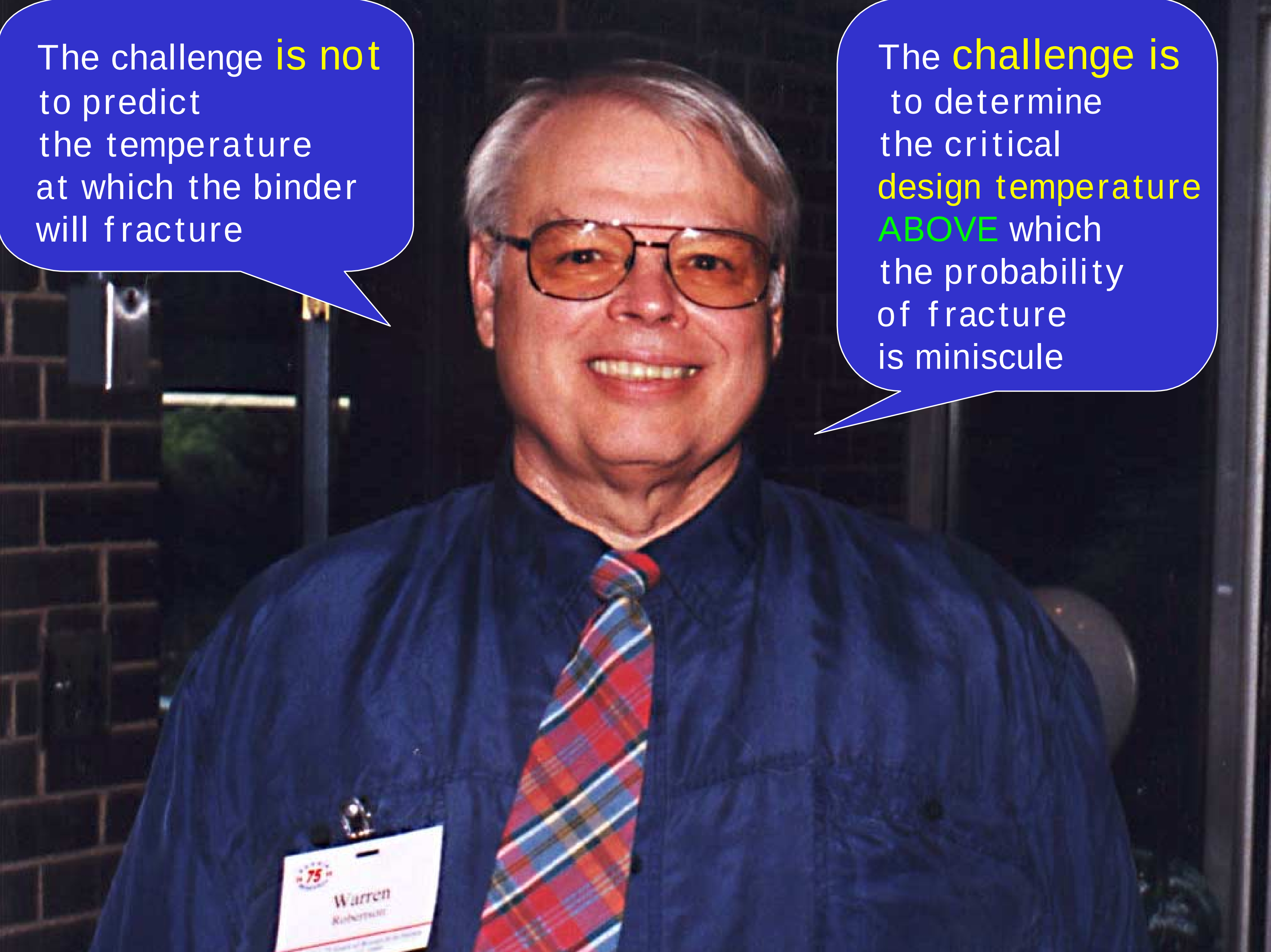
The challenge **is not** to predict the temperature at which the binder will fracture but to determine the critical design temperature ABOVE which the probability of fracture is miniscule

For future consideration...

- Understanding stress-strain behavior of thin films in relation to bulk binder properties?
- Effect of physical hardening on binder strength (failure stress)?
- Effect of strain on binder strength at/near fracture

Fracture is a flaw (not a flow) phenomenon

Consider use of fracture energy and/or fracture toughness as design parameters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Warren


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