Specification Adjustments to Improve Cracking Resistance

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Acknowledgement

WHRP
Wisconsin Highway Research Program

- Project 0092-14-06 Critical Factors Affecting Asphalt Durability
  - Evaluate changes to the composition of asphalt mixtures that WisDOT should consider to improve durability
    - Resistance to load associated cracking
    - Resistance to aging

http://wisconsindot.gov/documents2/research/14-06-revised-final-report.pdf

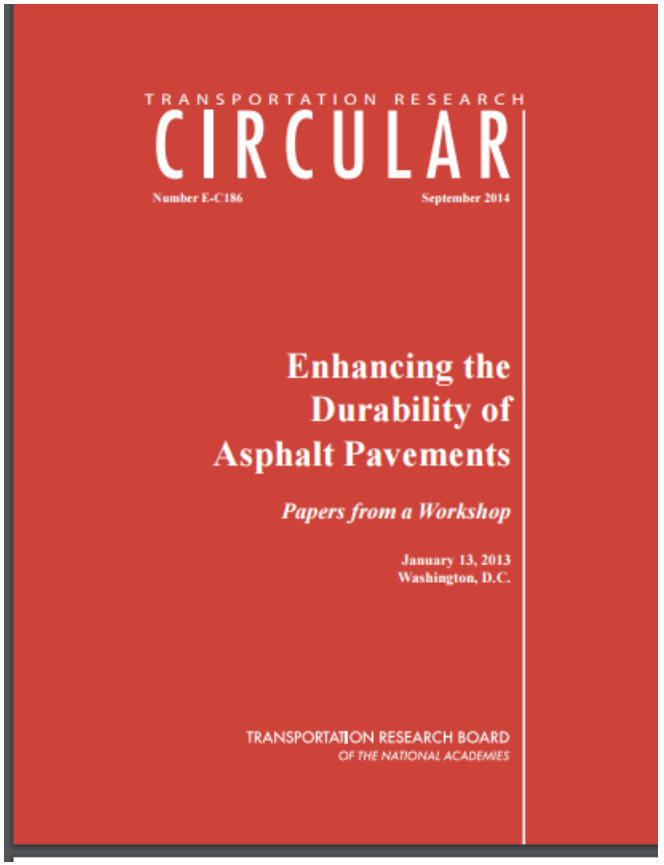
Today's Talk

- How Can Resistance to Load Associated Cracking Be Improved?
- Wisconsin Experiment
- Application to Mix Design Specifications
- Conclusions
- Final Thought

How Can Resistance to Load Associated Cracking Be Improved?

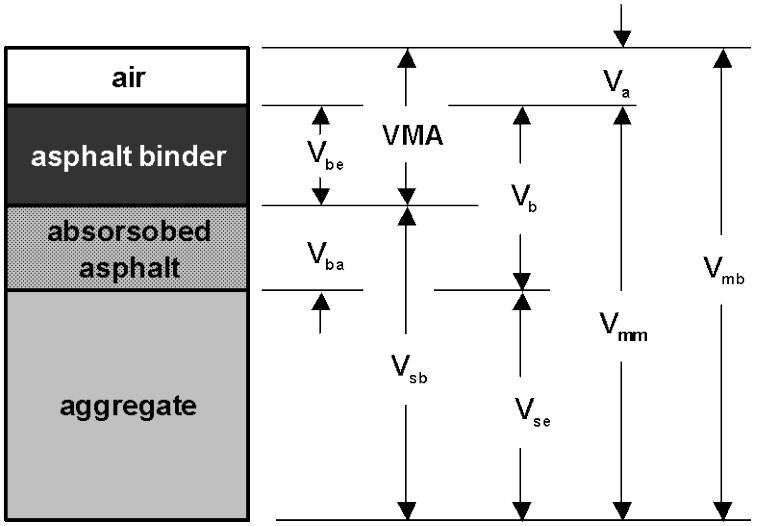
- Published in Transportation Research Circular

http://onlinepubs.trb.org/onlinepubs/circulars/ec186.pdf



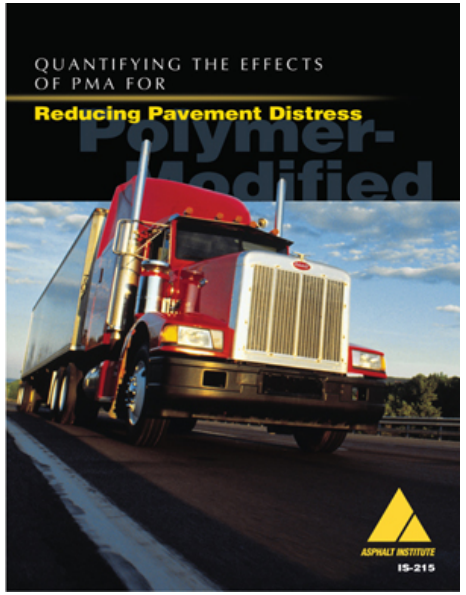
1: Increase Effective Binder Content

- Many studies show resistance to cracking improves with increasing effective binder content (VBE)
  - Increase design VMA
  - Decrease design air voids
  - Decrease design gyrations
  - Smaller NMAS mixtures
  - SMA
    - Polymer modified binder
    - High effective binder content



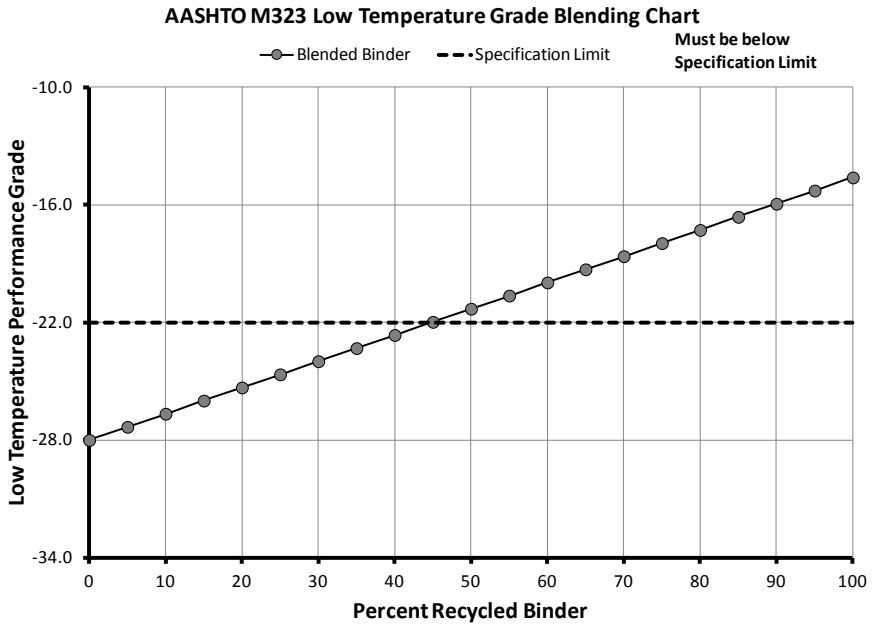
2: Use Polymer Modification

- Polymer modified binders show superior performance
  - Increases pavement life 2 to 10 years
  - NV, LA specify polymer modified binder for all surface mixtures
  - In one study, polymer modified mixtures with RAP perform better in fatigue than virgin mixtures without RAP



3: Use a Softer Binder in Mixtures with RAP/RAS

- AASHTO M 323 Blending Chart Analysis
- Conflicting results from laboratory studies on effectiveness
  - General improvement for thermal cracking
  - Test dependent for load associated cracking



4: Place a Limit on RAP/RAS Binder Effectiveness

- Use Less Than Total Recycled Binder Content in Volumetric Calculations
  - RAP Binder 90 % Effective?
  - RAS Binder 70 % Effective?

Laboratory Experiment

- Factors
  - Effective binder volume
  - Recycled binder content
  - Virgin binder low temperature grade
  - Polymer modification

Specification Properties

- Responses
  - Resistance to simulated long-term aging
  - Resistance to intermediate temperature cracking

Factor Levels

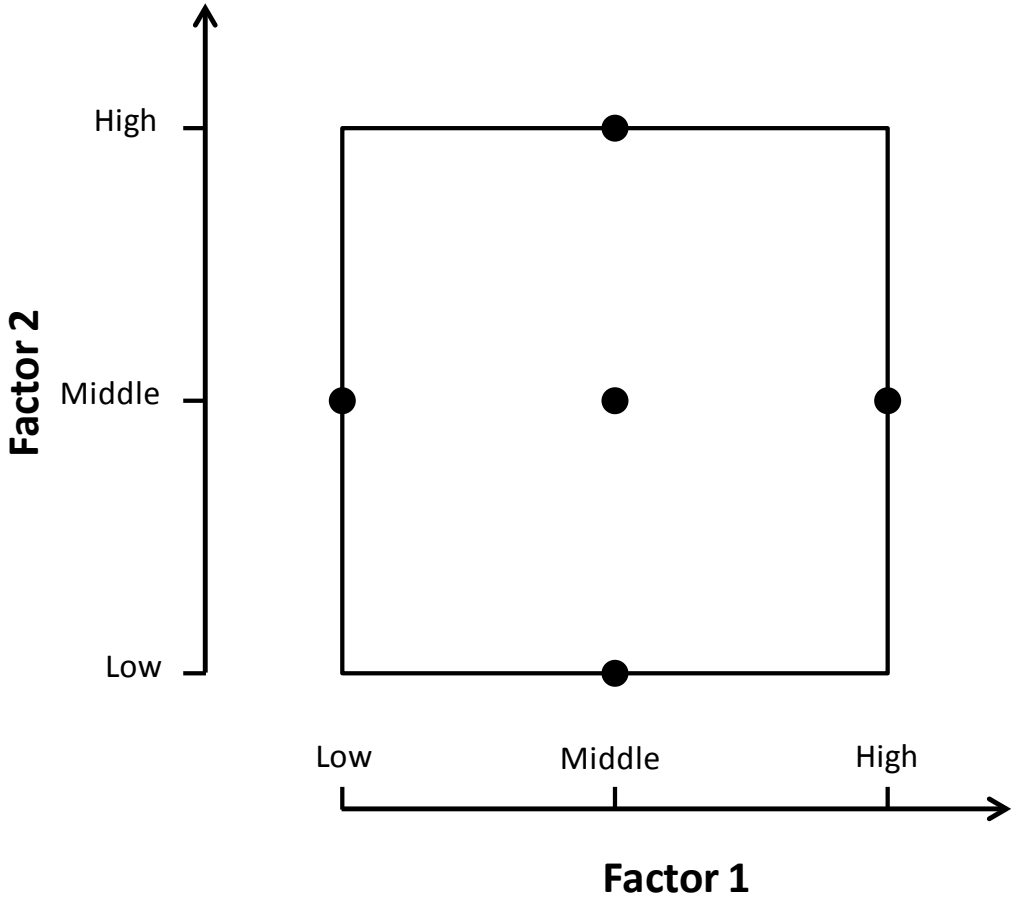
Factor	Low	Middle	High
Effective Binder Volume (Nominal Maximum Aggregate Size, mm)	19.0	12.5	9.5
Recycle Binder Content	Virgin	RAP	RAP+RAS
Low Temperature Grade	-22	-28	-34
Polymer Modification	Neat	V	E

- Conditioning
  - Short-term
    - 4 hours at 135 °C
  - Long-term
    - Short-term + 120 hours at 85 °C

Full Factorial

$3^4 \times 2 = 162$

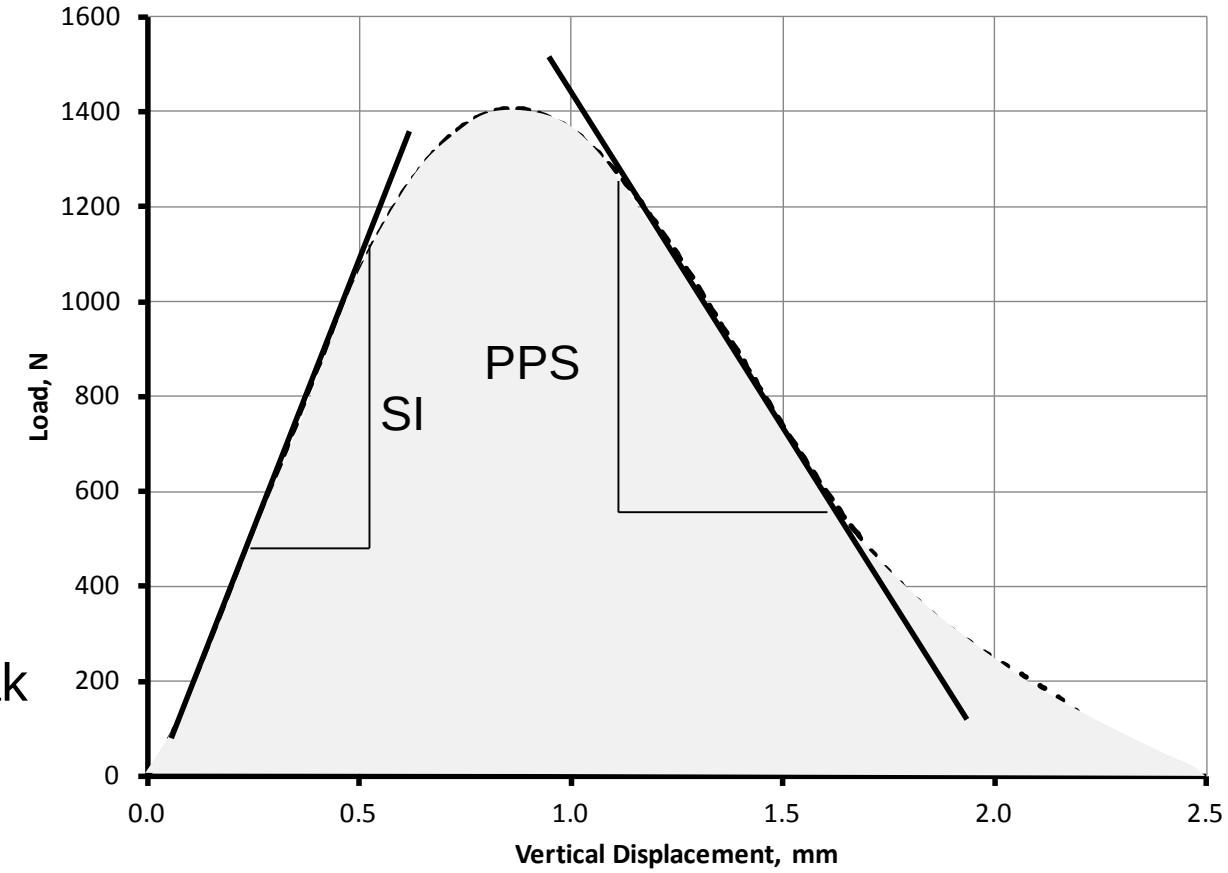
Box Behnken Design (Partial Factorial)



Experimental Design

Run	Mix ID	NMAS, mm	Recycle	Low Grade	Modification	Space
1	8	19.0	Virgin	-28	V	V_{be} – Recycle
2	9	9.5	Virgin	-28	V	
3	3	19.0	RAP+RAS	-28	V	
4	4	9.5	RAP+RAS	-28	V	
5	6	12.5	RAP	-22	S	Low Grade – Modification
6	6	12.5	RAP	-34	S	
7	6	12.5	RAP	-22	E	
8	6	12.5	RAP	-34	E	
9	6	12.5	RAP	-28	V	Center
10	5	19.0	RAP	-28	S	V_{be} – Modification
11	1	9.5	RAP	-28	S	
12	5	19.0	RAP	-28	E	
13	1	9.5	RAP	-28	E	
14	2	12.5	Virgin	-22	V	Recycle - Low Grade
15	7	12.5	RAP+RAS	-22	V	
16	2	12.5	Virgin	-34	V	
17	7	12.5	RAP+RAS	-34	V	
18	6	12.5	RAP	-28	V	Center
19	2	12.5	Virgin	-28	S	Recycle – Modification
20	7	12.5	RAP+RAS	-28	S	
21	2	12.5	Virgin	-28	E	
22	7	12.5	RAP+RAS	-28	E	
23	5	19.0	RAP	-22	V	V_{be} – Low Grade
24	1	9.5	RAP	-22	V	
25	5	19.0	RAP	-34	V	
26	1	9.5	RAP	-34	V	
27	6	12.5	RAP	-28	V	Center

Illinois SCB (Flexibility Index)



SI = Stiffness Index
Slope @ 50% of Peak Load
AI=Aging Index
$=SI_{LTOA}/SI_{STOA}$

FI = Energy/Post Peak Slope
Resistance to cracking increases with increasing FI

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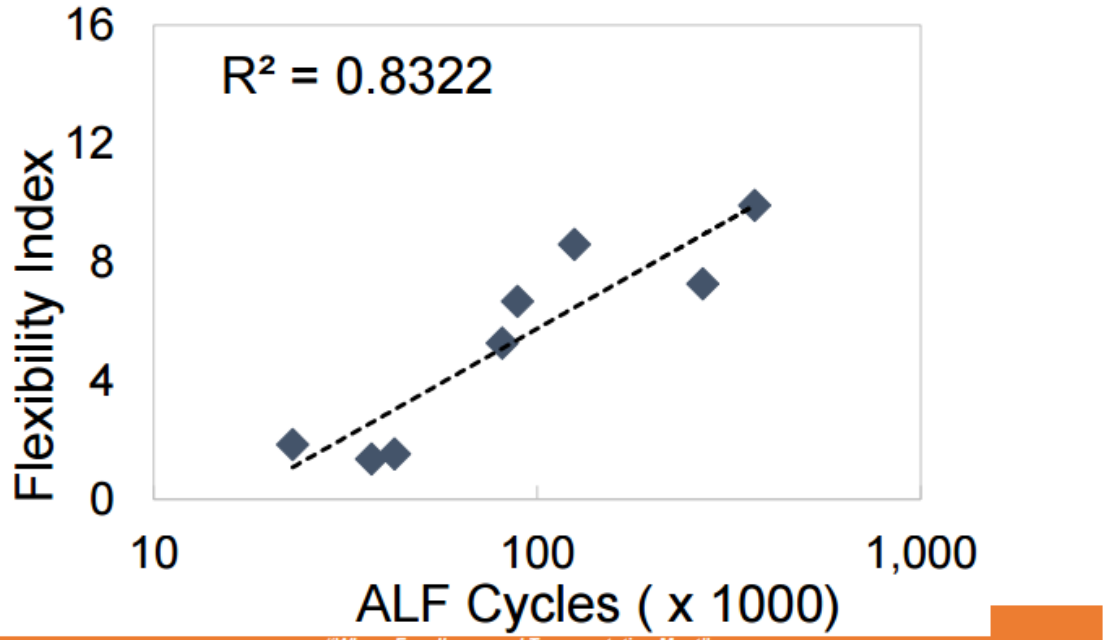
FI Correlation to Cracking Performance

Illinois Center for Transportation
University of Illinois at Urbana Champaign

I-FIT Prediction of Fatigue (ALF)



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Imad L. Al-Qadi
I-FIT (Illinois Flexibility Index Test) Protocol – Contractor Perspectives
http://bituminousconference.ict.illinois.edu/files/2016/12/4.-Imad-Al-Qadi.pdf

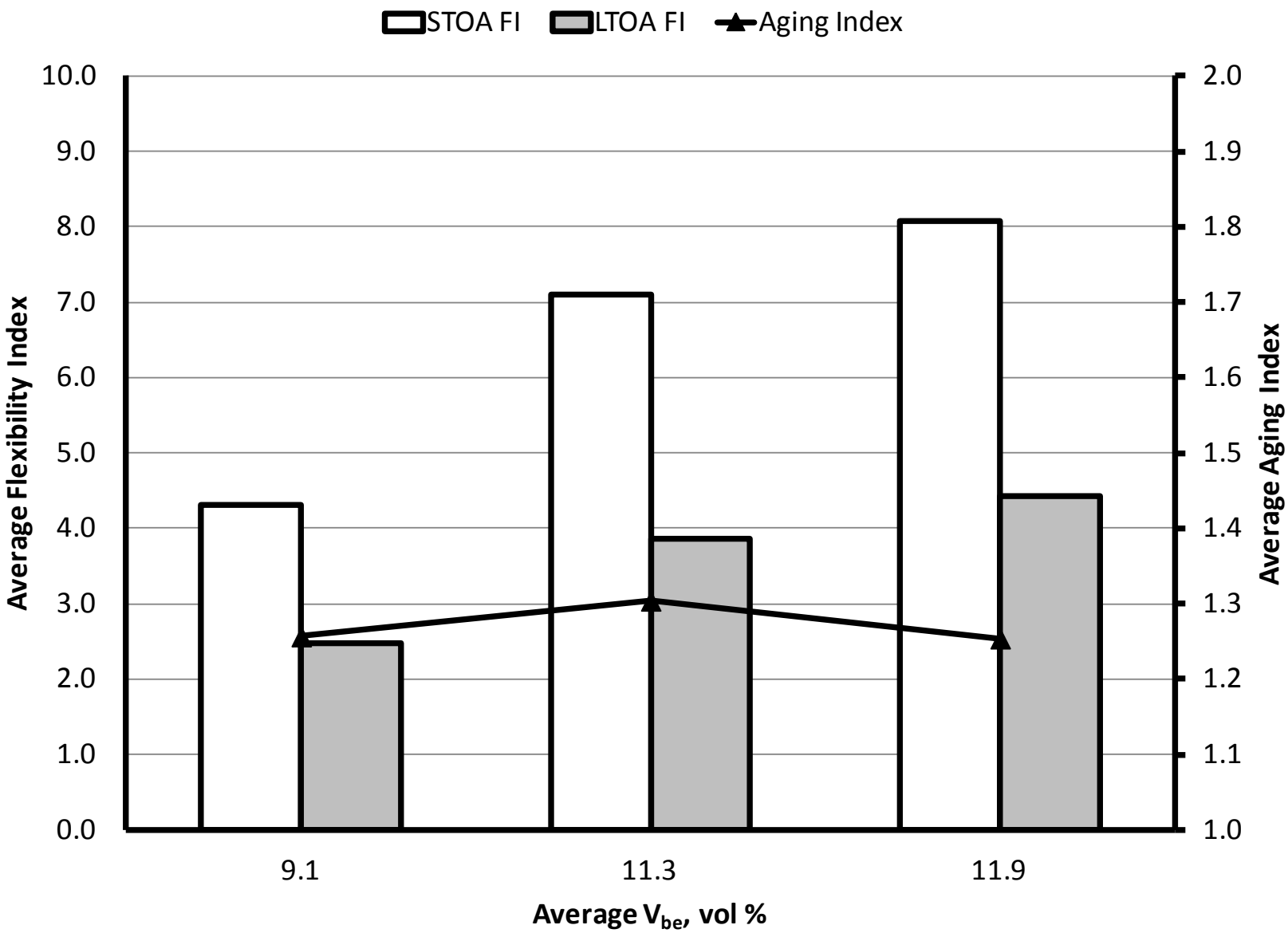
Virgin Binders

Binder	Modification	M 320 Cont. Grade			Jnr, 1/kPa		%R, %	
		H	I	L	64 C	58 C	64 C	58 C
64S-22	None	66.1	23.7	-25.6	3.05		NA	
64V-22	Medium	77.6	22.8	-25.1	0.34		49.4	
64E-22	High	80.6	21.9	-25.3	0.10		79.1	
58S-28	None	58.2	20.2	-29.0		3.64		NA
58V-28	Medium	68.5	19.1	-28.9		0.57		34.6
58E-28	High	74.4	15.8	-31.8		0.07		86.0
52S-34	None	54.2	11.9	-34.0		6.42		NA
58V-34	Medium	62.9	13.1	-36.4		0.57		59.6
58E-34	High	68.7	10.5	-36.2		0.24		75.1

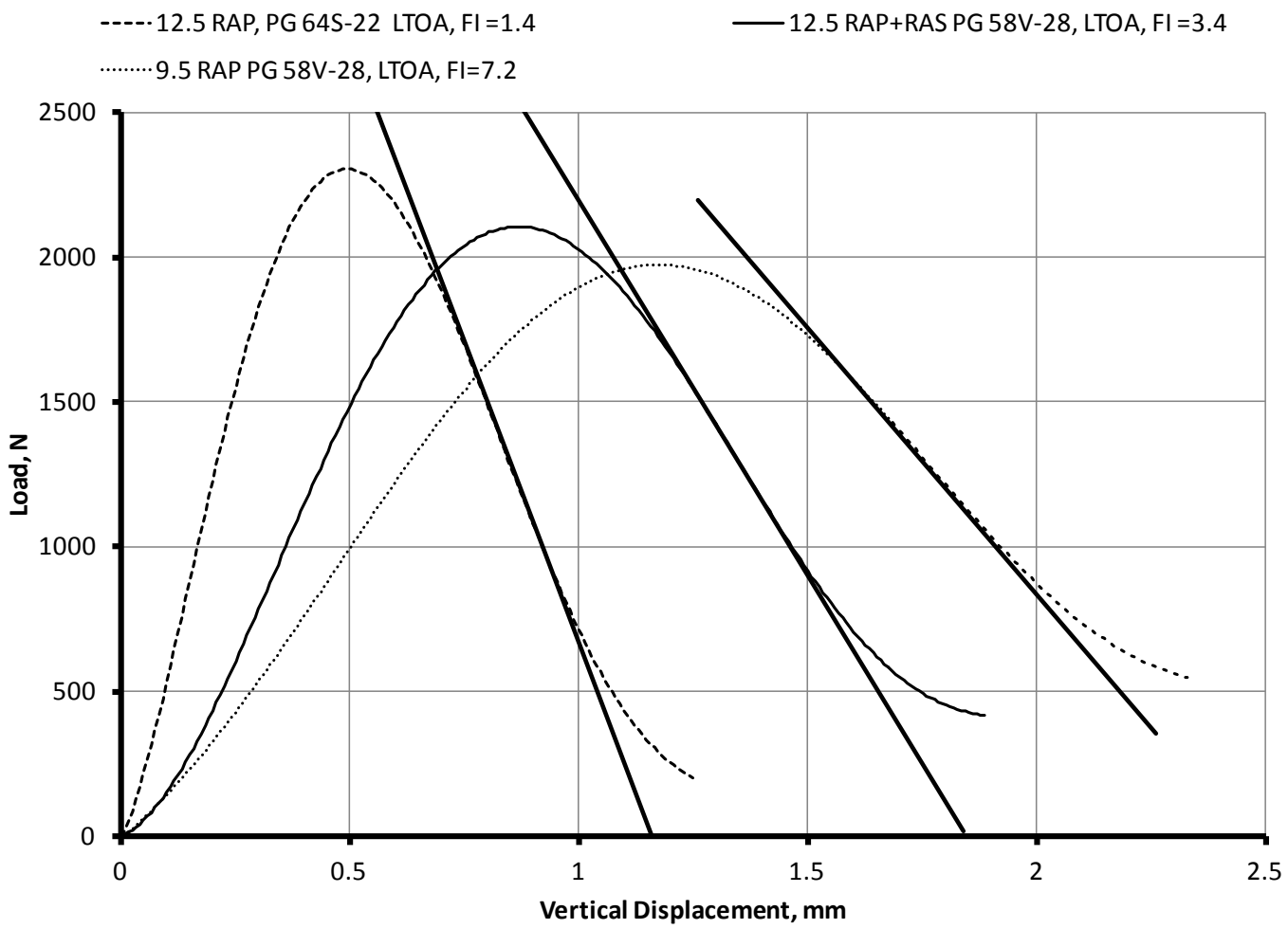
Mixtures

Type	Mix ID	Nom Max Size, mm	Gradation	Binder Content, wt %	VBE, vol. %	RAP Binder ratio	RAS Binder ratio
Virgin	8	19.0	Fine	4.8	9.9	0	0
	2	12.5	Fine	5.7	11.6	0	0
	9	9.5	Fine	6.3	11.7	0	0
RAP	5	19.0	Fine	4.9	8.8	0.255	0
	6	12.5	Fine	5.4	10.5	0.186	0
	1	9.5	Fine	6.1	12.0	0.246	0
RAP + RAS	3	19.0	Fine	5.1	9.2	0.208	0.162
	7	12.5	Fine	5.8	12.3	0.119	0.158
	4	9.5	Fine	5.7	11.7	0.121	0.180

Effect of VBE



What is Changing?



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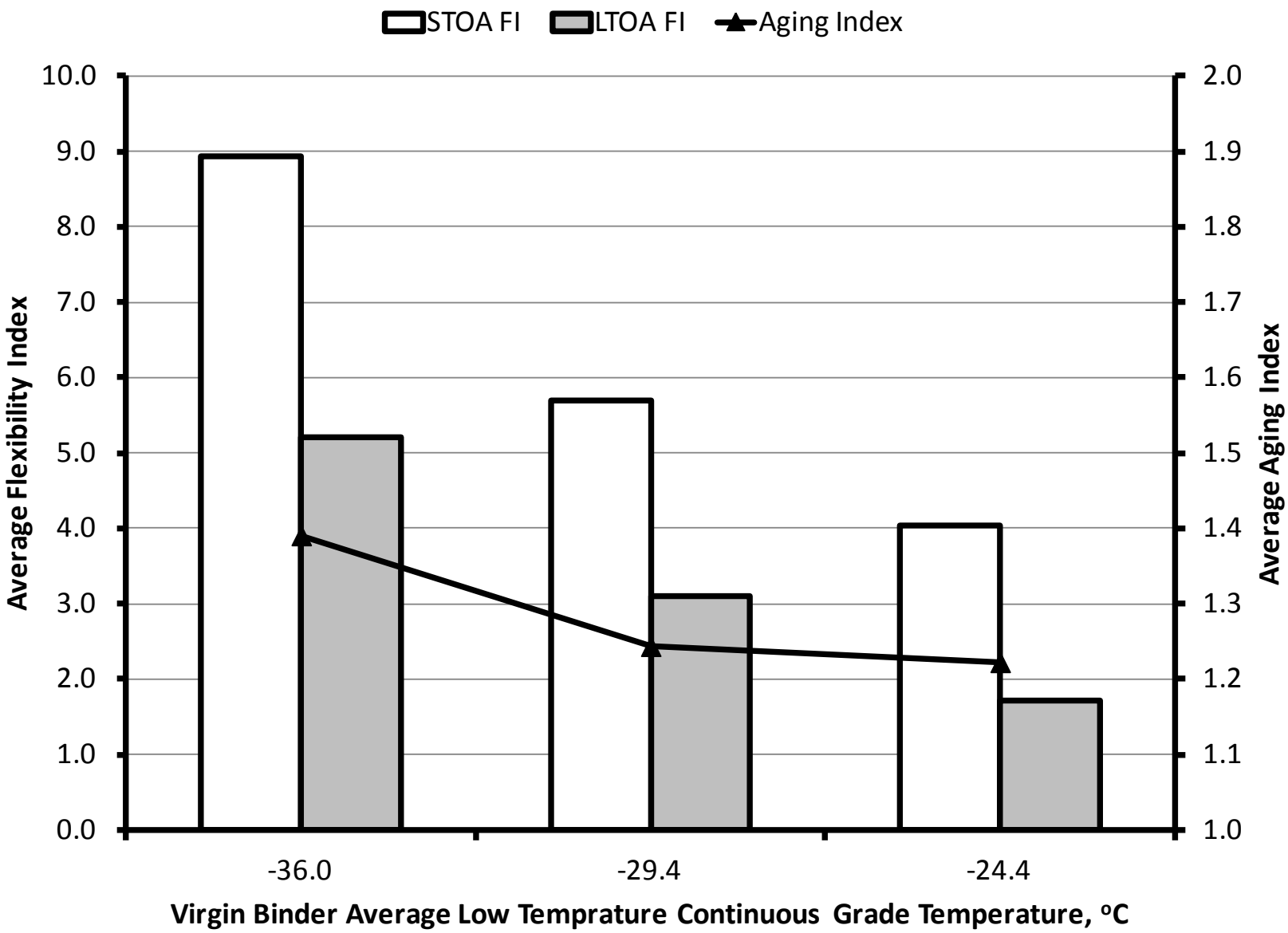
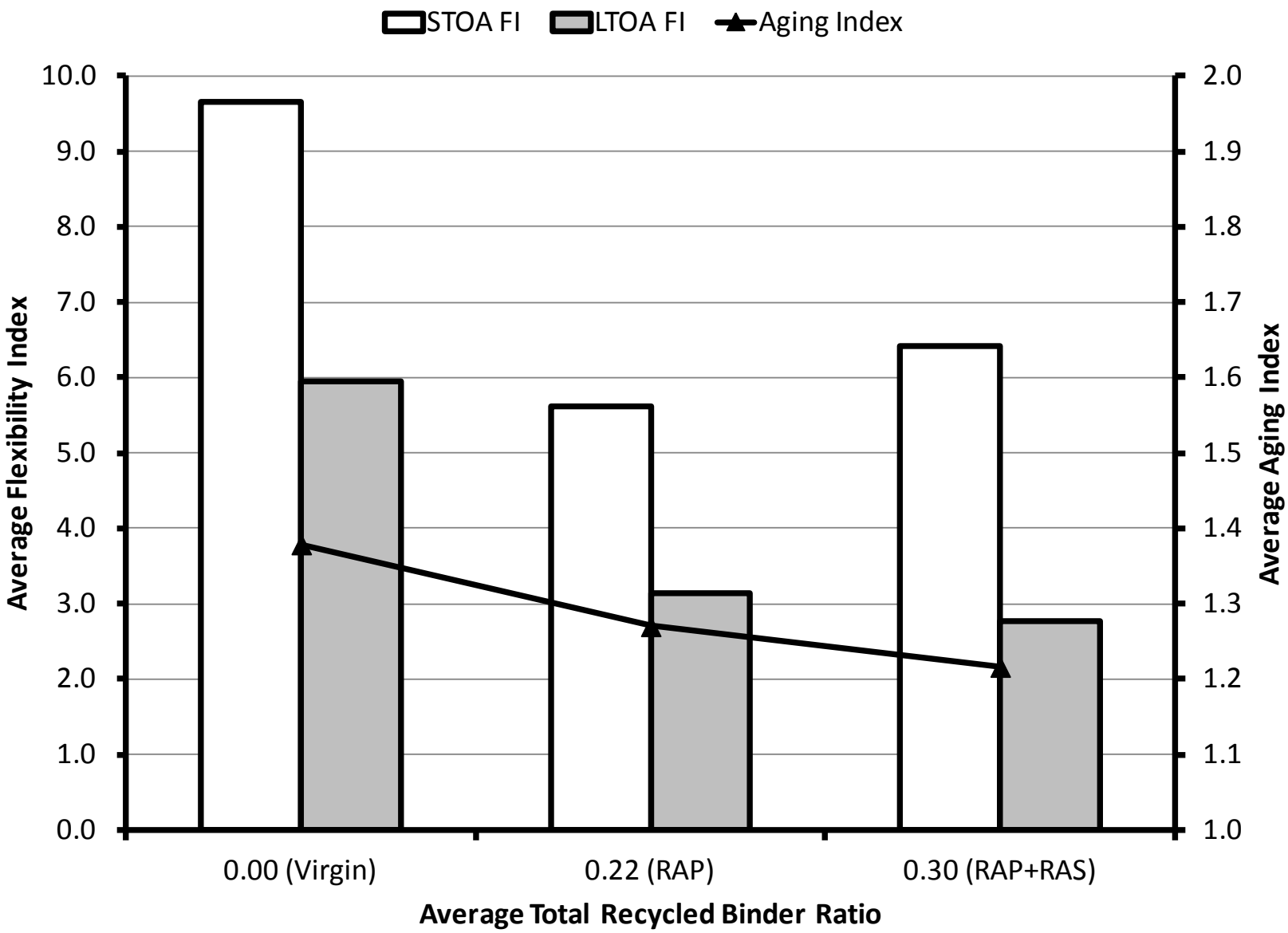
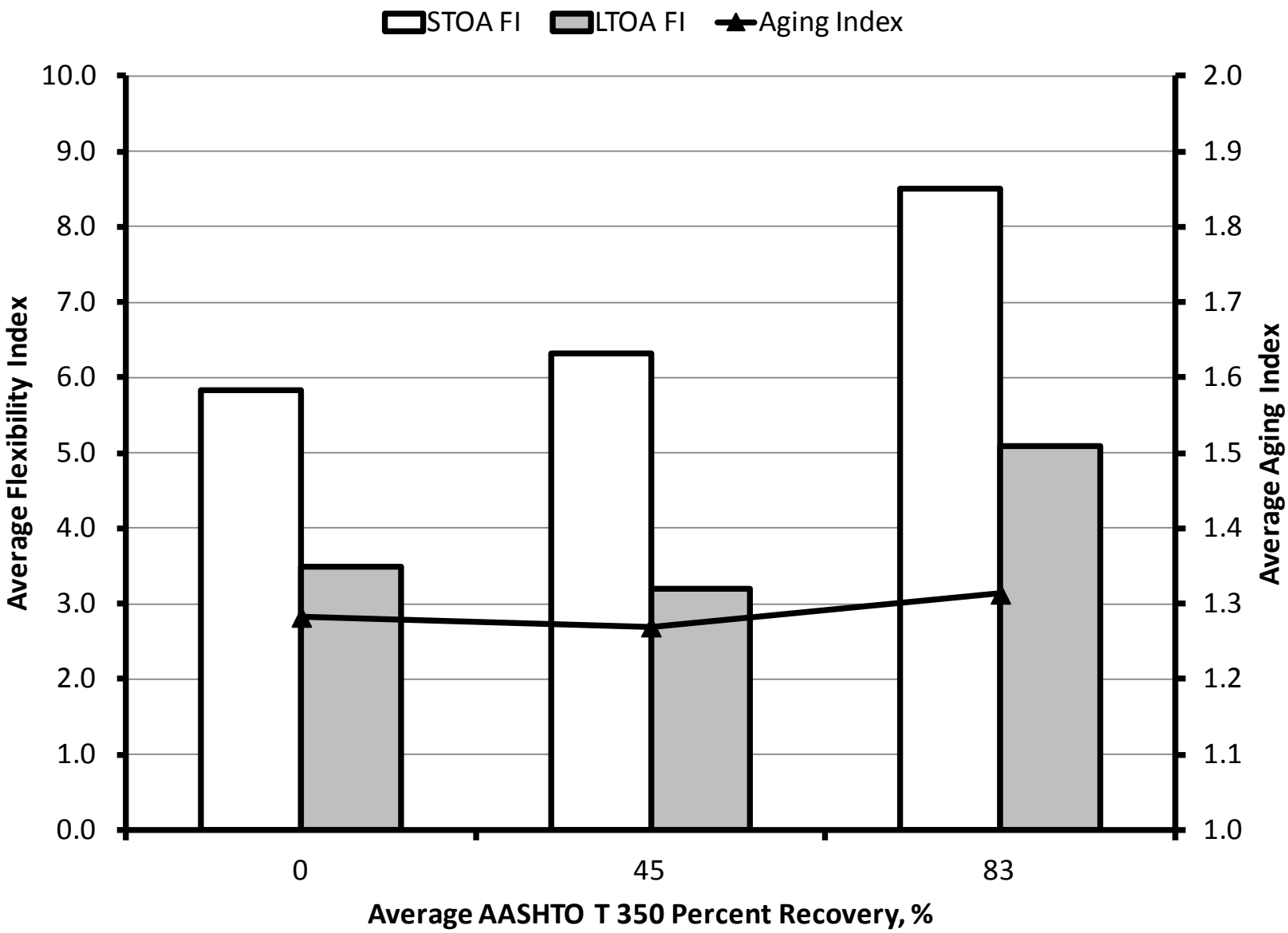
Effect of Virgin Binder Grade



Effect of Recycled Binder



Effect of Polymer Modification



Regression Equation

- Relating FI to Factors Controlled by Specifications
  - VBE
  - Virgin Binder Low Temperature Grade
  - Recycle Content
  - Modification
- Development Considered
  - Rationality of Coefficients
  - Significance of Predictor Variables
  - Goodness of Fit
  - Residuals

Flexibility Index Regression Equation

$$FI_{STOA} = -18.759 + 1.368 \times VBE - 0.3905 \times \left(T_{Virgin}\right)_{Low} - 10.181 \times RBR_{EFF} + 3.100 \times \left(\frac{R\%}{100}\right)^2$$

Where:

FI_{STOA} = short-term oven conditioned flexibility index

VBE = effective volume of binder, vol %

$(T_{Virgin})_{Low}$ = continuous low temperature grade of the virgin binder, °C

RBR_{EFF} = effective RAP binder ratio

$$RBR_{EFF} = \frac{\%RAPBinder}{\%TotalBinder} + F\left(\frac{\%RASBinder}{\%TotalBinder}\right)$$

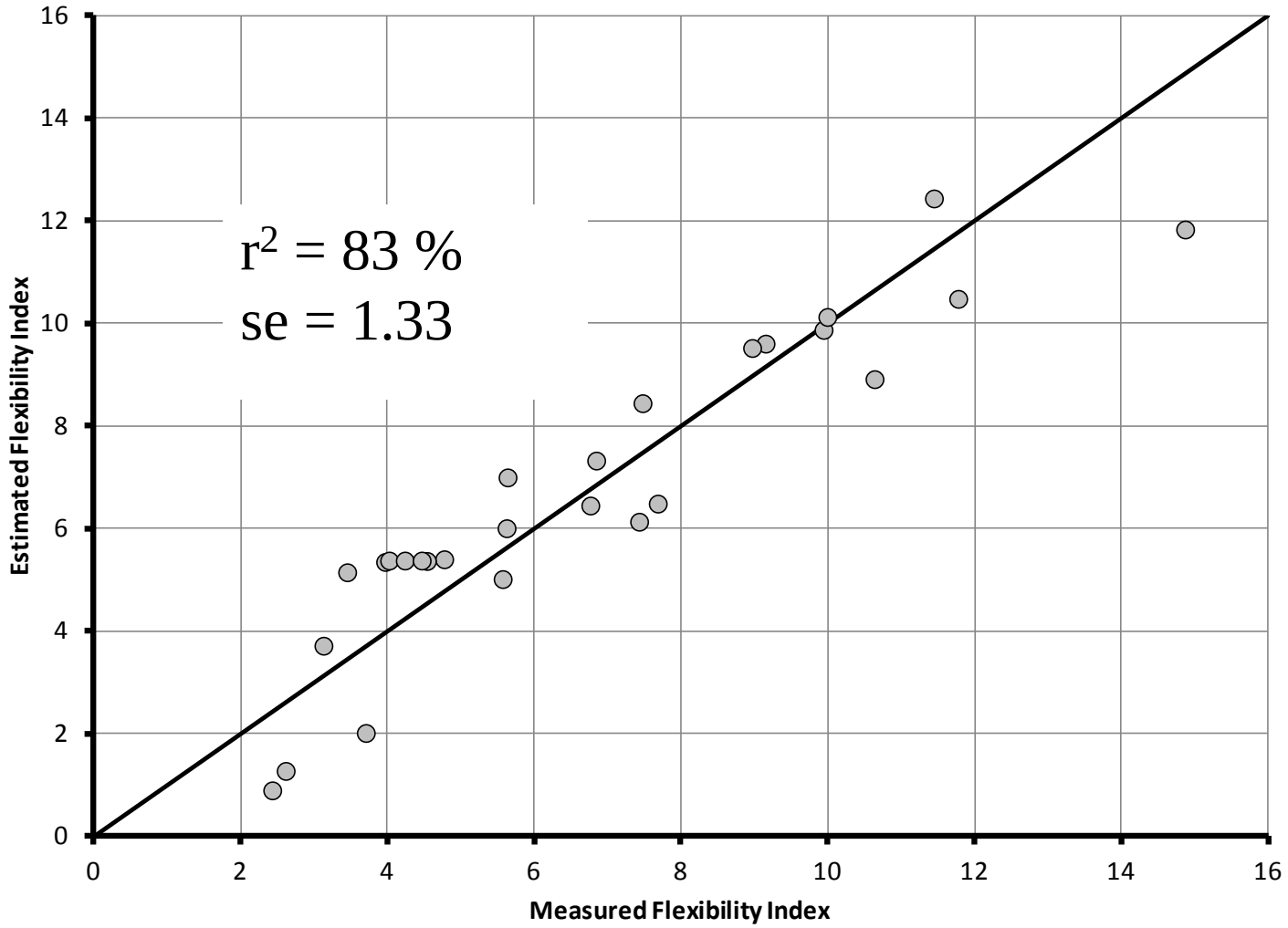
F = ratio of intermediate grade change for RAS to RAP

R% = percent recovery from AASHTO M332

Analysis of Coefficients

Variable	Partial Regression Coefficient	t- Statistic	p-value	Standardized Partial Regression Coefficient
Intercept	-18.759	-6.051	0.000004	NA
VBE	1.368	6.325	0.000002	0.52
Virgin Binder Low PG	-0.3905	-5.773	0.000008	-0.49
Effective RAP Binder Ratio	-10.181	-4.736	0.000100	-0.39
% Recovery	3.100	2.893	0.008445	0.25

Predicted vs Measured

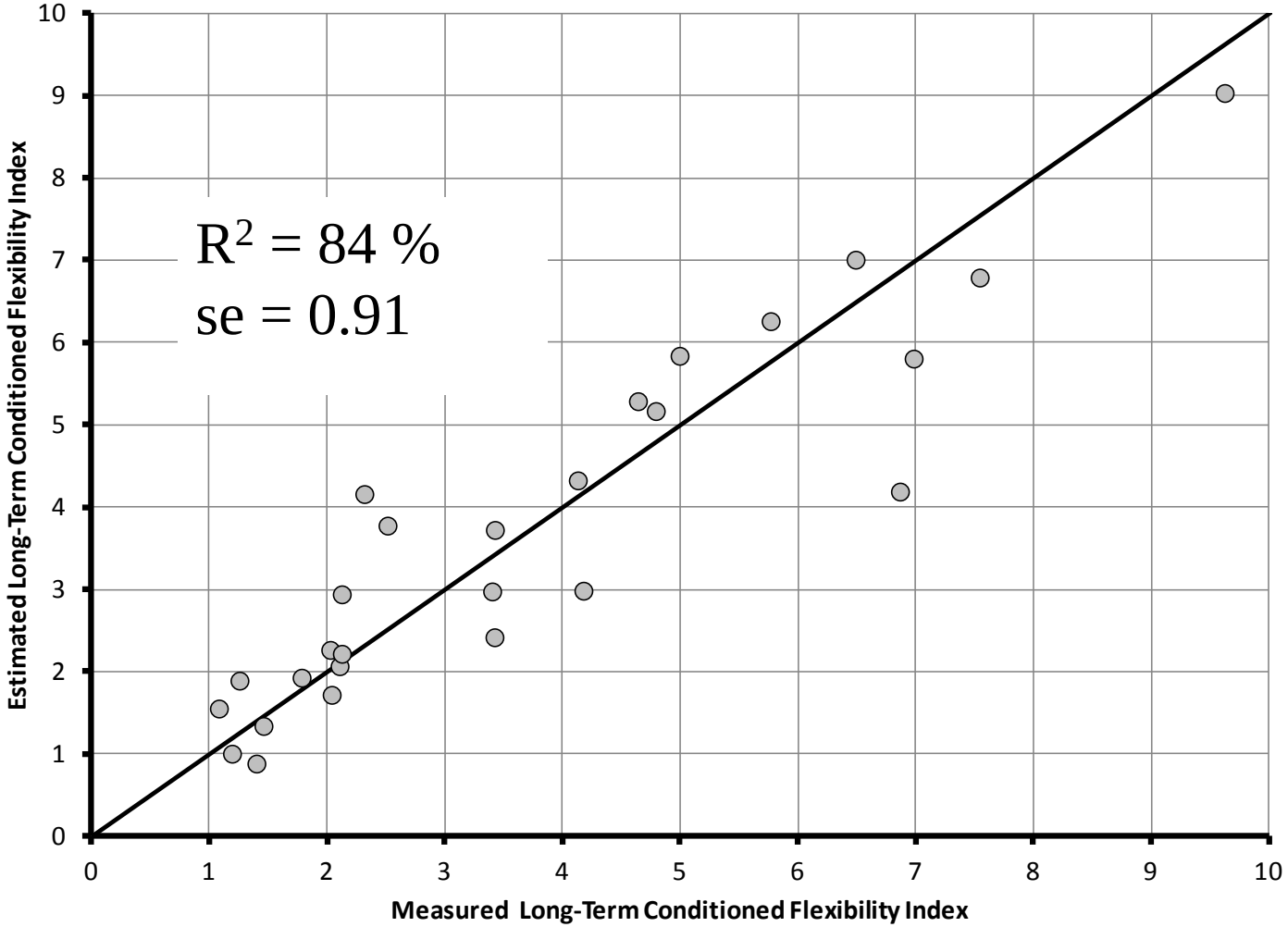


Long-Term Aged Flexibility Index

$$FI_{LTOA} = 0.6550 \times FI_{STOA} - 0.7019$$

FI_{STOA}	FI_{LTOA}	FI_{LTOA}/FI_{STOA}
14.00	8.47	0.60
12.00	7.16	0.60
10.00	5.85	0.58
8.00	4.54	0.57
6.00	3.23	0.54
4.00	1.92	0.48
2.00	0.61	0.30

Predicted vs Measured



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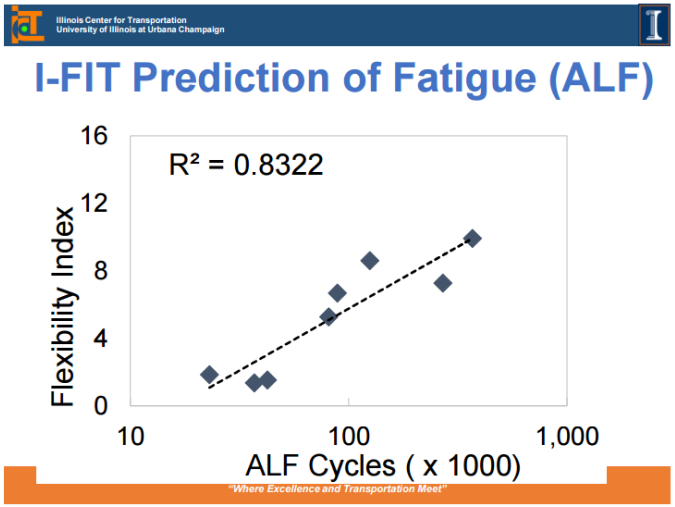
Application 1 Factor Effects

$$FI_{STOA} = -18.759 + 1.368 \times VBE - 0.3905 \times \left(T_{Virgin}\right)_{Low} - 10.181 \times RBR_{EFF} + 3.100 \times \left(\frac{R\%}{100}\right)^2$$

- Solve for FI for selected
  - VBE
  - Virgin Binder Low Temperature Grade
  - Recycle Content
  - Modification

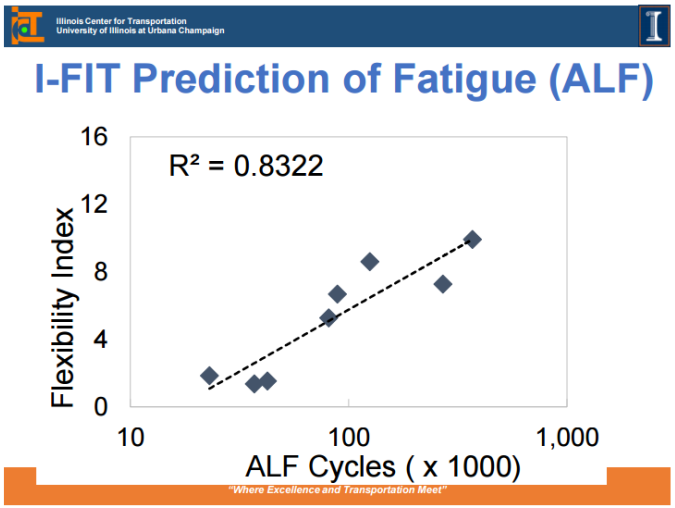
Effect of Recycled Binder
No Grade Change

VBE	Low Grade	RBR	FI	% of Control Life
10.5	-28	0.00	6.5	100
10.5	-28	0.05	6.0	92
10.5	-28	0.10	5.5	84
10.5	-28	0.15	5.0	77
10.5	-28	0.20	4.5	69
10.5	-28	0.25	4.0	61
10.5	-28	0.30	3.5	53



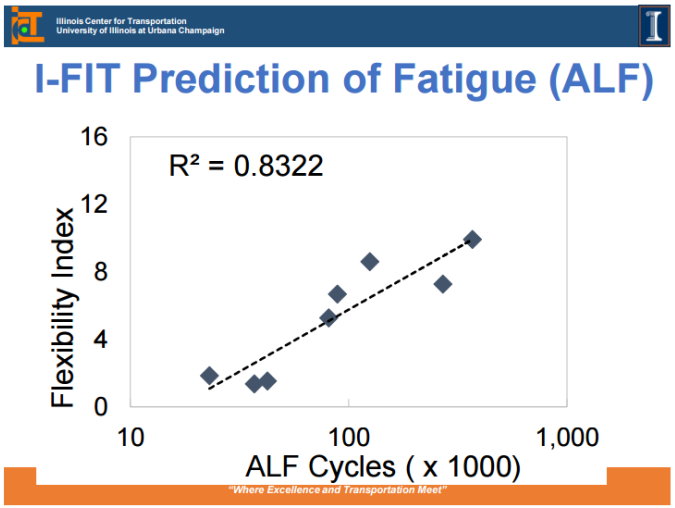
Effect of Recycled Binder AASHTO M323 Recommendations

VBE	Low Grade	ABR	FI	% of Control Life
10.5	-28	0.00	6.5	100
10.5	-28	0.05	6.0	92
10.5	-28	0.10	5.5	84
10.5	-28	0.15	5.0	77
10.5	-34	0.20	6.9	105
10.5	-34	0.25	6.3	97
10.5	-34	0.30	5.8	89



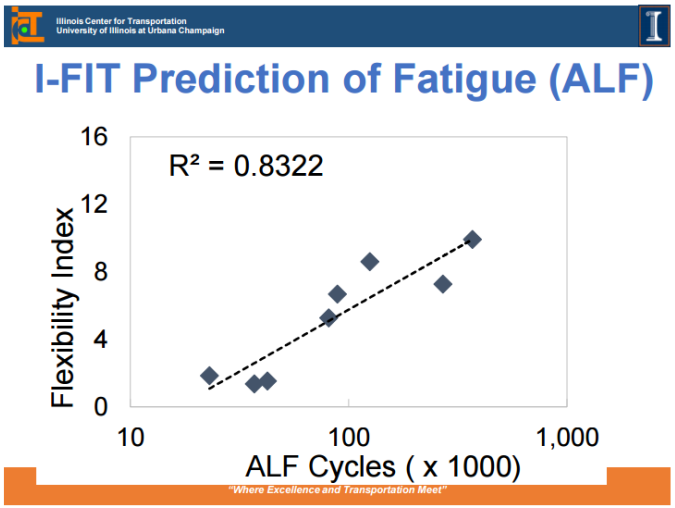
Effect of Recycled Binder Smaller NMAS Mix or VBE Increase

VBE	Low Grade	ABR	FI	% of Control Life
10.5	-28	0.00	6.5	100
10.5	-28	0.05	6.0	92
10.5	-28	0.10	5.5	84
10.5	-28	0.15	5.0	77
11.5	-28	0.20	5.9	90
11.5	-28	0.25	5.4	82
11.5	-28	0.30	4.9	74



Effect of Recycled Binder Polymer Modification

VBE	Low Grade	ABR	% R	FI	% of Control Life
10.5	-28	0.00	0	6.5	100
10.5	-28	0.05	0	6.0	92
10.5	-28	0.10	0	5.5	84
10.5	-28	0.15	0	5.0	77
10.5	-28	0.20	75	6.3	96
10.5	-28	0.25	75	5.7	88
10.5	-28	0.30	75	5.2	80



Application 2 Specification

$$FI_{STOA} = -18.759 + 1.368 \times VBE - 0.3905 \times \left(T_{Virgin}\right)_{Low} - 10.181 \times RBR_{EFF} + 3.100 \times \left(\frac{R\%}{100}\right)^2$$

- Select FI (e.g. virgin mix at minimum VBE) then solve for combinations of factors giving equal FI
- Yields a specification with selected cracking resistance

Example Design Specification

Effective RAP Binder Ratio	Minimum Design VBE, vol %							
	58-28 S	58-28 H	58-28 V	58-28 E	58-34 S	58-34 H	58-34 V	58-34 E
0.00	10.0	9.8	9.3	8.8	VBE Below Experimental Range			
>0.00 ≤0.05	10.4	10.2	9.7	9.1				
>0.05 ≤0.10	10.7	10.5	10.1	9.5	9.1	8.9		
>0.10 ≤0.15	11.1	10.9	10.4	9.9	9.4	9.2		
>0.15 ≤0.20	11.5	11.3	10.8	10.2	10.1	9.6	9.1	
>0.20 ≤0.25	11.9	11.7	11.2	10.6	10.4	10.2	9.5	8.9
>0.25 ≤0.30	12.2	12.0	11.5	11.0	10.8	10.6	10.1	9.3
>0.30 ≤0.35	Low Temperature Grade Controls				11.2	11.0	10.5	9.6
>0.35 ≤0.40					11.5	11.3	10.9	10.3
>0.40 ≤0.45					11.9	11.7	11.2	10.6
>0.45 ≤0.50					12.3	12.1	11.6	11.0

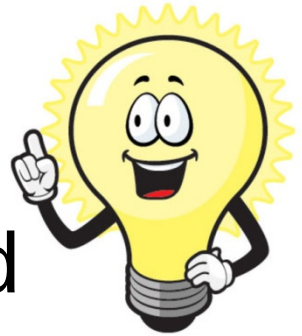
Conclusions

- Resistance to aging not significantly affected by composition over range of typical mixtures
- Resistance to cracking affected by factors that can be controlled by specifications
  - VBE
  - Virgin Binder Low Temperature Grade
  - Recycle Content
  - Modification

Conclusions

- For binders with normal aging characteristics improving resistance to cracking for short-term aging also improved resistance to cracking for long-term aging
- Statistical design and analysis used for process improvement yielded useful regression equation
  - Agencies to set specification requirements
  - Producers to design mixtures to meet a performance test requirement

Final Thought



- Use this approach to produce balanced mix design?
  - Agency and producers agree on performance tests that serve as basis
  - Agency and producers agree on acceptable materials and range of acceptable mixtures
  - Develop specifications based on results of a similar experiment
  - Use normal quality control testing and tolerances

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