

Effect of Polymer Modification on I-FIT Parameters

Andrew Hanz, MTE Services Inc.

FHWA Asphalt Binder ETG

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Acknowledgements

- MTE Services
 - Chad Lewis, Alex Engstler, Doug Herlitzka
- DuPont
 - CJ DuBois, Hal Panabaker

Background

- A request was made to a state agency to include Elvaloy Terpolymer on the approved products list.
- At the time this project began the I-FIT test was being used to evaluate new polymers.
 - FI Index > 8.0
 - Comparable to SBS formulation.
- Elvaloy Terpolymer is not a new product, it has been used in Wisconsin for over 20 years with proven field performance.

Experimental Plan

Factor	Levels	Description
Base Asphalt Grade	2	PG 58-28, MIA PG 64-22, MIA
SBS Polymer Type	1	Kraton 1184
Elvaloy [®] Terpolymer Type	2	5160, 5170
Formulations	4	Control – No Modification 5160 – Target 2 PG grade increase 5170 – Target 2 PG grade increase SBS – Target 2 PG grade increase

Summary of Blends

- Base Binder + 1.8% Elvaloy 5160 + 0.2% PPA (115%)
- Base Binder + 1.5% Elvaloy 5170 + 0.2% PPA (115%)
- Base Binder + 3.5% SBS 1184 + 0.2% BGA

Final Binder Properties

PG 64-22 Formulations

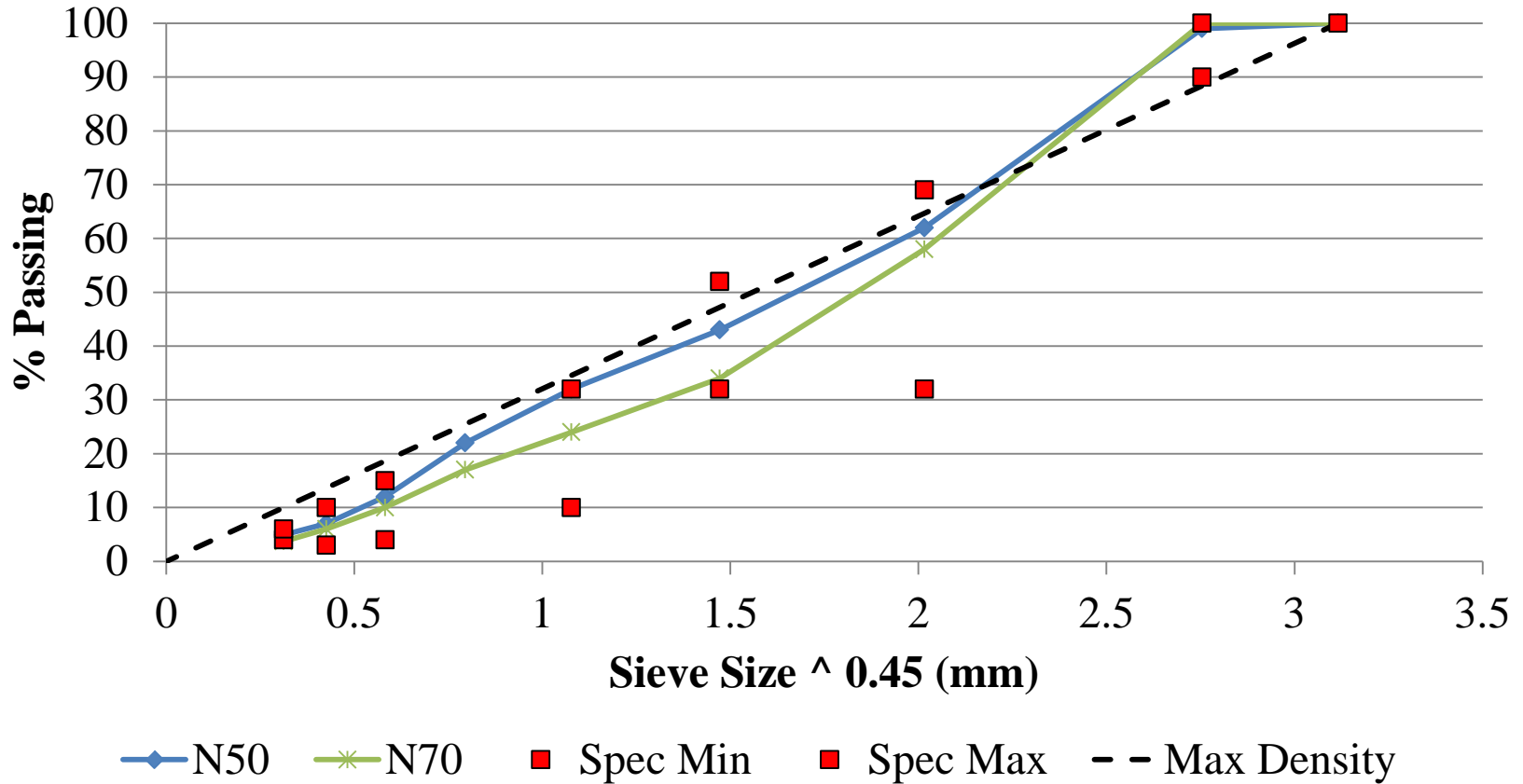
Parameter	Standard	Limit	Elvaloy 5160	Elvaloy 5170	SBS 1184
Tests on Original Binder					
HT Continuous Grade (Un-aged)	AASHTO M320	N/A	76.9	79.0	81.4
Force Ductility @4C, Force Ratio	AASHTO T300	>0.35	0.540	0.464	0.554
Toughness and Tenacity, Toughness, in-lbs	ASTM D5801	>110 (12.5)	272	225	397
Toughness and Tenacity, Tenacity, in-lbs		>75 (8.5)	235	182	344
Tests on RTFO Binder					
HT Continuous Grade (RTFO)	AASHTO M320	N/A	77.7	78.7	80.4
Elastic Recovery @ 25°C	ASTM D6084 (Proc. A)	>70	70.5%	73.0%	81.3

Final Binder Properties

PG 58-28 Formulations

Parameter	Standard	Limit	Elvaloy 5160	Elvaloy 5170	SBS 1184
Tests on Original Binder					
HT Continuous Grade (Un-aged)	AASHTO M320	N/A	71.9	73.6	74.3
Force Ductility @4C, Ductility Ratio	AASHTO T300	>0.35	0.727	0.791	0.572
Toughness and Tenacity, Toughness, in-lbs	ASTM D5801	>110 (12.5)	272	137	332
Toughness and Tenacity, Tenacity, in-lbs		>75 (8.5)	151	127	315
Tests on RTFO Residue					
HT Continuous Grade (RTFO)	AASHTO M320	N/A	72.9	74.1	73.2
Elastic Recovery @ 25°C	ASTM D6084 (Proc. A)	>70	75.0%	77.5%	85.0%

Mix Designs



- N50 and N70 correspond to the design gyration level.
- Same virgin aggregates.

Mix Designs

RAP/RAS Content & Volumetrics

Mix Design	AB (%)	%AV at Ndes	VMA	VFA	RCY AB (%)			ABR		
					RAP	RAS	Total	RAP	RAS	Total
N50	5.8	3.6	15.1	73.5	1.2	0.8	2.00	20.3	14.0	34.3
N70	5.9	3.5	15.3	73.9	0.6	0.0	0.6	9.6	0	9.6

Differences

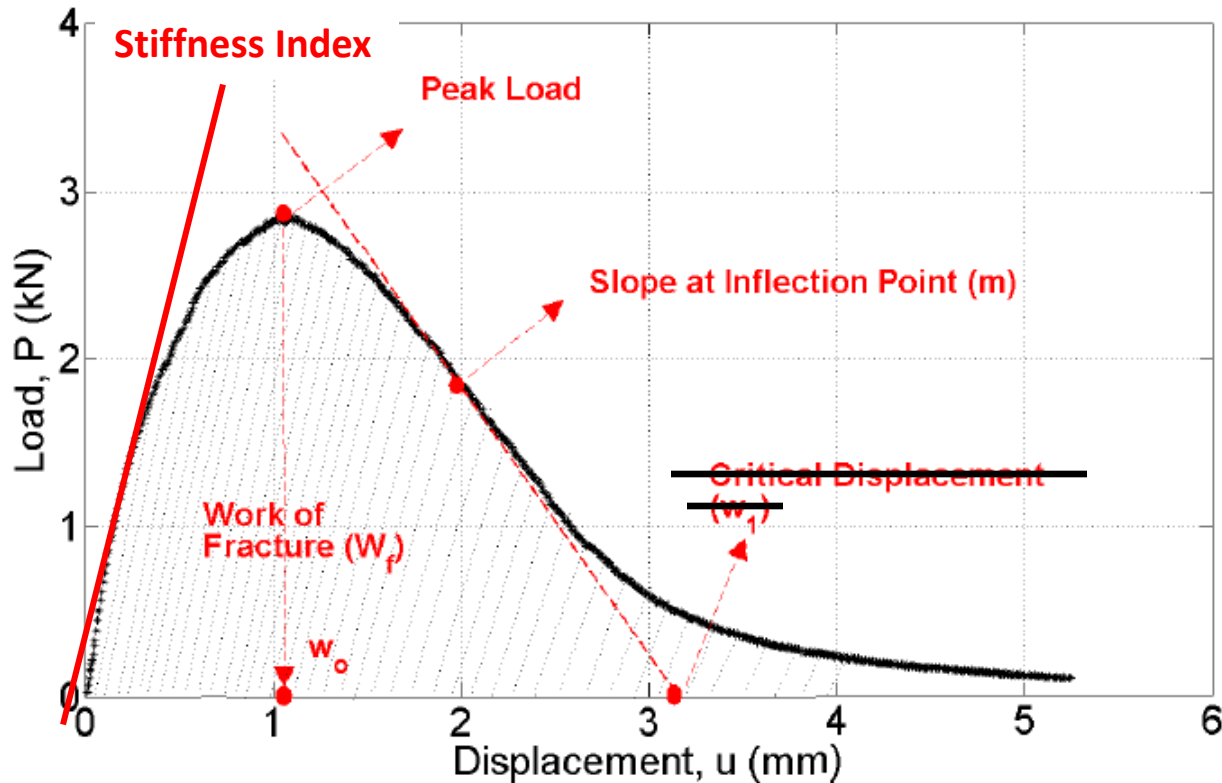
- Aggregate structure
- Recycled products and ABR values for mix designs:
 - N50 has 34% PBR, 40% of the binder replacement is from RAS.

Sample Preparation and Conditioning

1. One hour conditioning at 146°C (unmodified) and 152°C (modified).
 - Conditioning time set by agency for aggregates with absorption < 1.5%.
2. 160 mm samples compacted to 7.5% AV target.
3. SCB samples take from center of sample. Target AV for test samples = 7.0%.

I-FIT Test (TP 124)

Outputs used in Analysis



Flexibility Index

$$FI = \frac{G_f}{m} \times A$$

G_f = Fracture Energy

m = Post-Peak Slope

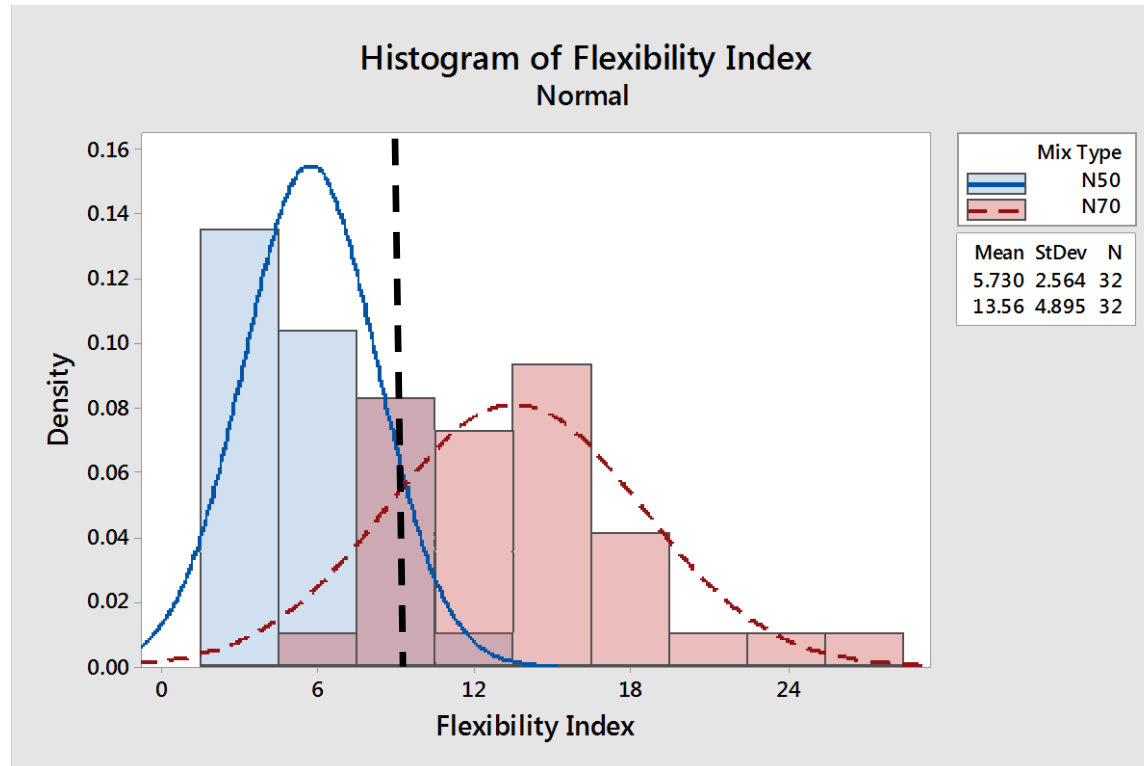
A = Scaling Factor

Stiffness Index: Slope of the load vs. displacement curve at 50% Peak Load.

Did not use critical displacement value in analysis.

Results

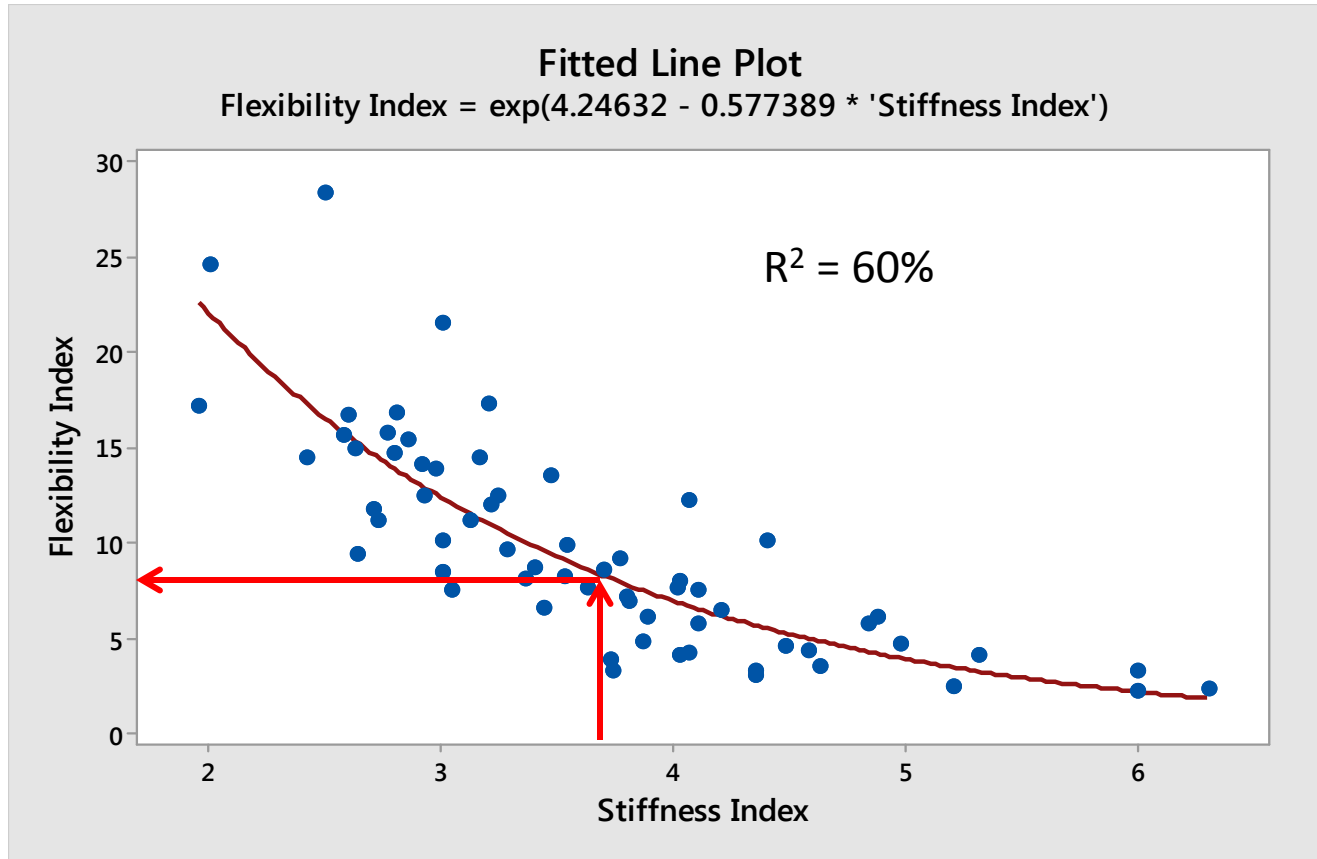
N50 & N70 Designs – Flexibility Index



- Includes unmodified and modified binders using both PG 58-28 and PG 64-22 base grades.
- N50: Narrow distribution, meaning with higher RBR there is not many opportunities to improve Flexibility Index. Even with softer grade majority of FI values < 8.0.
- N70: More broad distribution reflective of change in base grades.

Results

Stiffness Index vs. Flexibility Index



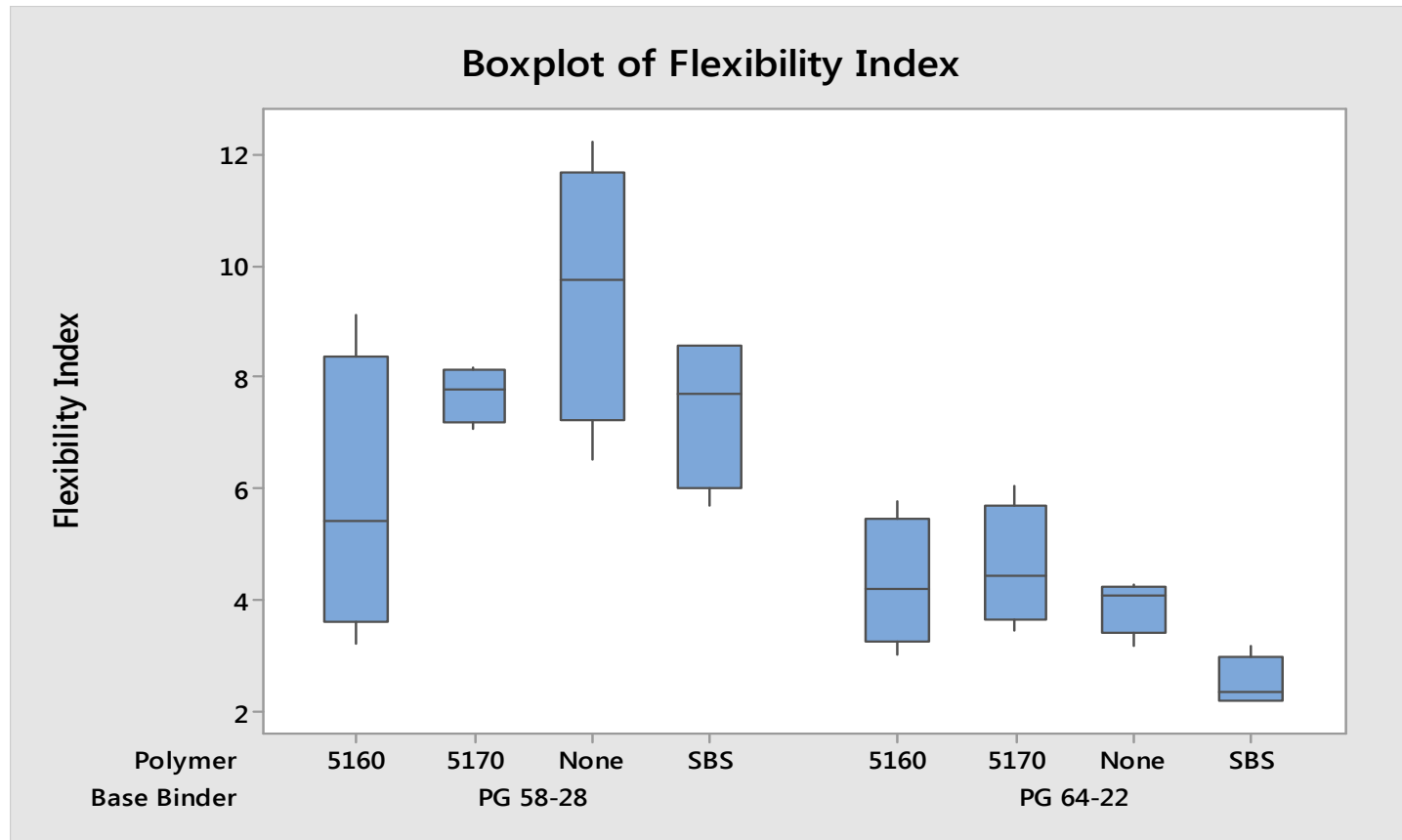
- At Stiffness Index > 4.0 kN/mm mixes did not meet the FI > 8.0 threshold and FI values are generally near or below 5.0.
- Due to relationship with stiffness N50 and N70 designs were analyzed separately.

Results – Basic Statistics

Mix	Binder	N	Mean	SE Mean	St Dev	Min	Max	Range
Flexibility Index								
N50	PG 58-28	16	7.6	0.54	2.16	3.2	12.2	9.0
	PG 64-22	16	3.8	0.28	1.13	2.2	6.1	3.9
N70	PG 58-28	16	16.6	1.14	4.55	11.2	28.3	17.1
	PG 64-22	16	10.5	0.77	3.07	6.4	17.2	10.8
Post-Peak Slope (kN/mm)								
N50	PG 58-28	16	-2.6	0.19	0.75	-4.9	-1.5	3.4
	PG 64-22	16	-5.5	0.35	1.39	-8.3	-3.3	5.0
N70	PG 58-28	16	-1.2	0.06	0.24	-1.7	-0.7	1.0
	PG 64-22	16	-2.5	0.17	0.70	-3.6	-1.5	2.1
Fracture Energy (J/m²)								
N50	PG 58-28	16	1857	47.4	189.7	1587	2167	580
	PG 64-22	16	1973	42.3	169.3	1600	2234	634
N70	PG 58-28	16	1873	40.6	162.5	1565	2079	514
	PG 64-22	16	2485	58.1	232.5	2107	2895	788
Stiffness Index (kN/mm)								
N50	PG 58-28	16	3.7	0.10	0.40	2.6	4.1	1.5
	PG 64-22	16	4.9	0.19	0.75	3.7	6.3	2.6
N70	PG 58-28	16	2.7	0.09	0.34	2.0	3.2	1.3
	PG 64-22	16	3.4	0.12	0.48	2.7	4.4	1.7

Results

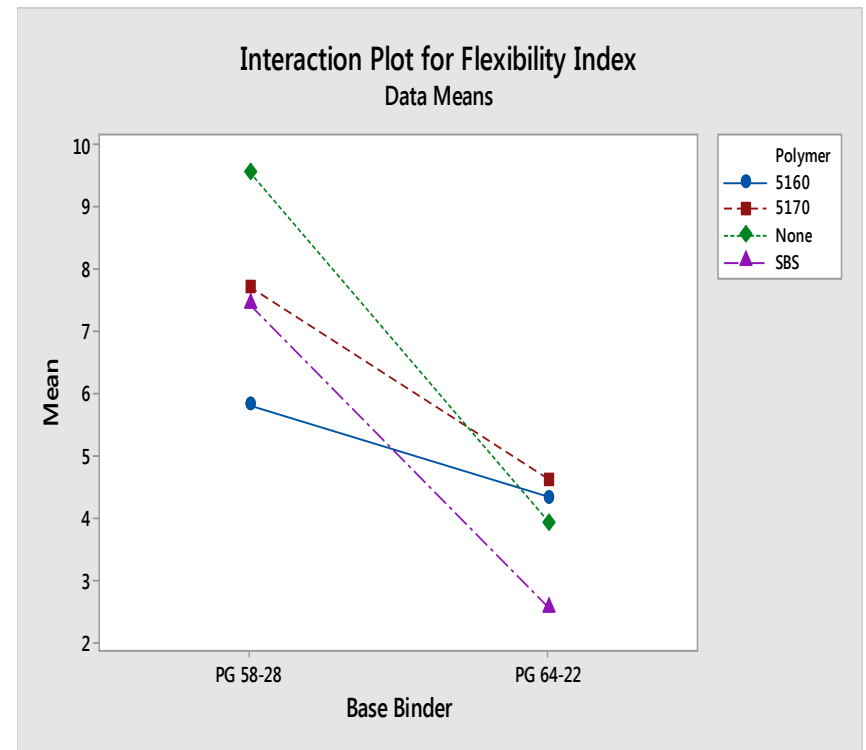
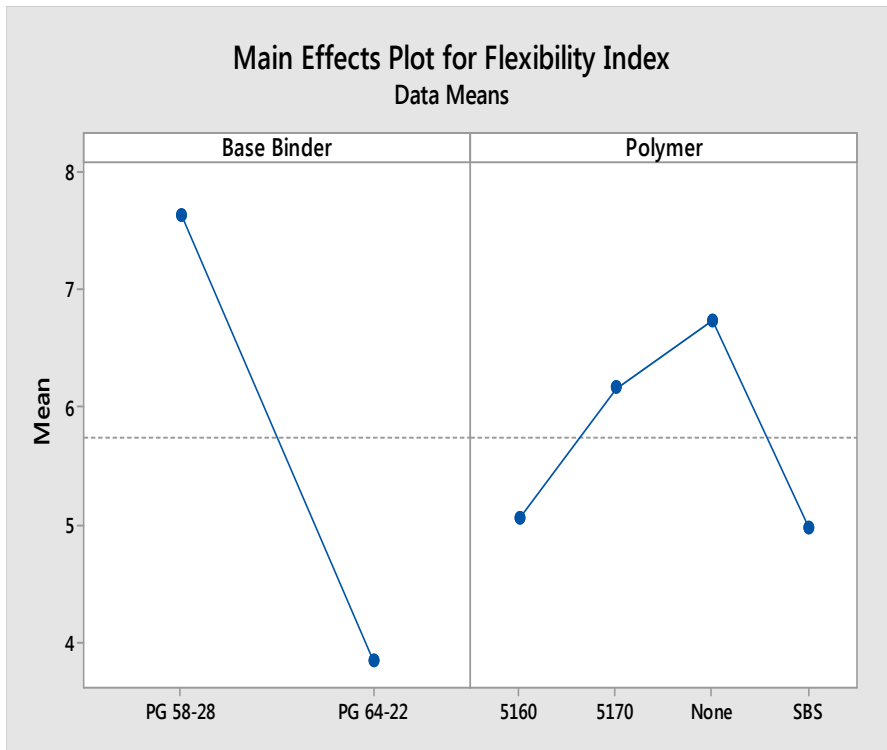
N50 Design



High variability observed for some of the PG 58-28 samples.

Results N50 Design

Main Effects and Interaction Plots



- Effect of base binder (stiffness) approximately double than the modification.
- Unmodified materials performed as well or better than PMAs with both polymer types.
- Ranking of binder modifications changed with base binder.

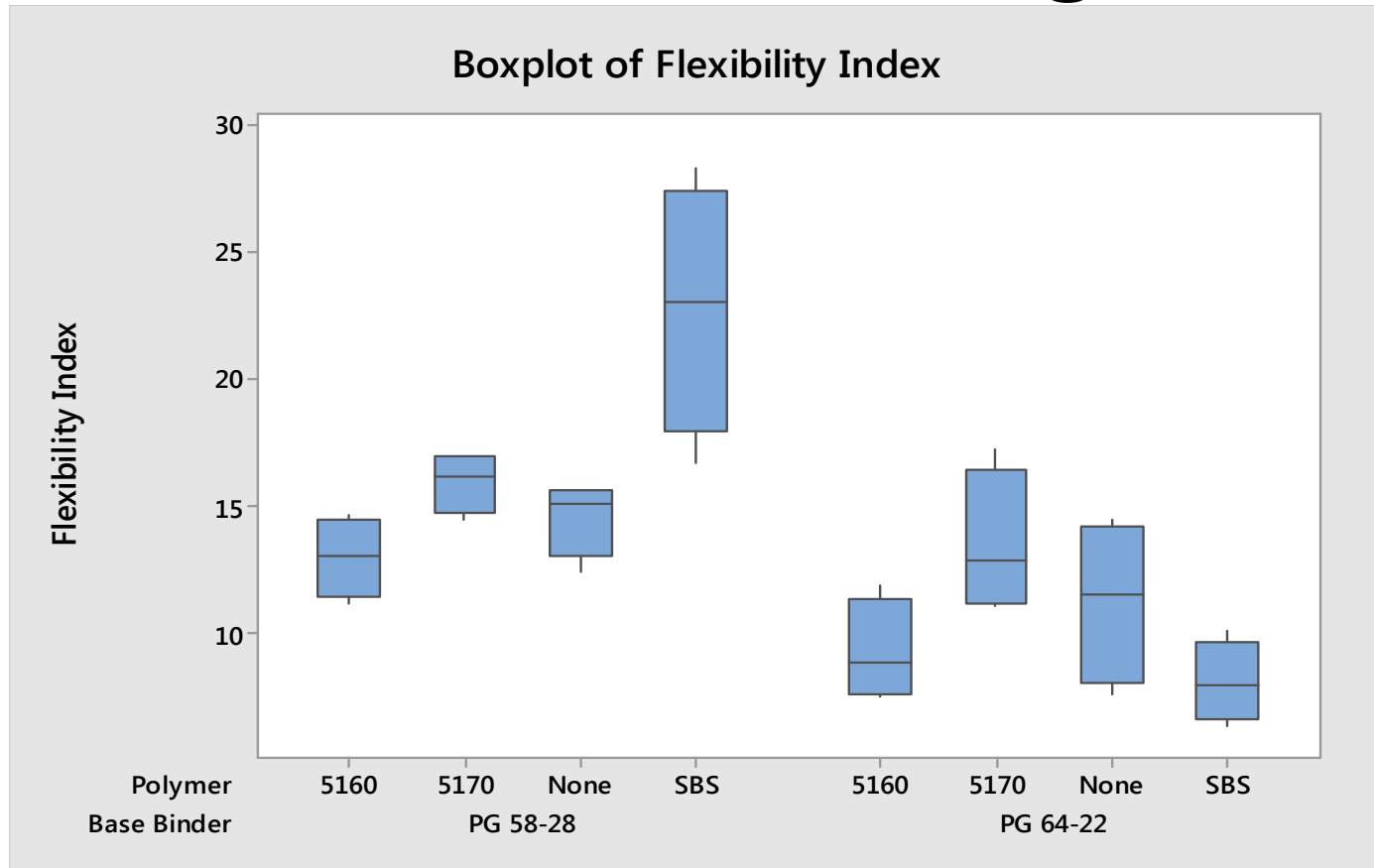
Results N50 Design

Binder*Polymer Comparisons

Base Binder * Polymer	N	Mean	Grouping				
PG 58-28, None	4	9.55	A				
PG 58-28, 5170	4	7.70	A	B			
PG 58-28, SBS	4	7.42	A	B	C		
PG 58-28, 5160	4	5.81		B	C	D	
PG 64-22, 5170	4	4.60		B	C	D	E
PG 64-22, 5160	4	4.31			C	D	E
PG 64-22, None	4	3.91				D	E
PG 64-22, SBS	4	2.52					E

- Only two mixes did not share a grouping that included both PG 58-28 and PG 64-22 base binders.
- The best performing material was also the softest.
- Range in FI values for PG 58-28 was approximately double PG 64-22.

Results N70 Design

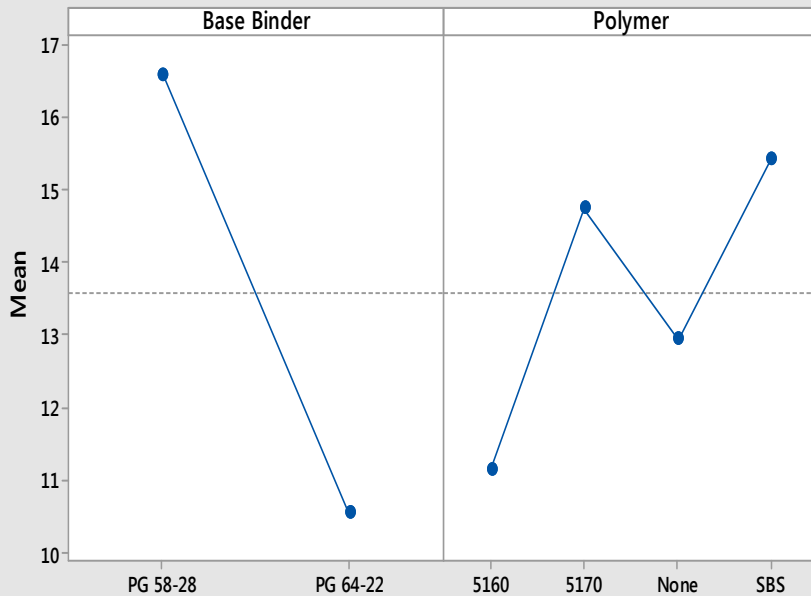


- Effect of binder replacement: All values are higher than the N50 design by a factor of 2-3.
- N70, PG 58-28 + SBS was the only mix/binder formulation significantly different than the control. High variability was observed for combination.

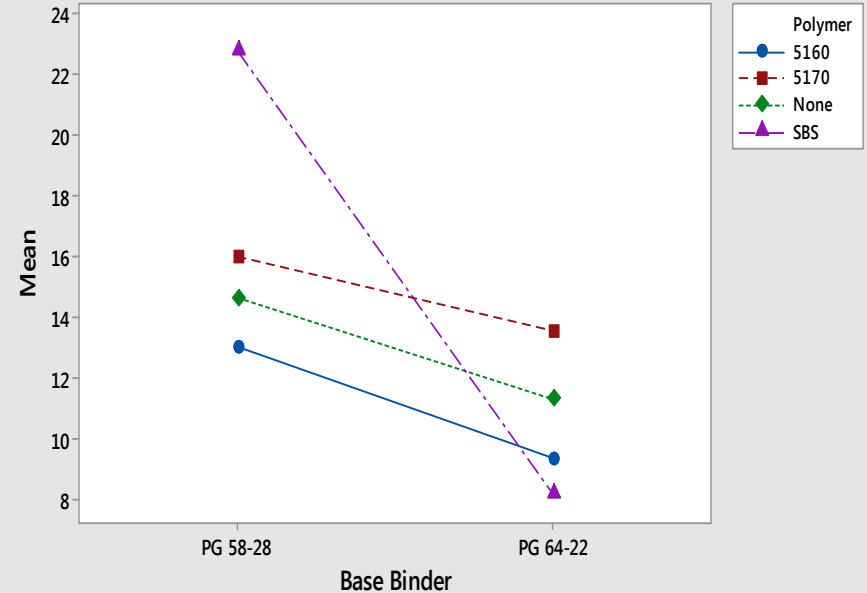
Results N70 Design

Main Effects and Interaction Plots

Main Effects Plot for Flexibility Index
Data Means



Interaction Plot for Flexibility Index
Data Means



- Trends similar to N50 design, varying effects of polymer relative to control.
- Elvaloy materials are centered by the control, variation in FI is +/-2.
- Further review of SBS data needed, inconsistent trends with binder grade.

Results N70 Design

Binder*Polymer Comparisons

Base Binder * Polymer	N	Mean	Grouping			
PG 58-28, SBS	4	22.75	A			
PG 58-28, 5170	4	15.95		B		
PG 58-28, None	4	14.59		B	C	
PG 58-28, 5160	4	13.00		B	C	D
PG 64-22, 5170	4	13.52		B	C	D
PG 64-22, None	4	11.27		B	C	D
PG 64-22, 5160	4	9.30			C	D
PG 64-22, SBS	4	8.1				D

- Results similar to the N50 mix design, had a grouping that did not cross base both base binders.
- The test did also not discriminate between use of a PG 58-28 or a PG 64-22. Due to the low ABR and low %RAP both mixes had sufficient stiffness to pass FI.
- All mixes pass the FI > 8.0 criterion.

Discussion

- Sole use of Flexibility Index was not able to discriminate between polymer presence or polymer type.
- Other outputs of the test were investigated based on statistical analysis the following were selected:
 - Post-Peak Slope
 - Stiffness Index
 - Peak Load
- Fracture energy: Omitted because effect of polymer wasn't significant.

Results

Other Test Parameters

N50 Design

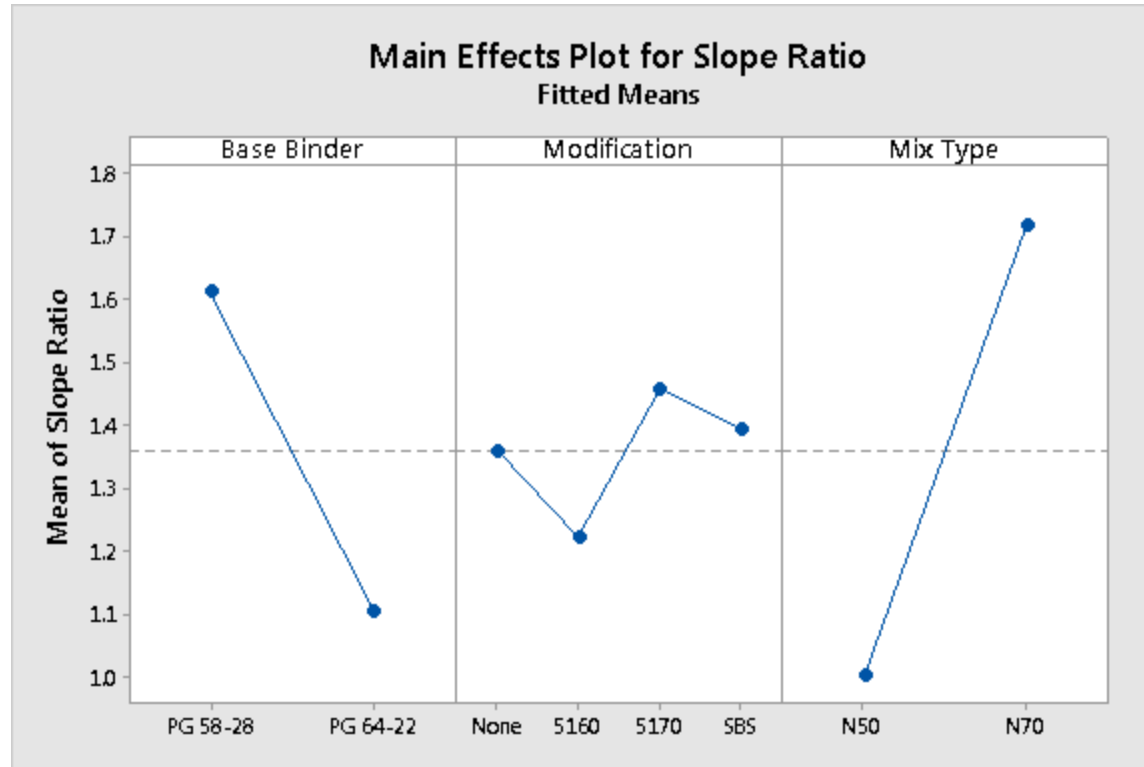
Factor	DOF	Post-Peak Slope (kN/mm)		Stiffness Index (kN/mm)		Peak Load	
		F-Value	P-Value	F-Value	P-Value	F-Value	P-Value
Polymer	3	5.91	0.004	6.96	0.002	0.28	0.839
Base Binder	1	104.8	<0.000	64.85	<0.000	50.8	<0.000
Replicates	3	0.82	0.495	1.23	0.325	0.95	0.433
Polymer*Base Binder	2	6.04	0.004	5.66	0.005	0.53	0.668
R ² (adj)		81.1%		75.7%		59.8%	

N70 Design

Factor	DOF	Post-Peak Slope (kN/mm)		Stiffness Index (kN//mm)		Peak Load (kN)	
		F-Value	P-Value	F-Value	P-Value	F-Value	P-Value
Polymer	2	6.21	0.003	4.27	0.017	18.6	<0.000
Base Binder	1	137.62	<0.000	44.90	<0.000	602.16	<0.000
Replicates	3	1.64	0.211	2.65	0.075	2.63	0.077
Polymer*Base Binder	2	10.97	<0.000	4.60	0.013	20.64	<0.000
R ² (adj)		85.6%		69.1%		95.9%	

Results

Initial Review of Slope Ratio



- Slope ratio = Stiffness Index/Post Peak Slope.
- Identifies increased mix stiffness due to base binder grade or increase in ABR.
- Not sensitive to modification.

Summary of Study

1. Successful in differentiating between mixes based on stiffness.
 - Beneficial to ABR or base binder grade selection.
2. Did not identify the effect of polymer or differentiate between polymer types.
 - Competing mechanisms of stiffening and increased elasticity with polymer modification.
 - The benefits of polymer modification on cracking resistance are well known.

Discussion on I-FIT

- Possible adjustments to evaluate polymer effects.
 - Analysis of additional test parameters.
 - Modify loading rate or test temp.
- Concerns with Aging
 - AASHTO R30 recommends 4 hours at 135°C, this uses 1 or 2 based on aggregate absorption.
 - As stiffness increases the range in possible FI values decreases. The relationship is exponential.
 - Can results after 1 hour aging be extrapolated to long-term cracking performance?
- Agree with the need for use in a balanced mix design approach to prevent selection of soft materials.

Thank You

Andrew Hanz, Ph.D.

Technical Director

MTE Services Inc.

608-779-6352 (office)

608-780-2509 (mobile)

andrew.hanz@mteservices.com

There is a full report of results available upon request.