

Another Approach to Balanced Mix Design?

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Acknowledgement

- 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

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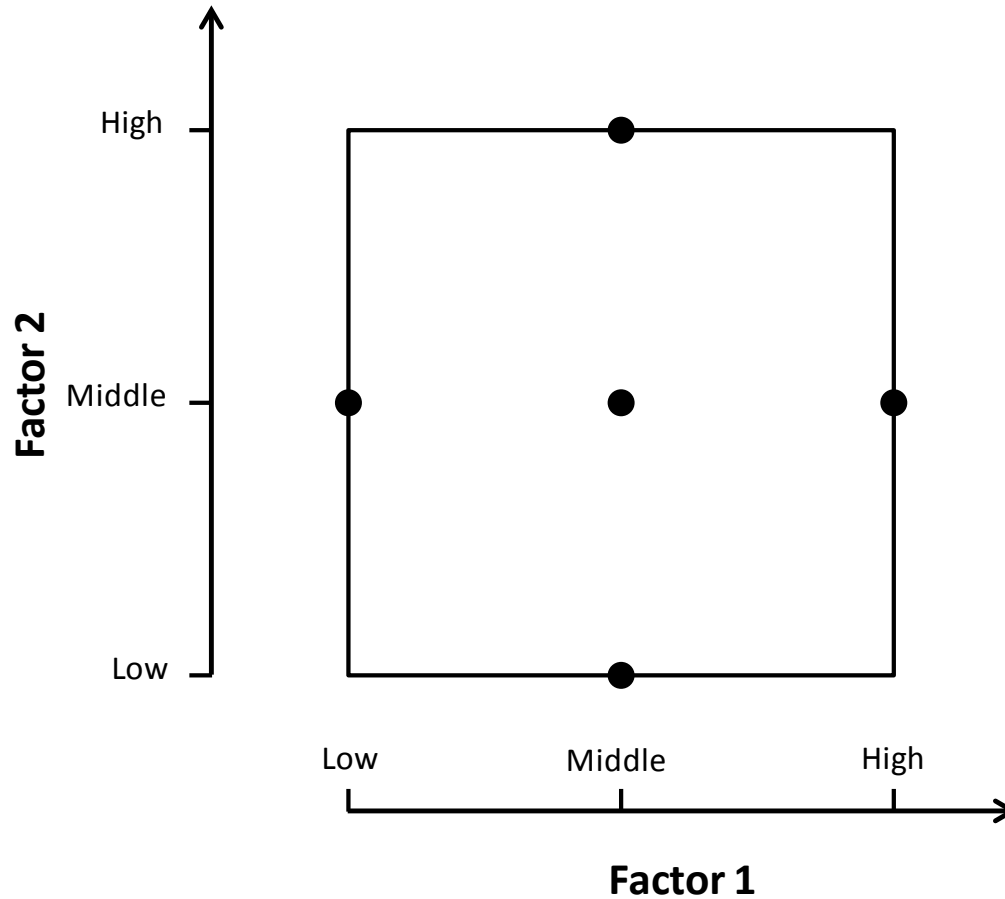
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WHRP Project 0092-14-06

- Synthesis of Current Research
 - Laboratory Experiment
 - Volume of Binder
 - Recycled Binder Content
 - Low Temperature Grade
 - Polymer Modification
 - Analysis of WisDOT Specifications
- Resistance to Cracking and Aging



Box Behnken Design



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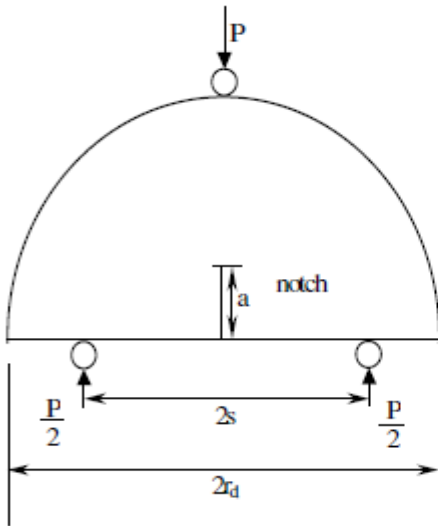


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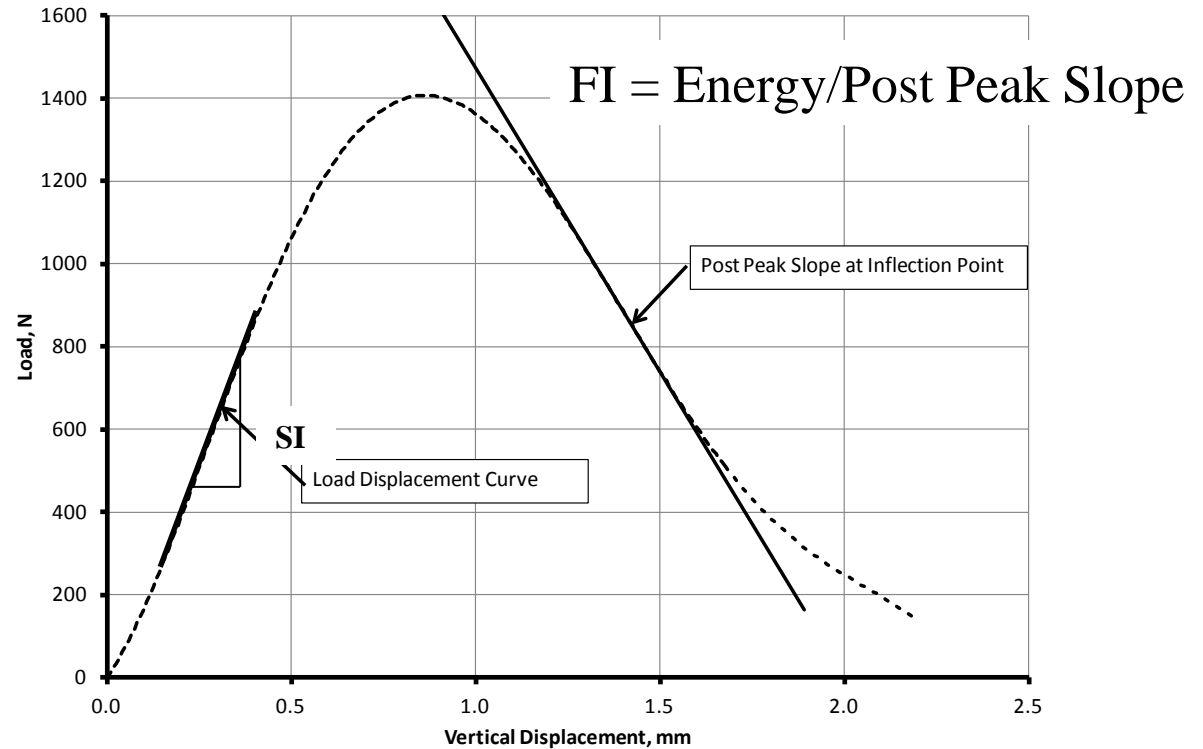
Run	VBE	Recycle	Mix #	Low Grade	Modification	Space
1	19.0	Virgin	8	-28	Medium	VBE – Recycle
2	9.5	Virgin	9	-28	Medium	
3	19.0	RAP+RAS	3	-28	Medium	
4	9.5	RAP+RAS	4	-28	Medium	
5	12.5	RAP	6	-22	None	Low Grade – Modification
6	12.5	RAP	6	-34	None	
7	12.5	RAP	6	-22	High	
8	12.5	RAP	6	-34	High	
9	12.5	RAP	6	-28	Medium	Center
10	19.0	RAP	5	-28	None	VBE – Modification
11	9.5	RAP	1	-28	None	
12	19.0	RAP	5	-28	High	
13	9.5	RAP	1	-28	High	
14	12.5	Virgin	2	-22	Medium	Recycle - Low Grade
15	12.5	RAP+RAS	7	-22	Medium	
16	12.5	Virgin	2	-34	Medium	
17	12.5	RAP+RAS	7	-34	Medium	
18	12.5	RAP	6	-28	Medium	Center
19	12.5	Virgin	2	-28	None	Recycle – Modification
20	12.5	RAP+RAS	7	-28	None	
21	12.5	Virgin	2	-28	High	
22	12.5	RAP+RAS	7	-28	High	
23	19.0	RAP	5	-22	Medium	VBE – Low Grade
24	9.5	RAP	1	-22	Medium	
25	19.0	RAP	5	-34	Medium	
26	9.5	RAP	1	-34	Medium	
27	12.5	RAP	6	-28	Medium	Center



Illinois SCB (Flexibility Index)



$2r_d = 150\text{mm}$,



Resistance to cracking increases with increasing FI

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Virgin Binders

Binder	Modification	Jnr, 1/kPa		%R, %		ΔT_c , C
		64 C	58 C	64 C	58 C	
PG 76-22	None	3.05		0		-0.3
PG 76-22,	Medium	0.34		49.4		0.9
PG 64-22	High	0.10		79.1		1.0
PG 58-28	None		3.64		0	-0.8
PG 64-28	Medium		0.57		34.6	-0.7
PG 70-28	High		0.07		86.0	-0.2
PG 52-34	None		6.42		0	1.6
PG 58-34	Medium		0.57		59.6	0.5
PG 64-34	High		0.24		75.1	0.5

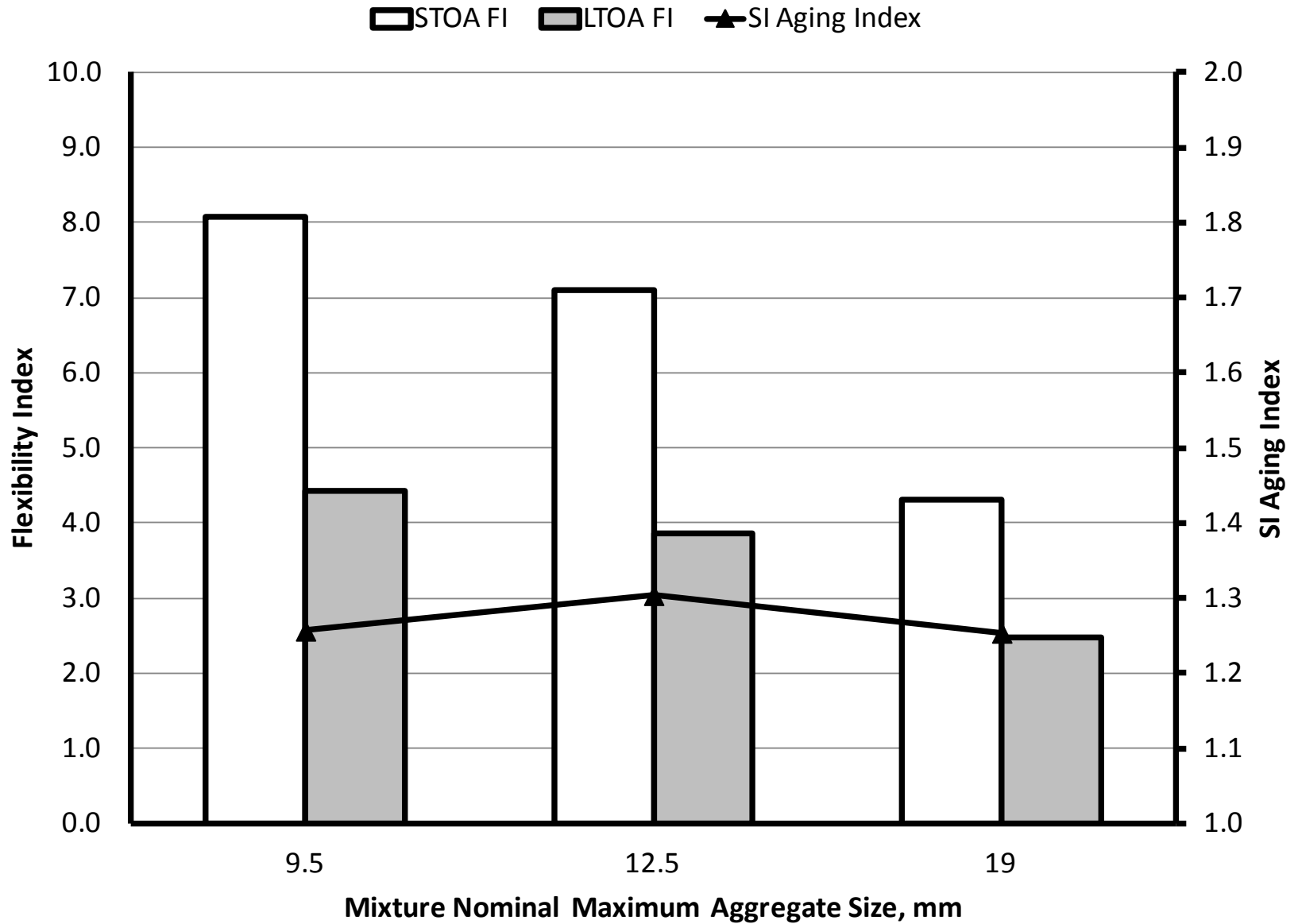


Mixtures

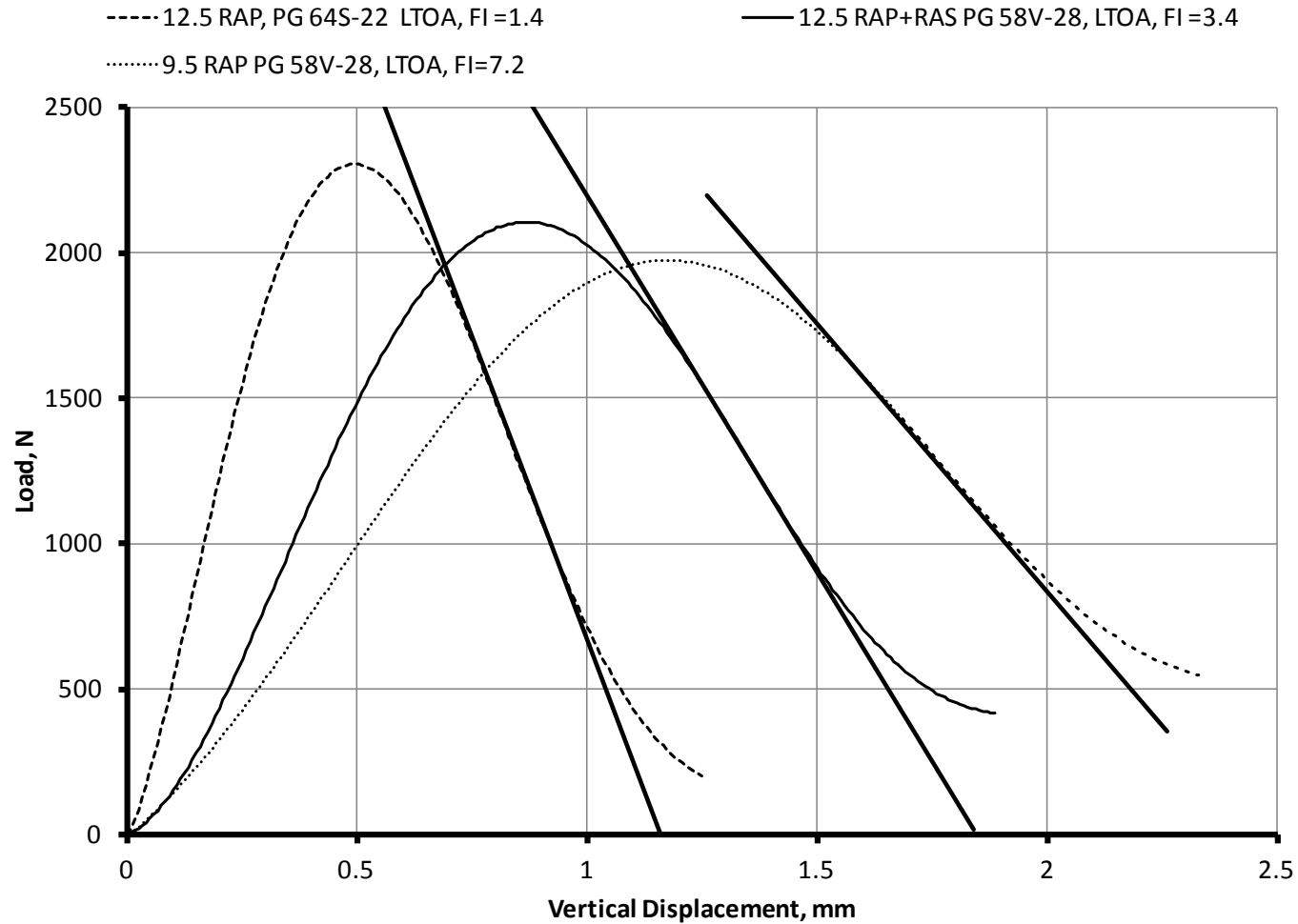
Type	Mix ID	Nom Max Size, mm	Binder Content, wt %	VBE, vol. %	RAP Binder ratio	RAS Binder ratio	Dust/Binder Ratio
Virgin	8	19.0	4.8	9.9	0	0	1.12
	2	12.5	5.7	11.6	0	0	0.86
	9	9.5	6.3	11.7	0	0	1.03
RAP	5	19.0	4.9	8.8	0.255	0	1.26
	6	12.5	5.4	10.5	0.186	0	0.99
	1	9.5	6.1	12.0	0.246	0	1.10
RAP + RAS	3	19.0	5.1	9.2	0.208	0.162	1.26
	7	12.5	5.8	12.3	0.119	0.158	0.96
	4	9.5	5.7	11.7	0.121	0.180	1.00



Effect of VBE



What is Changing?

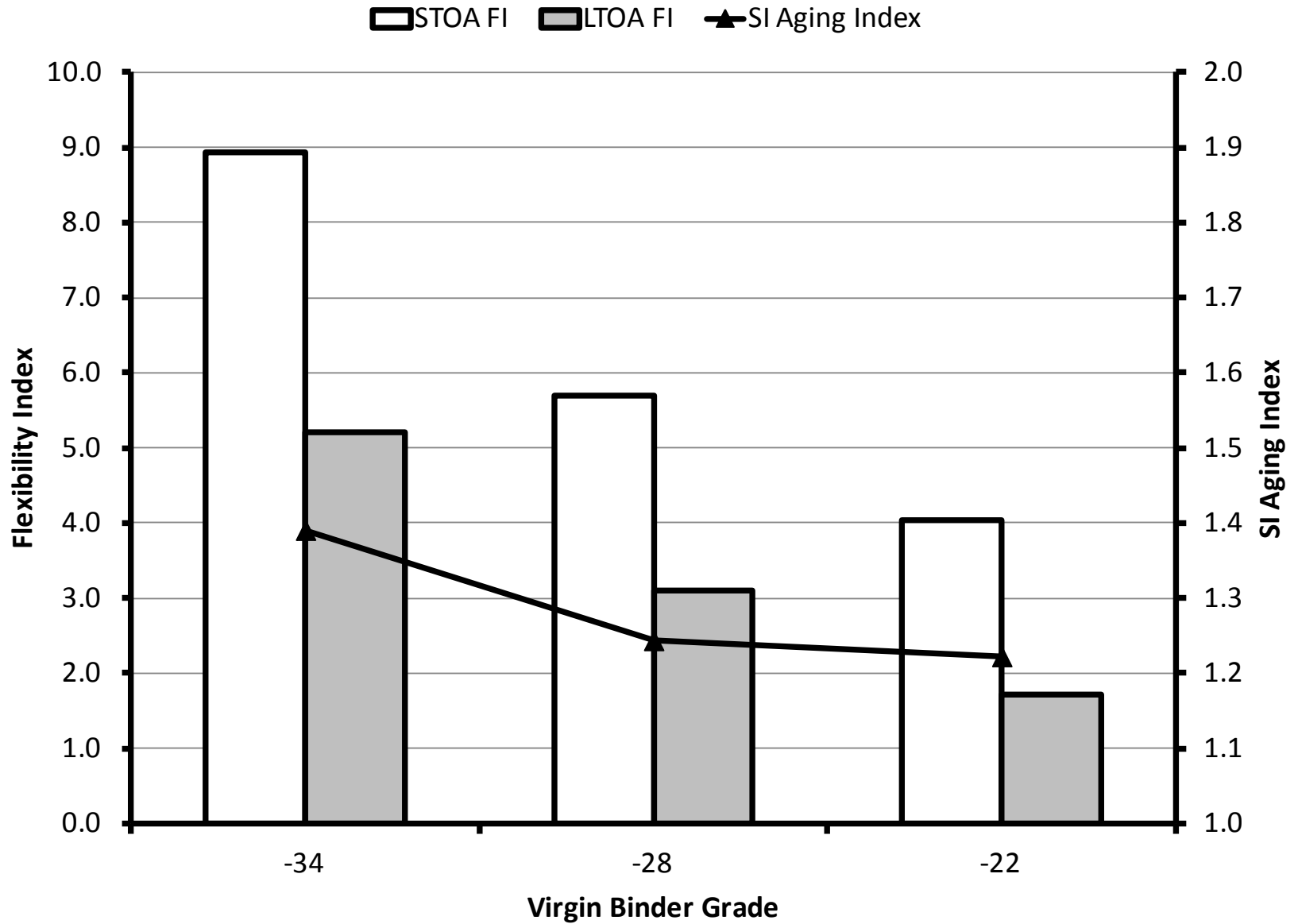


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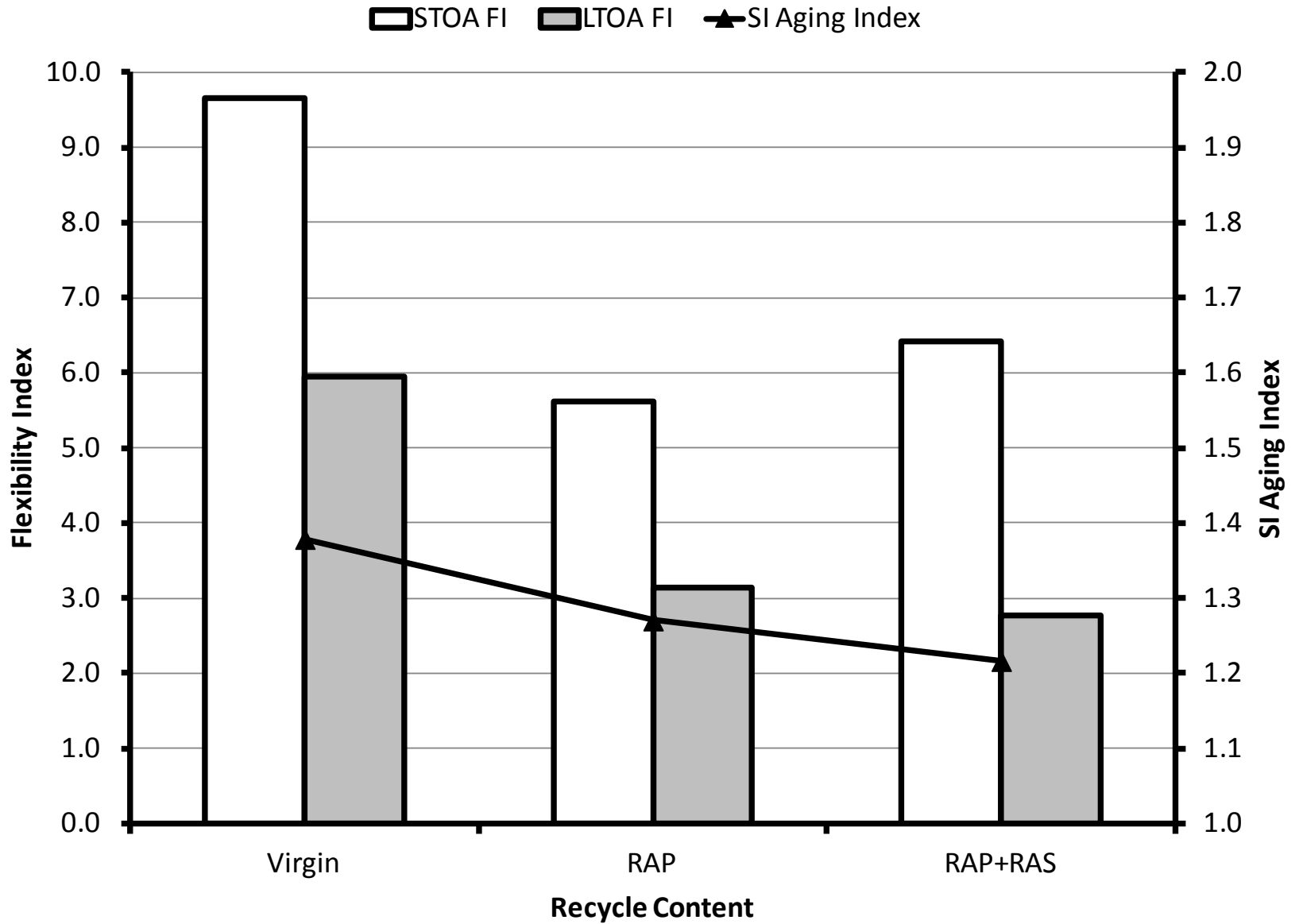


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Effect of Virgin Binder Grade

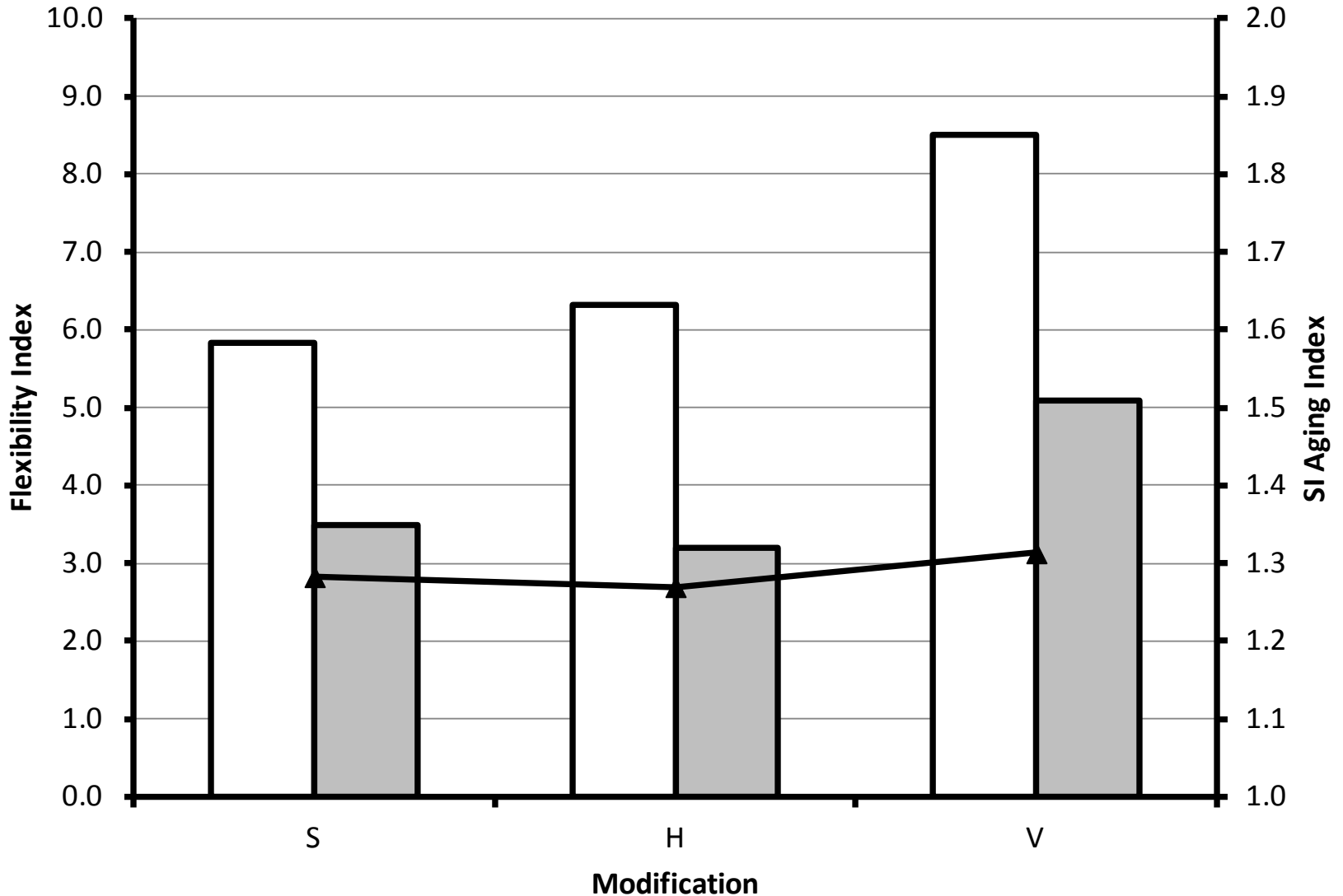


Effect of Recycled Binder



Effect of Polymer Modification

STOA FI LTOA FI SI Aging Index



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

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

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

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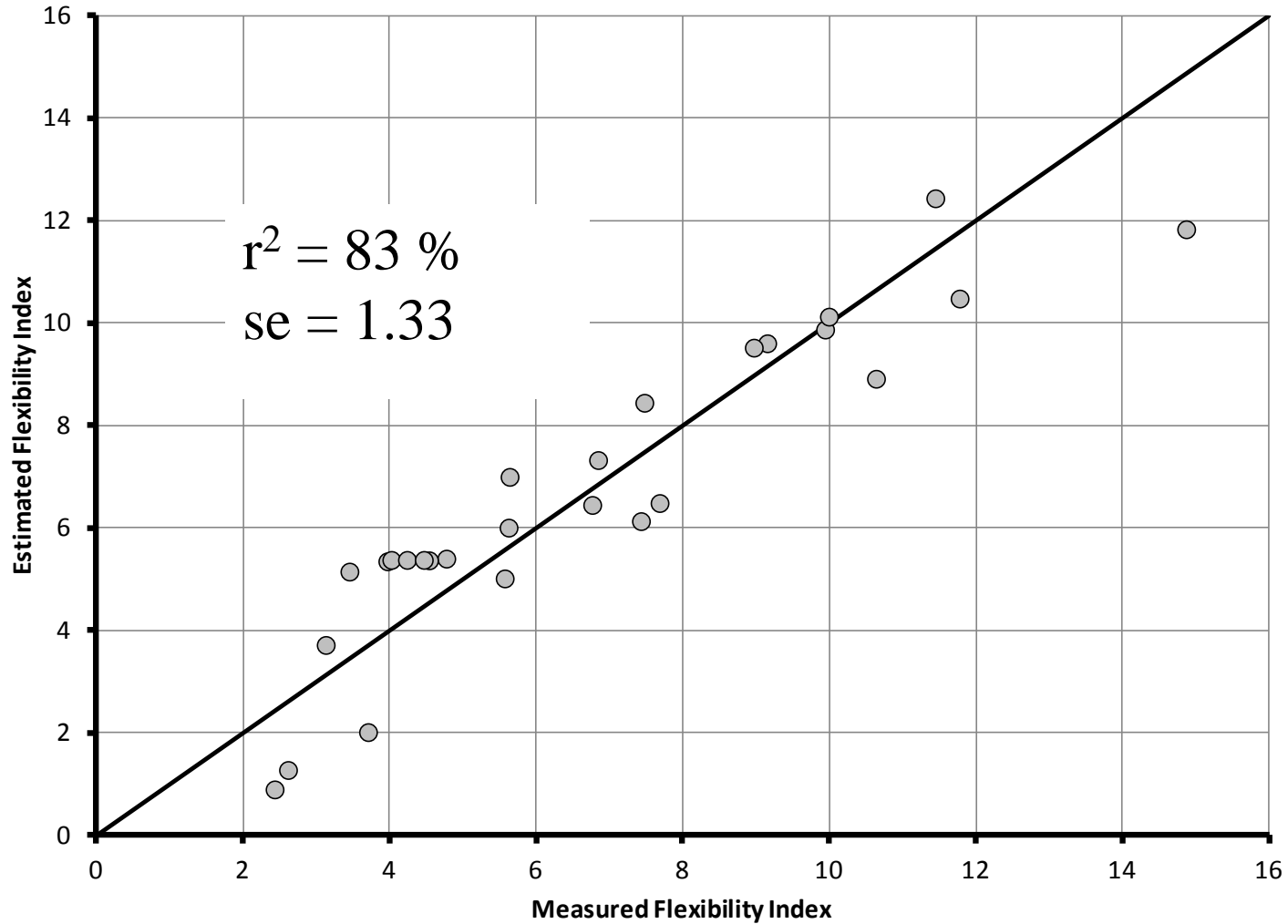
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Analysis of Coefficients

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



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Long-Term Aged Flexibility Index

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

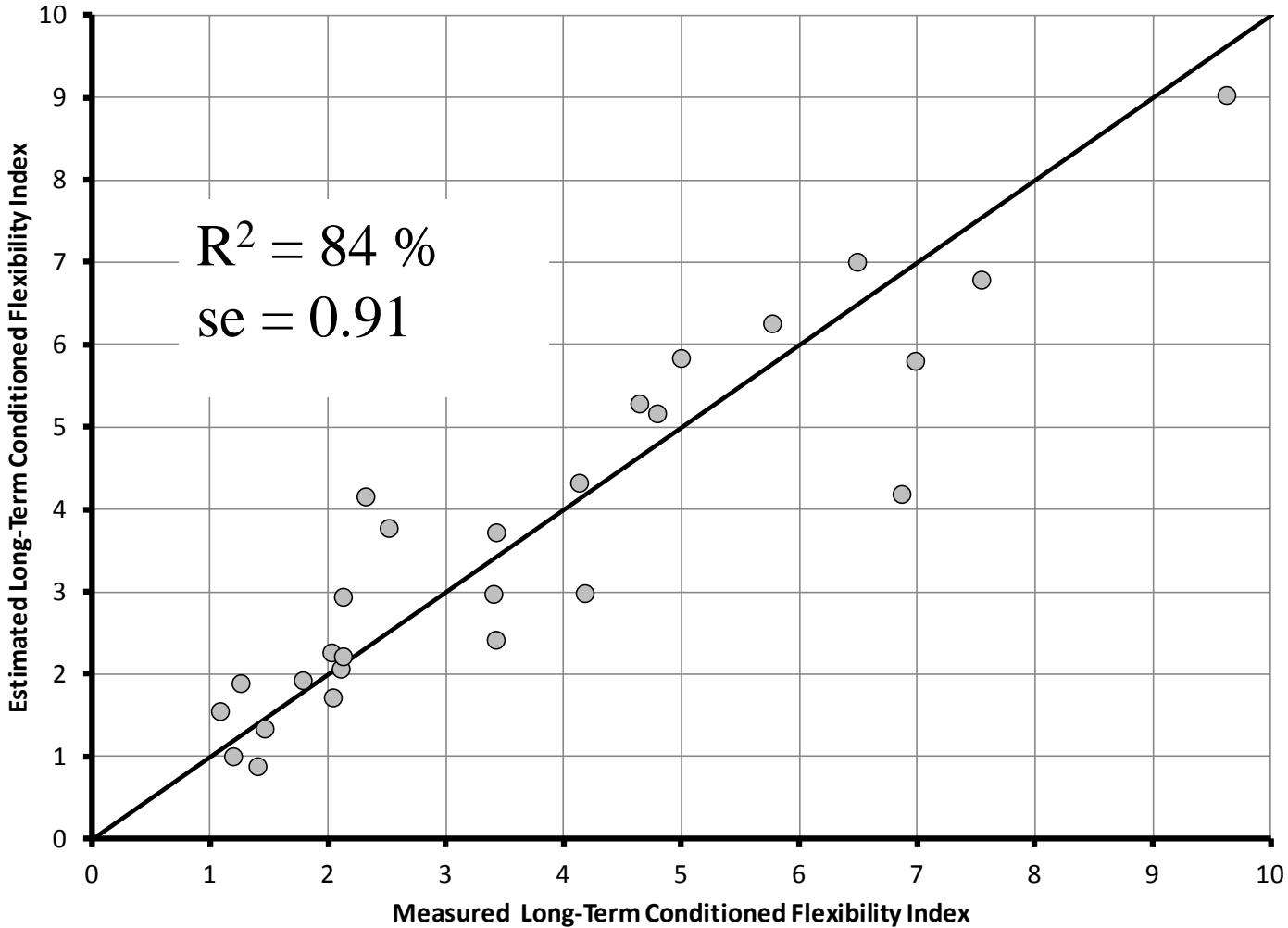
FI_{STOA}	FI_{LTOA}	FI_{LTOA}/FI_{STOA}
14.00	8.47	0.60
12.00	7.16	0.60
10.00	5.85	0.58
8.00	4.54	0.57
6.00	3.23	0.54
4.00	1.92	0.48
2.00	0.61	0.30

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Predicted vs Measured



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Example Design Specification

Effective RAP Binder Ratio	Minimum Design VBE, vol %							
	58-28 S	58-28 H	58-28 V	58-38 E	58-34 S	58-34 H	58-34 V	58-34 E
0.00	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
>0.00 ≤0.05	10.4	10.2	10.0	10.0	10.0	10.0	10.0	10.0
>0.05 ≤0.10	10.7	10.5	10.1	10.0	10.0	10.0	10.0	10.0
>0.10 ≤0.15	11.1	10.9	10.4	10.0	10.0	10.0	10.0	10.0
>0.15 ≤0.20	11.5	11.3	10.8	10.2	10.1	10.0	10.0	10.0
>0.20 ≤0.25	11.9	11.7	11.2	10.6	10.4	10.2	10.0	10.0
>0.25 ≤0.30	12.2	12.0	11.5	11.0	10.8	10.6	10.1	10.0
>0.30 ≤0.35	Low Temperature Grade Controls				11.2	11.0	10.5	10.0
>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

Discussion

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