Effect of Polymer Modification on I-FIT Parameters

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FHWA Asphalt Binder ETG

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Acknowledgements

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  - 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

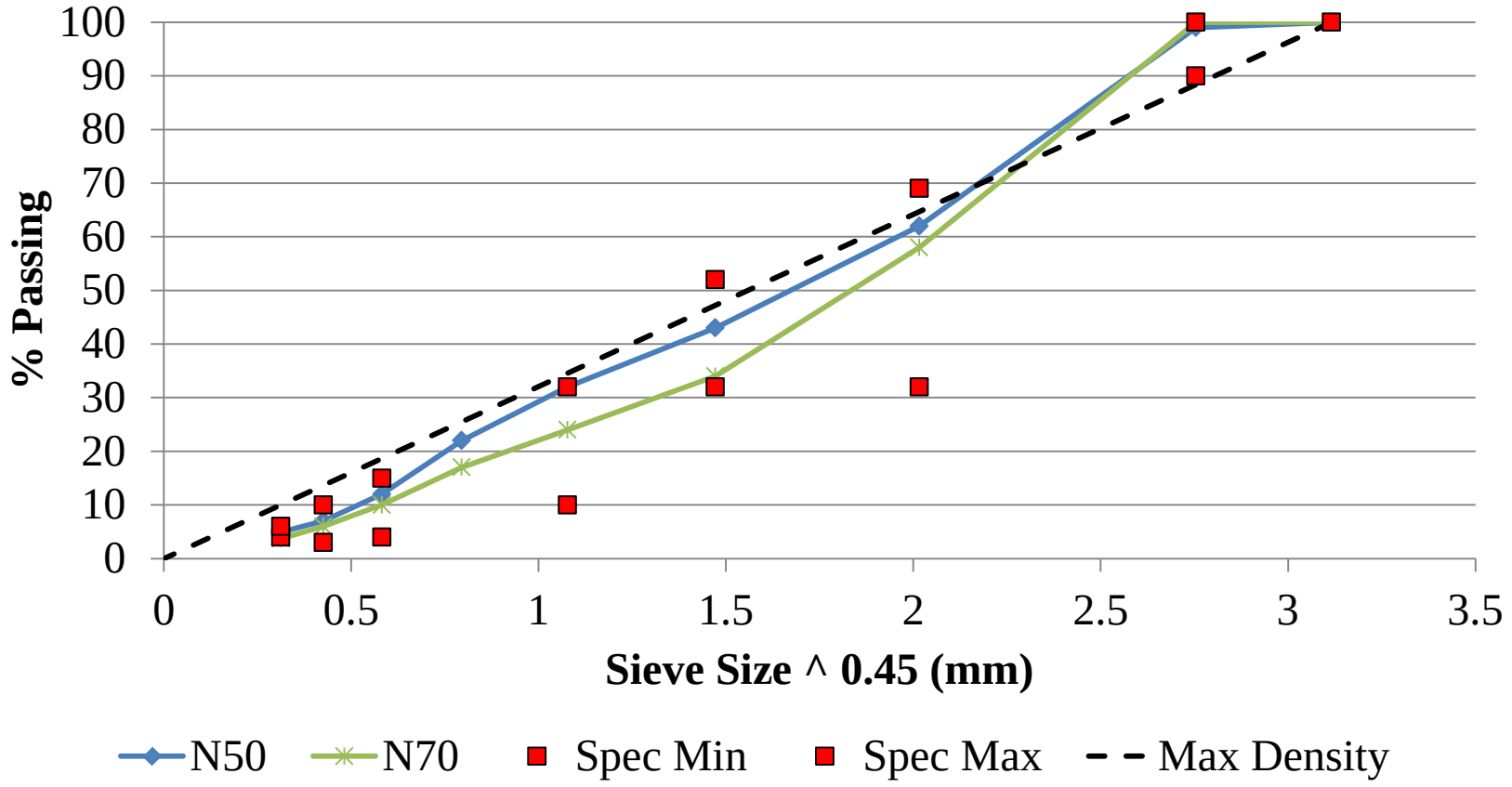
Parameter	Standard	Limit	Elvaloy 5160	Elvaloy 5170	SBS 1184
Tests on Original Binder					
HT Continuous Grade (Un-aged)	AASHTO M320	N/A	76.9	79.0	81.4
Force Ductility @4C, Force Ratio	AASHTO T300	>0.35	0.540	0.464	0.554
Toughness and Tenacity, Toughness, in-lbs	ASTM D5801	>110 (12.5)	272	225	397
Toughness 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

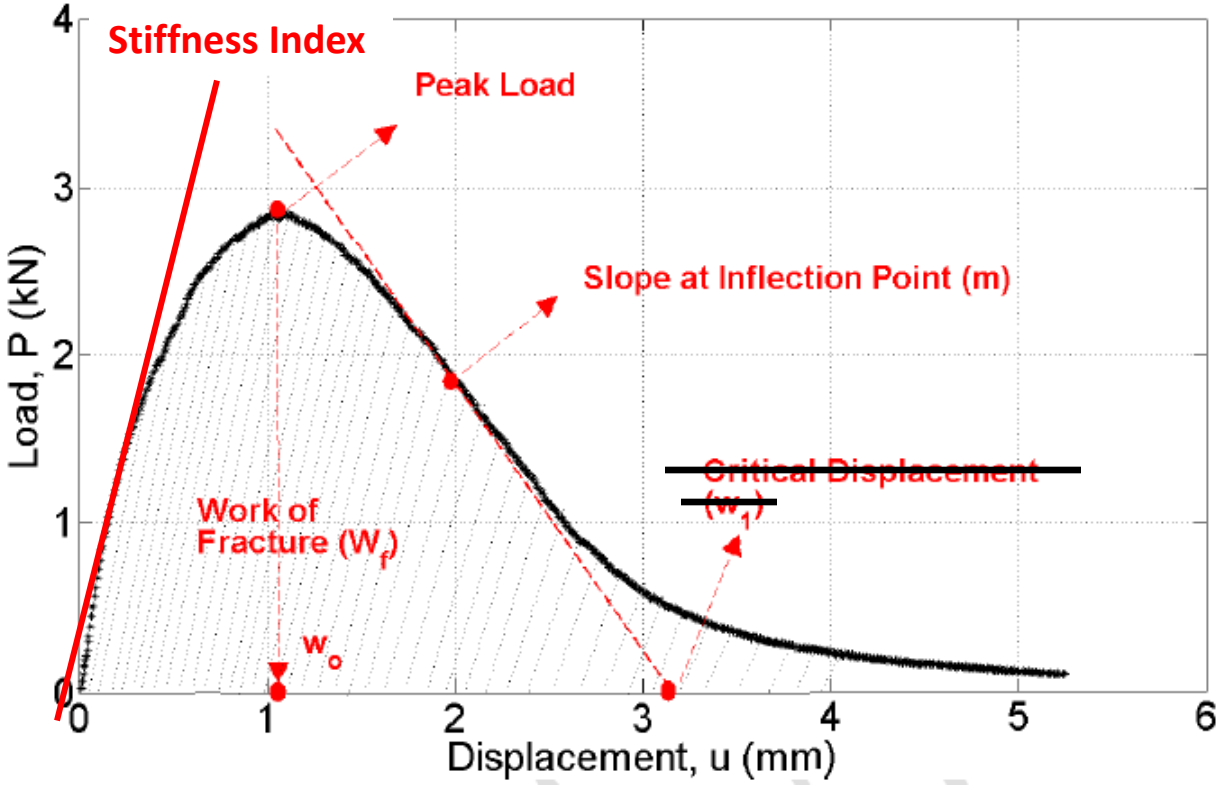
- Aggregate structure
- Recycled products and ABR values for mix designs:
  - N50 has 34% PBR, 40% of the binder replacement is from RAS.

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

$$FI = \frac{G_f}{m} \text{ x A}$$

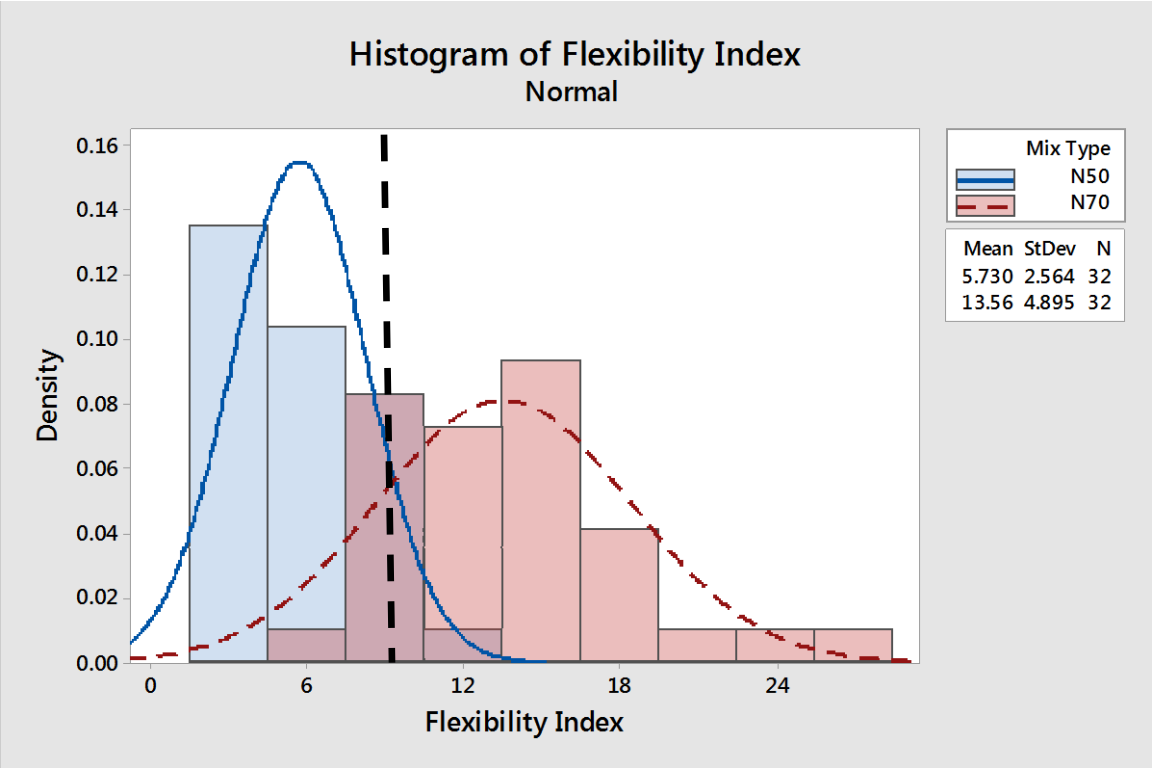
G_f = Fracture Energy
m = Post-Peak Slope
A= Scaling Factor

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

Did not use critical displacement value in analysis.

Results

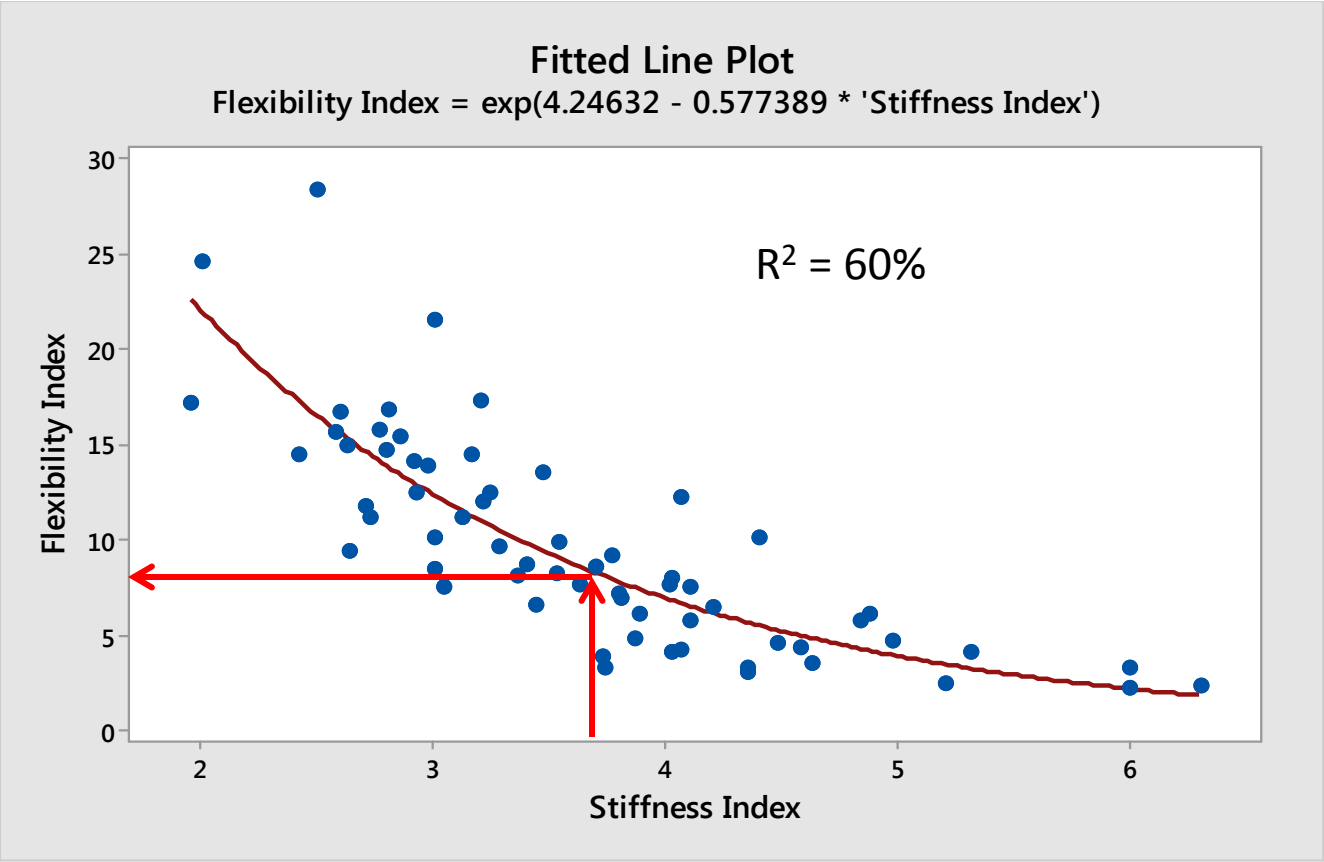
N50 & N70 Designs – Flexibility Index



- 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



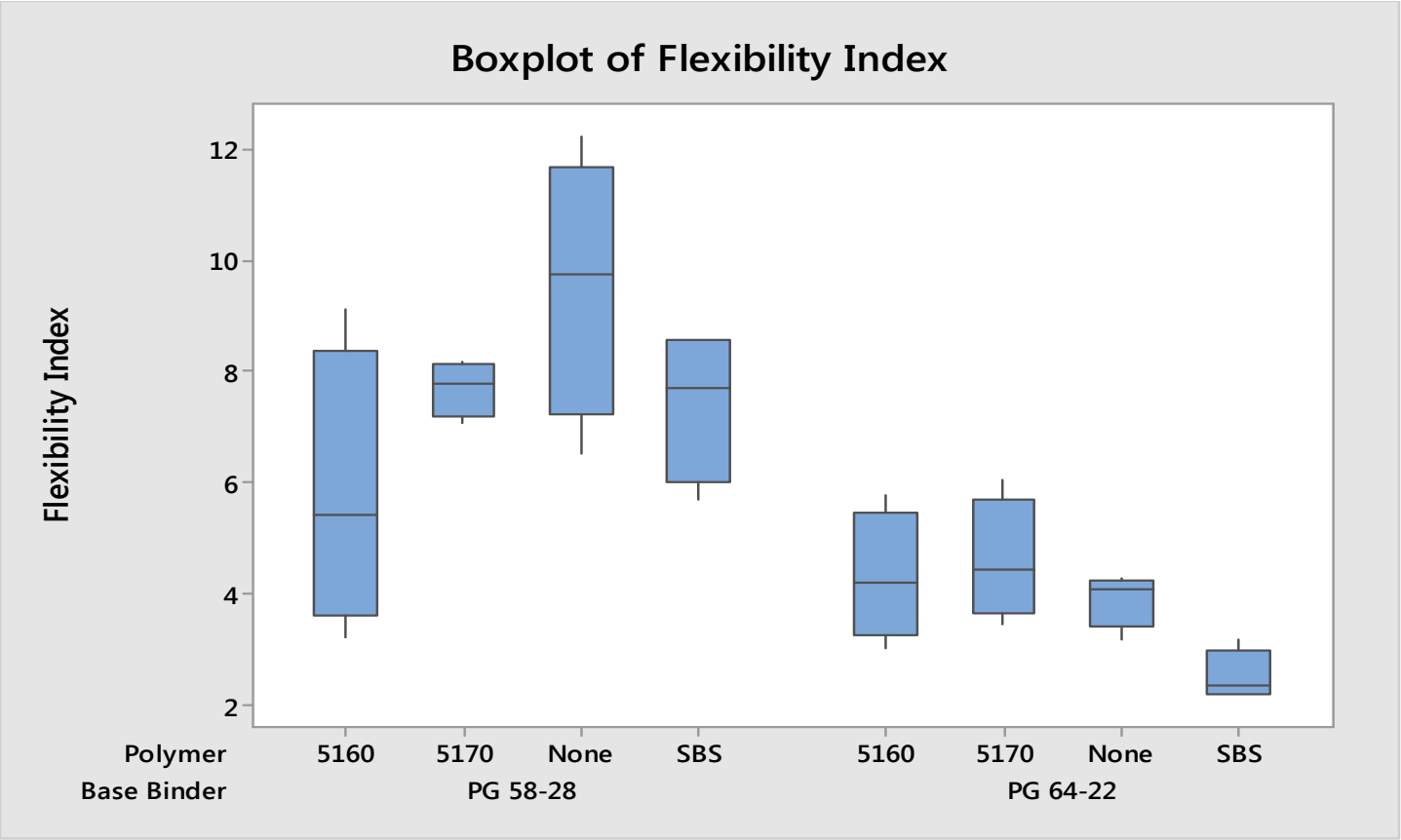
- At Stiffness Index > 4.0 kN/mm mixes did not meet the FI > 8.0 threshold and FI values are generally near or below 5.0.
- Due to relationship with stiffness N50 and N70 designs were analyzed separately.

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/m^2)								
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

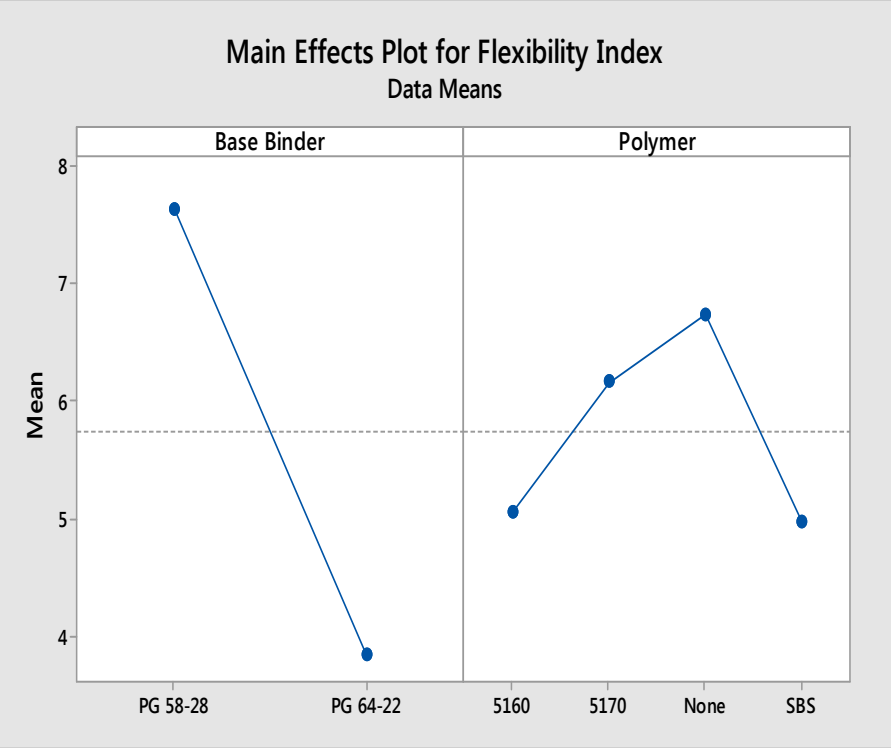
N50 Design

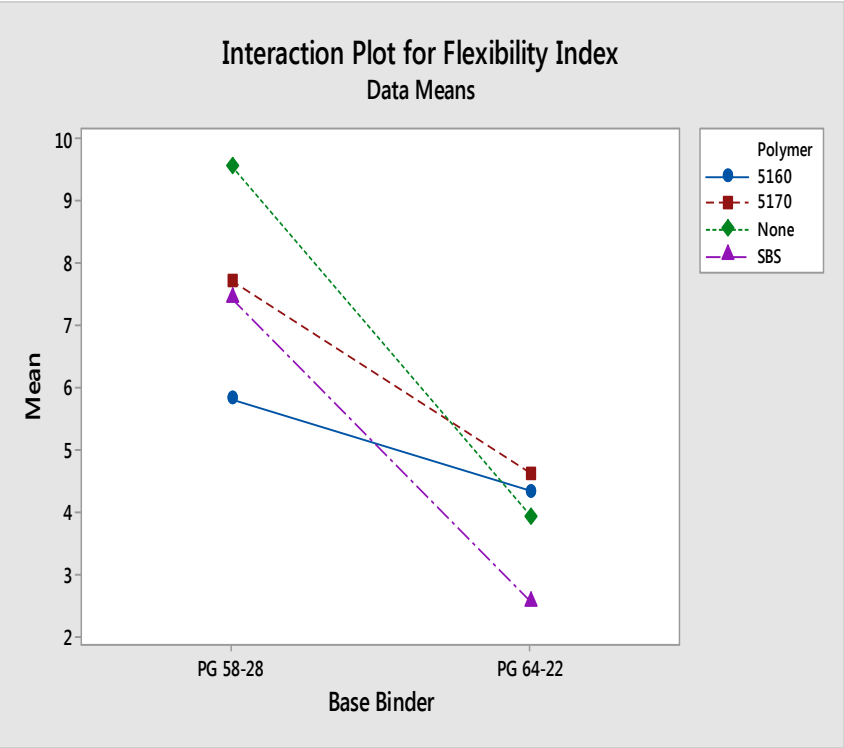


High variability observed for some of the PG 58-28 samples.

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.

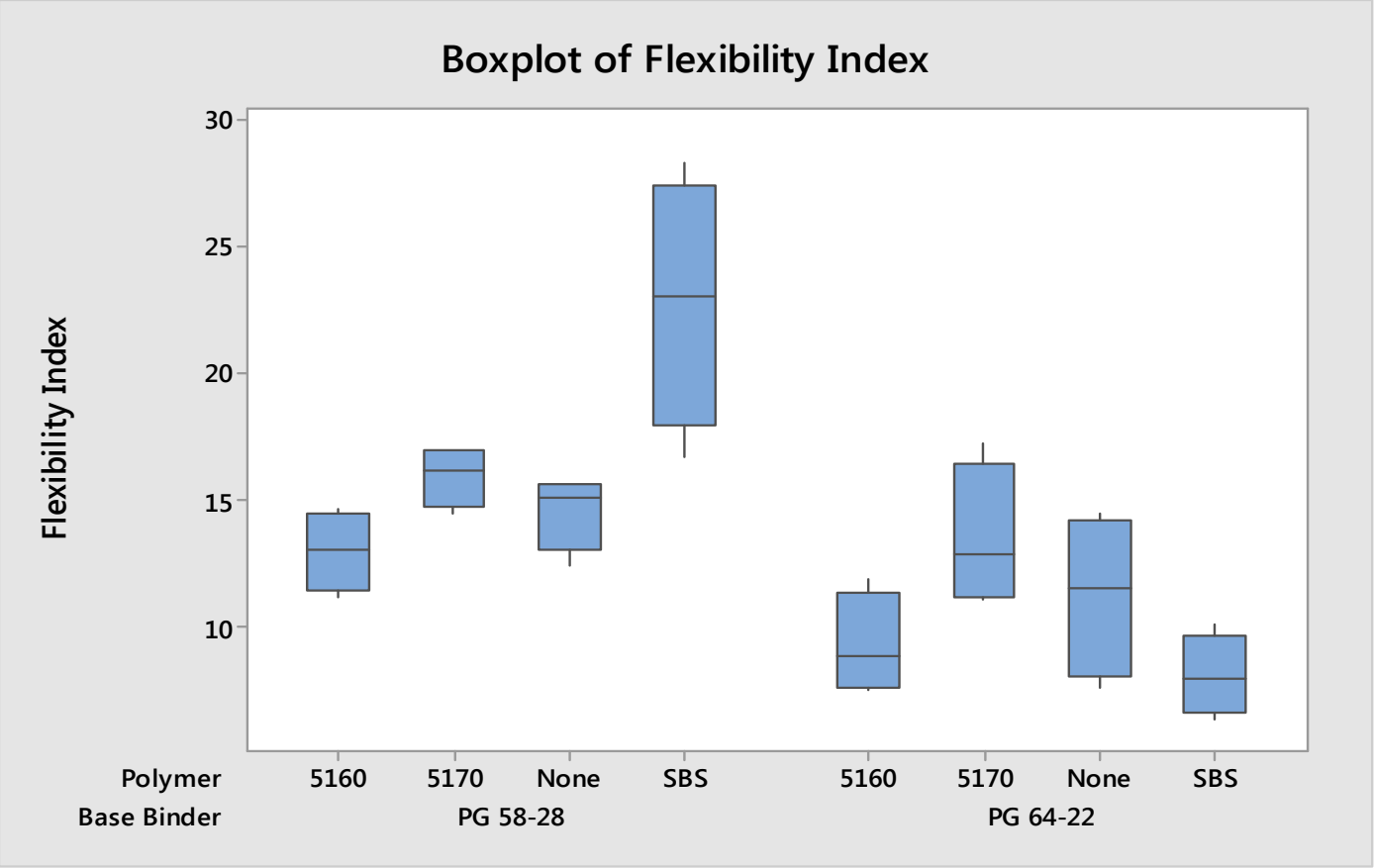
Results N50 Design

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.

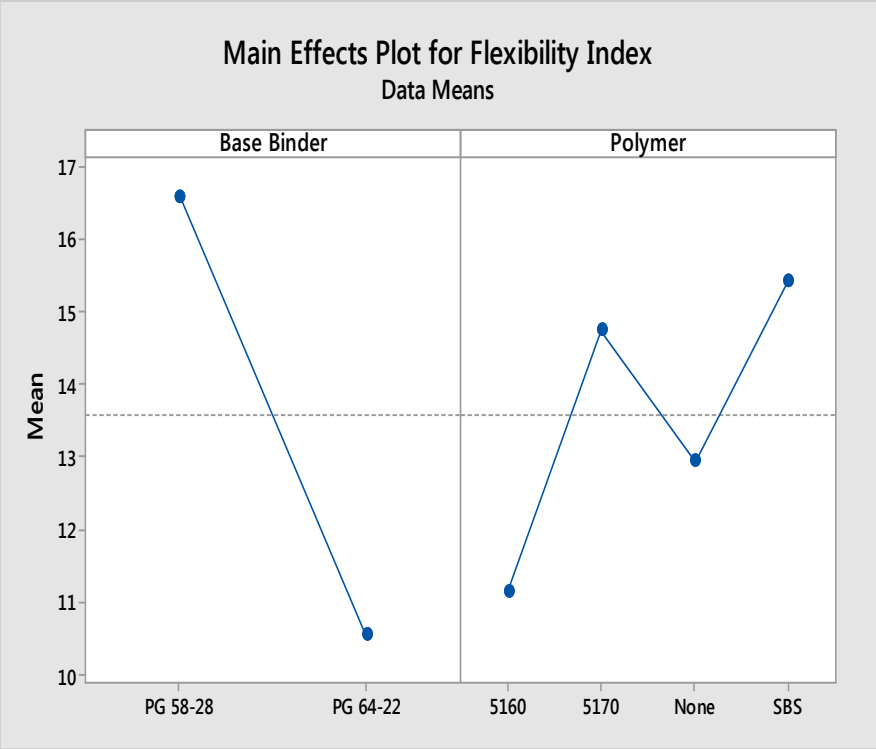
Results N70 Design

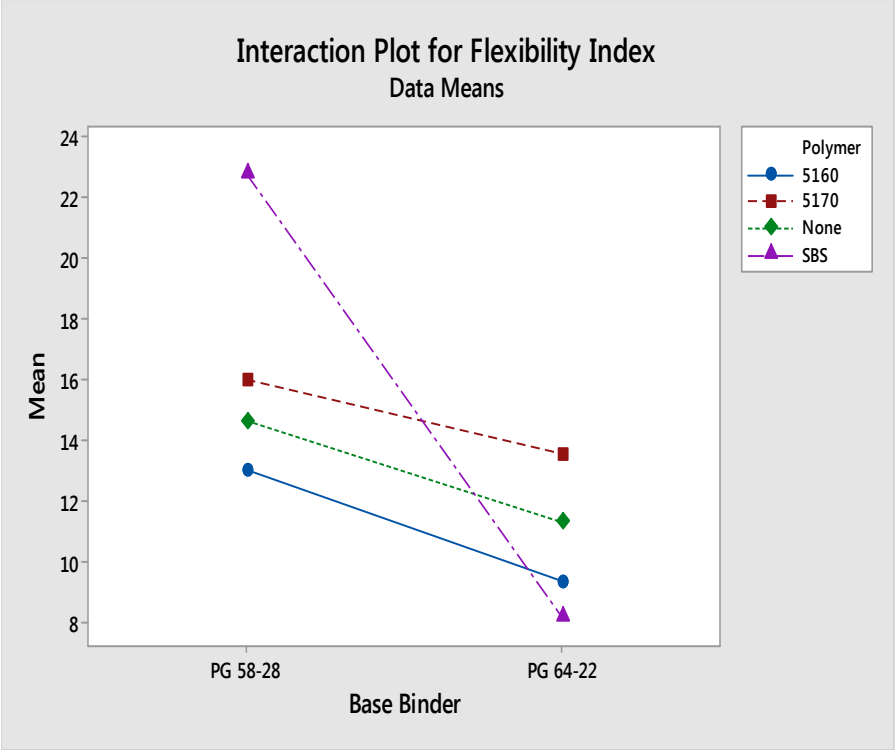


- Effect of binder replacement: All values are higher than the N50 design by a factor of 2-3.
- N70, PG 58-28 + SBS was the only mix/binder formulation significantly different than the control. High variability was observed for combination.

Results N70 Design

Main Effects and Interaction Plots





- 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

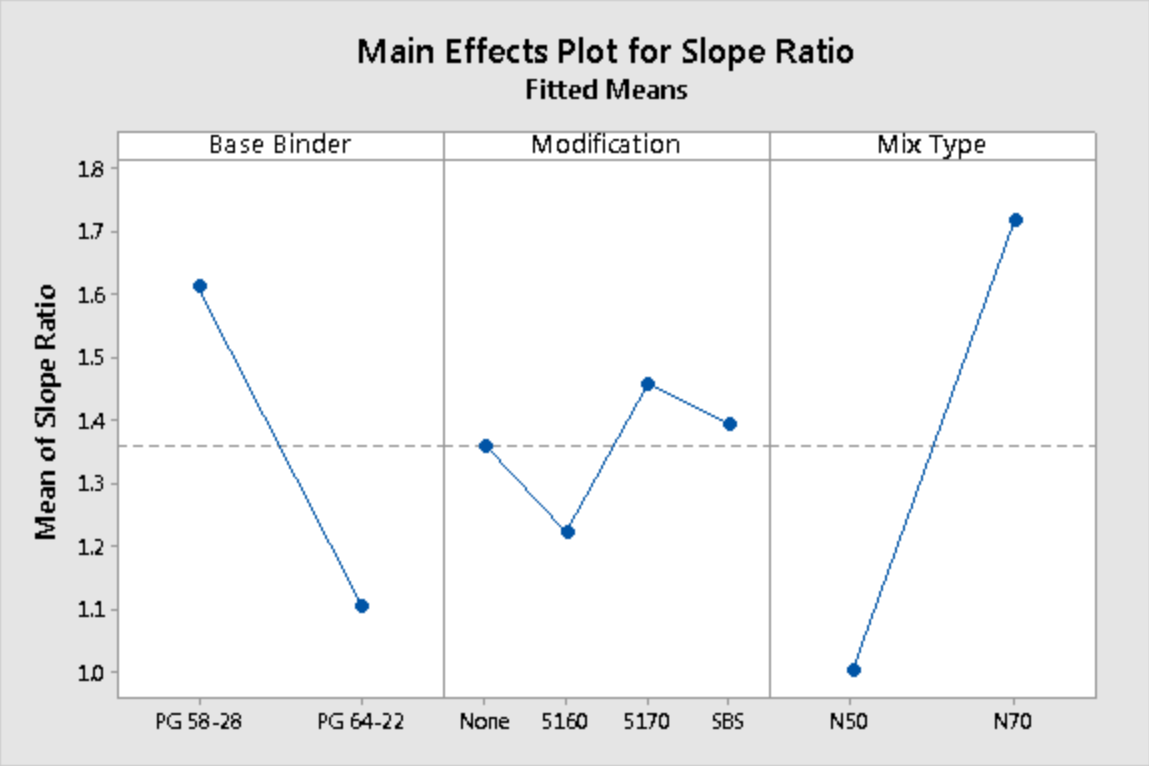
Factor	DOF	Post-Peak Slope (kN/mm)		Stiffness Index (kN/mm)		Peak Load	
		F-Value	P-Value	F-Value	P-Value	F-Value	P-Value
Polymer	3	**5.91**	**0.004**	**6.96**	**0.002**	0.28	0.839
Base Binder	1	**104.8**	**<0.000**	**64.85**	**<0.000**	**50.8**	**<0.000**
Replicates	3	0.82	0.495	1.23	0.325	0.95	0.433
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

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There is a full report of results available upon request.