Effect of Crumb Rubber on Rheological Properties of Asphalt Binder and Aggregate Packing of Asphalt Mixtures

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Hypothesis and Objective

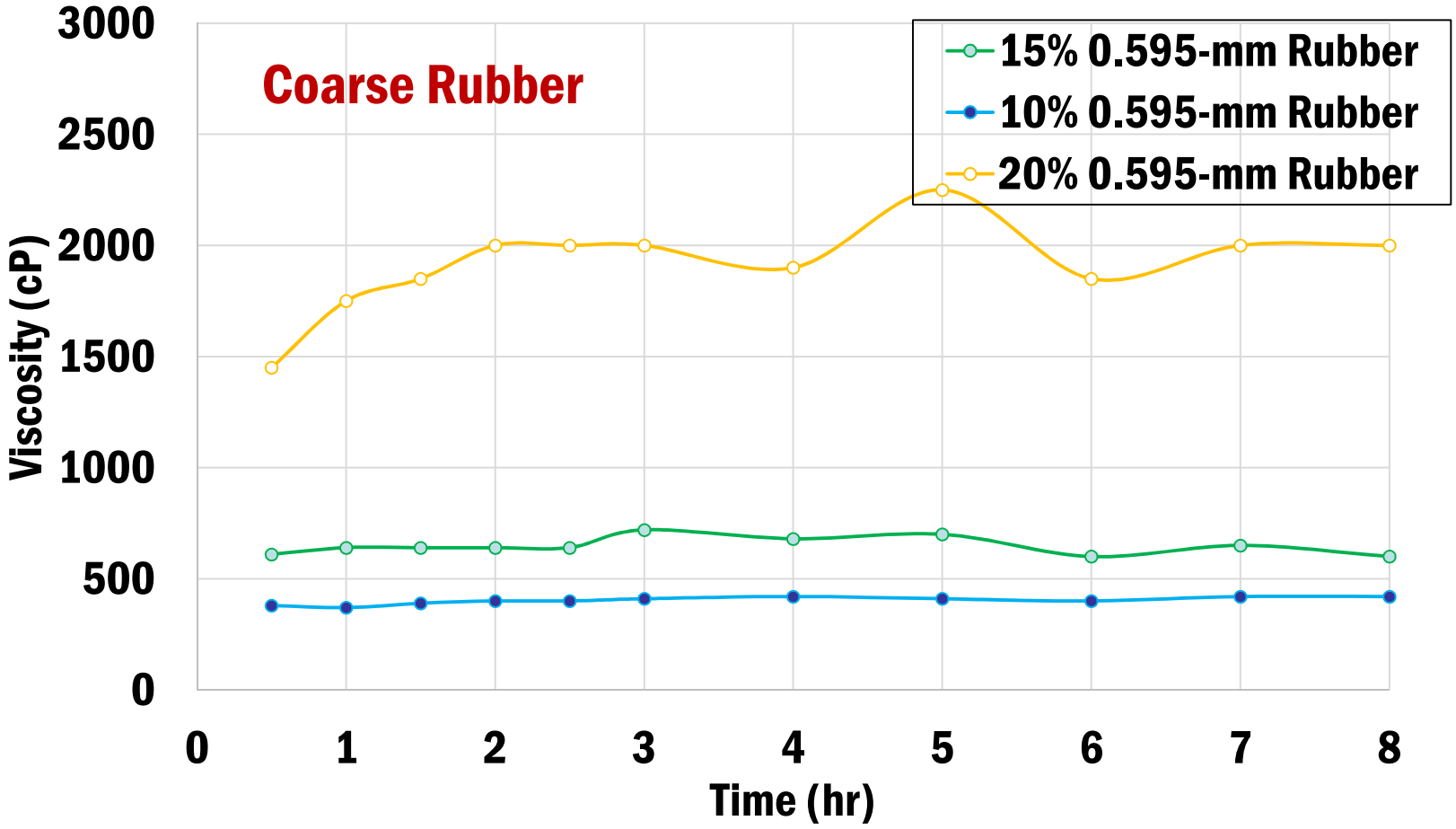
- **Hypothesis:**
  - Crumb rubber **size**, rubber **concentration**, and **reaction time** plays an important role in the rheological properties of rubber modified binders and aggregate packing of rubberized asphalt mixtures
- **Objective:**
  - Evaluate the effect of crumb rubber particles on the rheological properties of asphalt binders and the aggregate packing of the rubber modified asphalt mixtures

Rubber Modified Binder Preparation

Factor	Levels	Description
Base Binder	1	PG 64-22
Crumb Rubber Size	2	0.595 mm (Coarse) and 0.075 mm (Fine)
Crumb Rubber Concentration	3	10%, 15%, and 20%
Blending Duration (or Reaction Time)	2	Green and Reacted

Selection of Reaction Times

- Using Hand-held Viscometer @ 180±5 °C



Green and Reacted times selected from these graphs!

Rubberized Asphalt Mixture Preparation

Compaction Temperature (CT):
155°C

Mixing Temperature (MT):
145°C

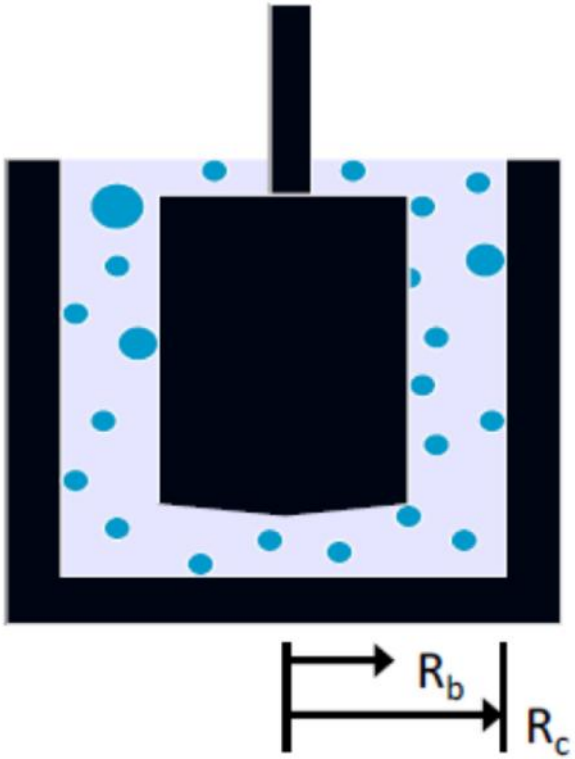
From Viscosity-Temperature Profile

Size (mm)	% Passing	
	Coarse Gradation	Fine Gradation
37.5	100.00	100.00
25	100.00	100.00
19	99.73	100.00
12.5	78.64	94.25
9.5	64.47	80.40
4.75	41.12	63.70
2.36	27.37	43.90
1.18	18.73	28.72
0.6	12.90	19.18
0.3	7.82	11.86
0.15	4.87	7.75
0.075	3.24	5.98
	AC: 5.4%	**AC: 4.8%**

Binder Testing Methods

Test Method	Binder Type	Evaluation Parameters/Response	Testing Standard
Cup and Bob	Original	Viscosity	-NA-
Multiple Stress Creep Recovery (MSCR)	RTFO	J_{nr} Stress Sensitivity	AASHTO TP70
High Temperature (HT) Performance Grading	Original and RTFO	$G^*/\sin\delta$	AASHTO T315
Elastic Recovery (ER)-DSR	RTFO	Elastic Recovery	AASHTO T XXX-13
Linear Amplitude Sweep (LAS)	PAV	Fatigue	AASHTO TP 101-12

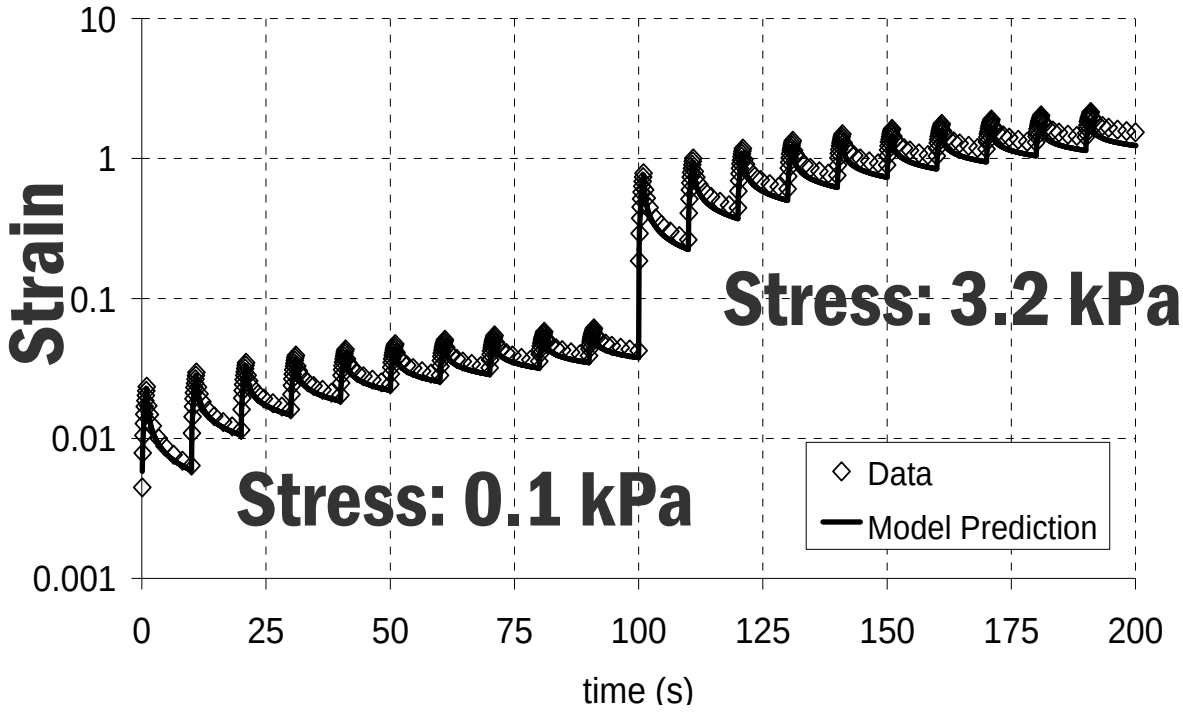
Binder Testing Methods
- Bob and Cup



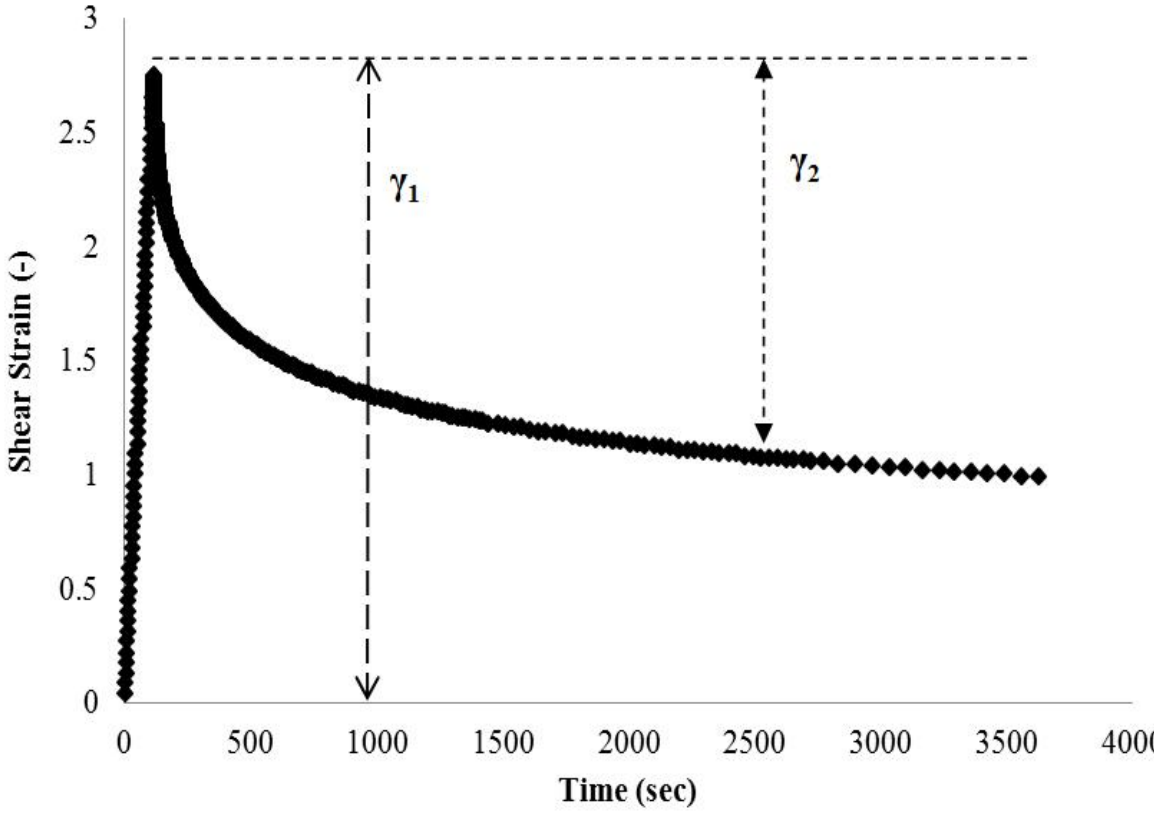
Output: Viscosity

Binder Testing Methods - MSCR

- Creep stress:0.1 kPa, 3.2 kPa
- 10 cycles
  - 1 sec constant creep stress
  - 9 sec zero stress
- Output: **Creep compliance (Jnr) and Percent Recovery (%R)** at 0.1 kPa, and 3.2 kPa



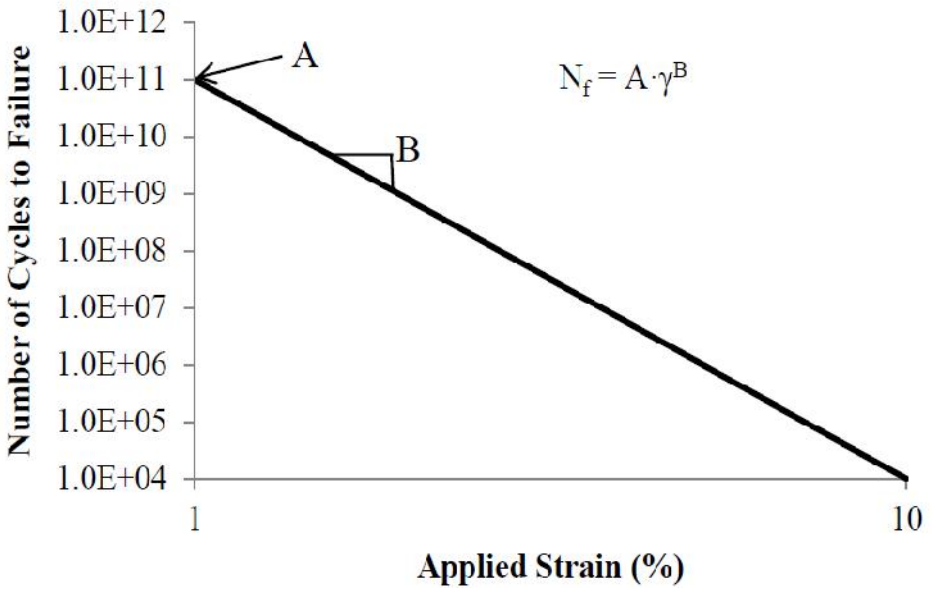
Binder Testing Methods - ER-DSR



Typical strain curve for elastic recovery test in the DSR

- Temperature: 25°C
- Conditioning Time: 20 minutes
- Constant strain rate of 0.02315 1/s is applied for 2 minutes.
- This step is run in strain controlled mode and then followed by a constant zero shear stress for a period of 30 minutes.
- This step is run in stress controlled mode and corresponds to the recovery part of the test.

Binder Testing Methods - LAS

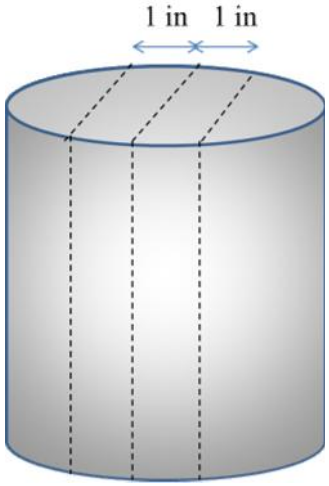


Fatigue law on log-scale (Hintz 2012)

The test involves two steps:

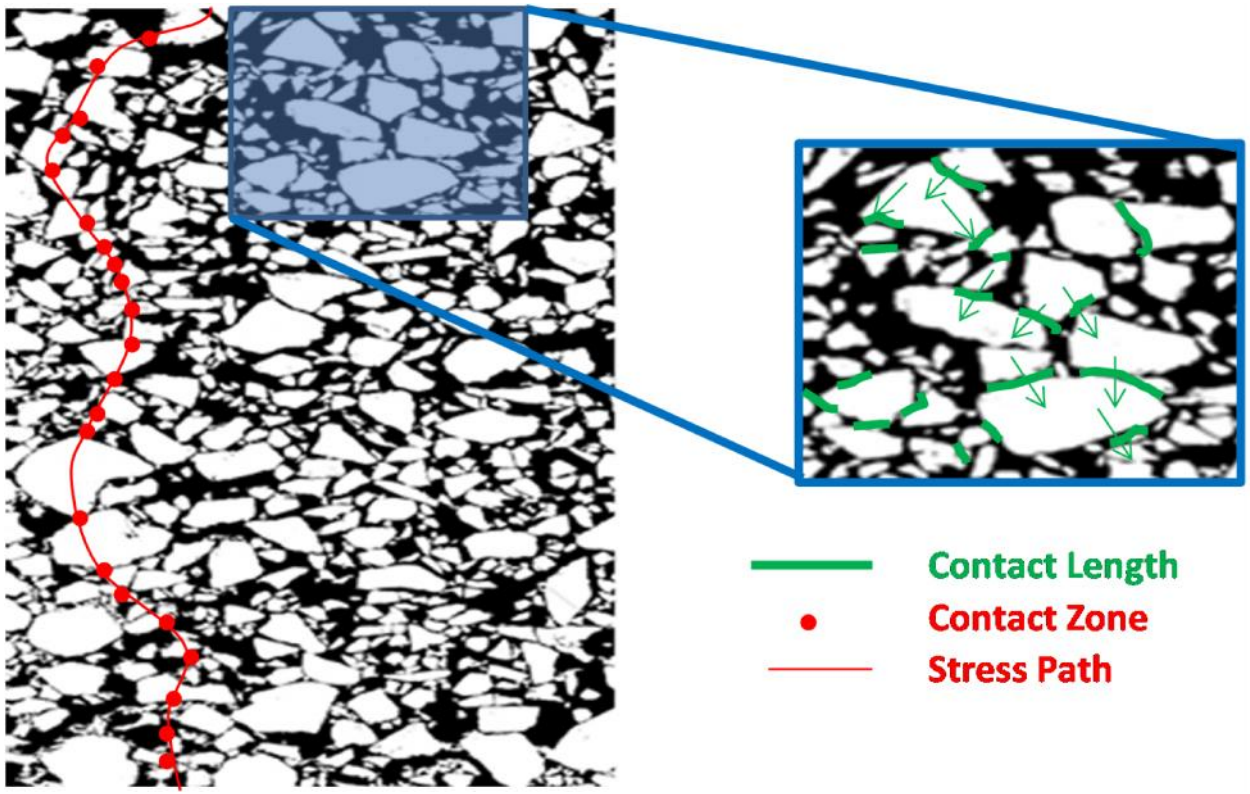
- An initial 100 cycles applied at 0.1% strain to determine undamaged linear viscoelastic properties, and
- A final step that consists of ramping strain amplitude, beginning at 0.1% and ending at 30% applied strain, over 3100 cycles of loading at 10 Hz.

Aggregate Packing Analysis - iPas2



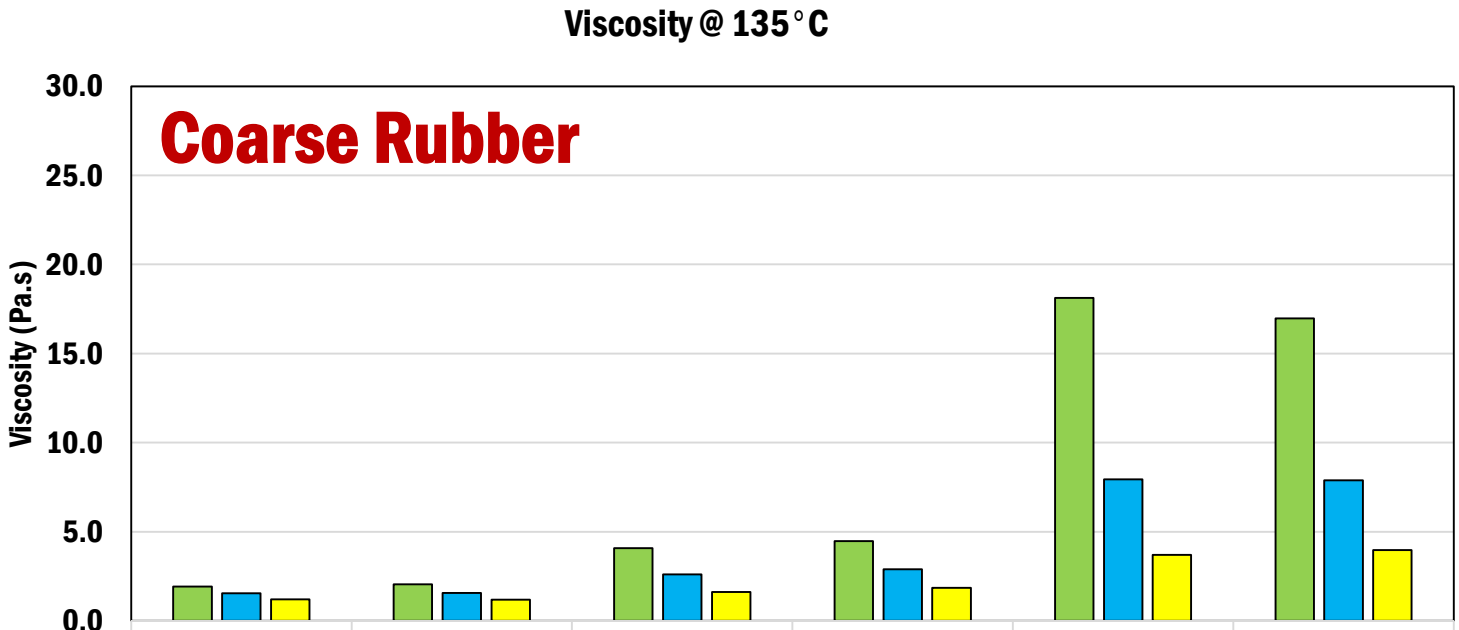
Cutting Sections

(Roohi et al. 2012)



Microstructural parameters

Binder Test Results - Viscosity



	10% Coarse Rubber - 2 h	10% Coarse Rubber - 5 h	15% Coarse Rubber - 2 h	15% Coarse Rubber - 5 h	20% Coarse Rubber - 1 h	20% Coarse Rubber - 4 h
1 rpm	1.9	2.0	4.1	4.5	18.1	17.0
10 rpm	1.5	1.6	2.6	2.9	7.9	7.9
100 rpm	1.2	1.2	1.6	1.9	3.7	4.0

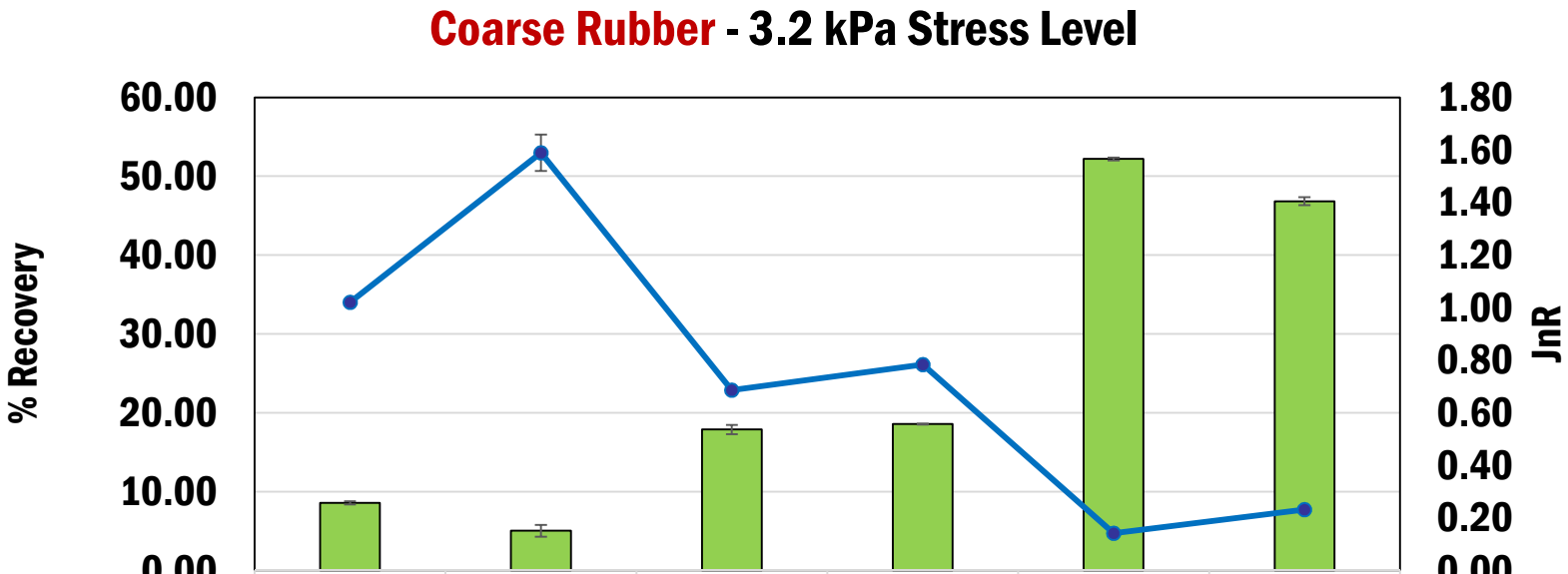
- Viscosity increases with increase in crumb rubber concentration, and decrease with increase in shear rate
- Binder modified with fine crumb rubber is more viscous than coarse crumb rubber

Binder Test Results –High Temperature True Grade (TG)

Binder	10% - Green Binder	10% - Reacted Binder	15% - Green Binder	15% - Reacted Binder	20% - Green Binder	20% - Reacted Binder
0.075-mm Fine Rubber						
Unaged Binder	78.2	76.3	82	81.7	91.1	85.6
RTFO Aged Binder	78	73.6	78.7	78.8	89.8	83.2
0.595-mm Coarse Rubber						
Unaged Binder	77.2	76.7	80.4	81	87.3	87.5
RTFO Aged Binder	81	77.8	84.7	82.6	87.7	91.5

- No change in TG for different reaction times
- TG increases with increase in crumb rubber concentration
  - 4 times grade bump for 20% concentration

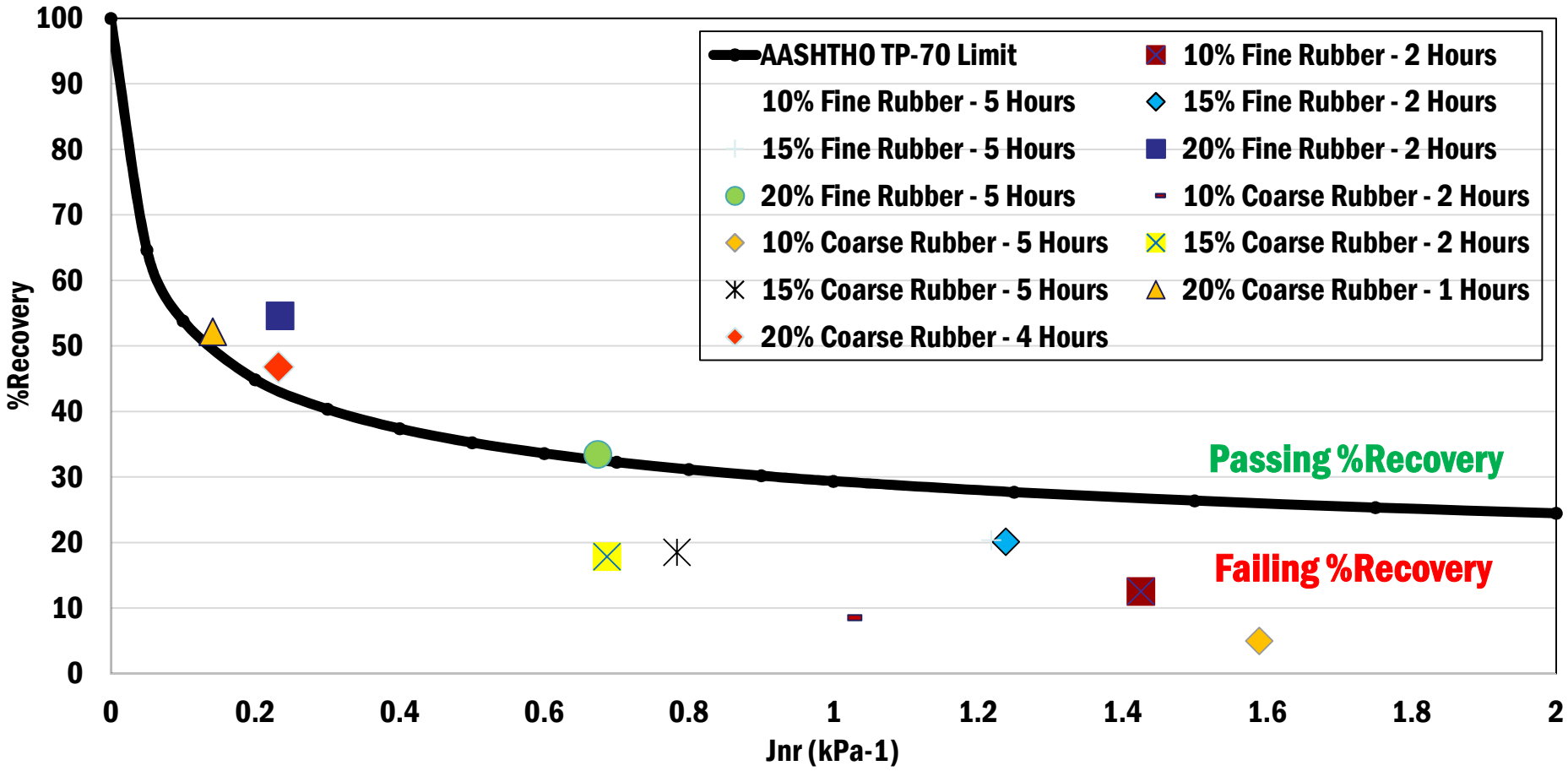
Binder Test Results - MSCR



	10% Coarse Rubber - 2 Hours	10% Coarse Rubber - 5 Hours	15% Coarse Rubber - 2 Hours	15% Coarse Rubber - 5 Hours	20% Coarse Rubber - 1 Hours	20% Coarse Rubber - 4 Hours
%Recovery	8.57	5.03	17.87	18.56	52.19	46.83
JnR	1.02	1.59	0.69	0.78	0.14	0.23

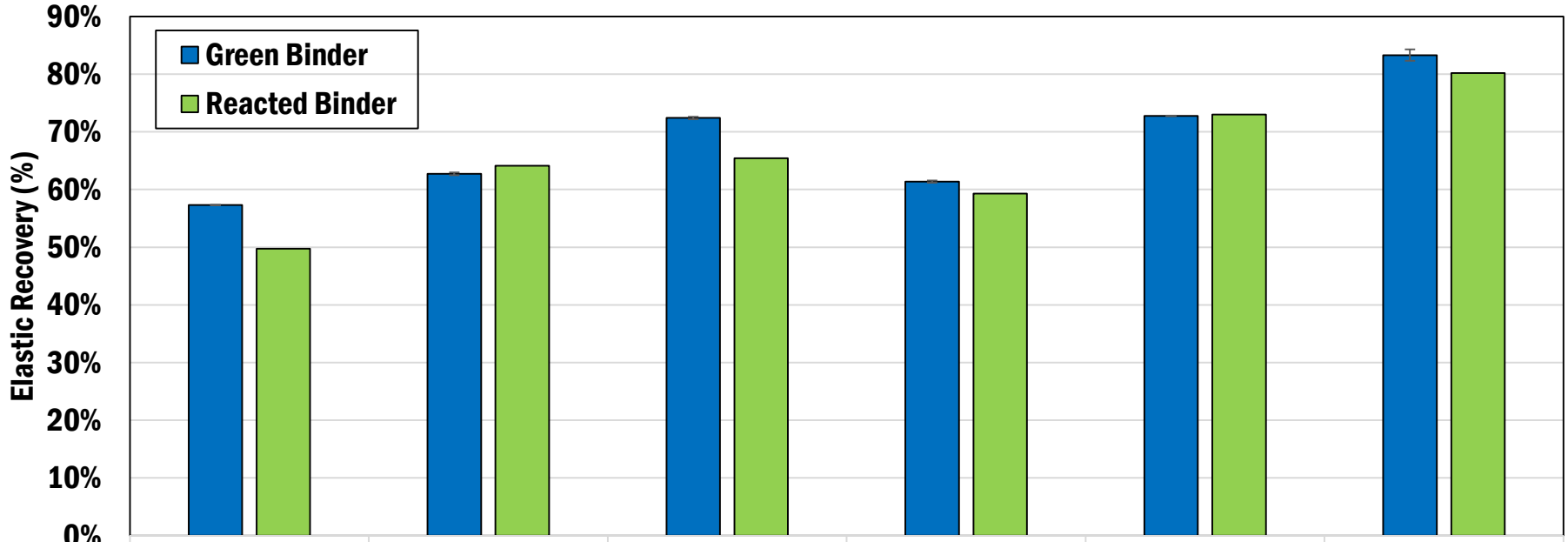
- The %Recovery was lower, and the Jnr was higher for all the reacted binders

Binder Test Results
- Jnr vs. %Recovery at 3.2 kPa Stress Level



Only 20% Crumb Rubber Concentration Passes!

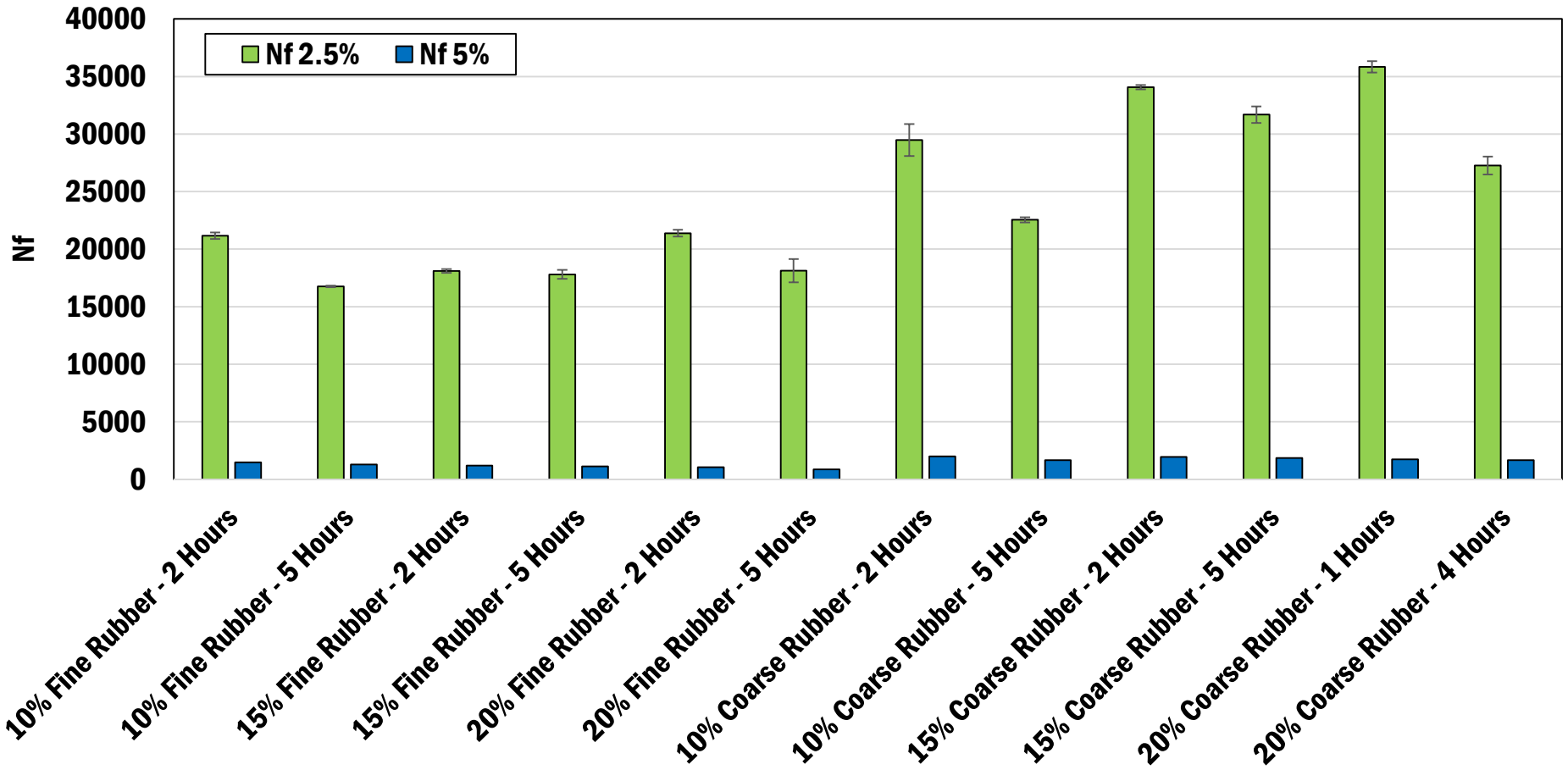
Binder Test Results – ER-DSR



	10% Fine Rubber	15% Fine Rubber	20% Fine Rubber	10% Coare Rubber	15% Coarse Rubber	20% Coarse Rubber
Green Binder	57%	63%	72%	61%	73%	83%
Reacted Binder	50%	64%	65%	59%	73%	80%

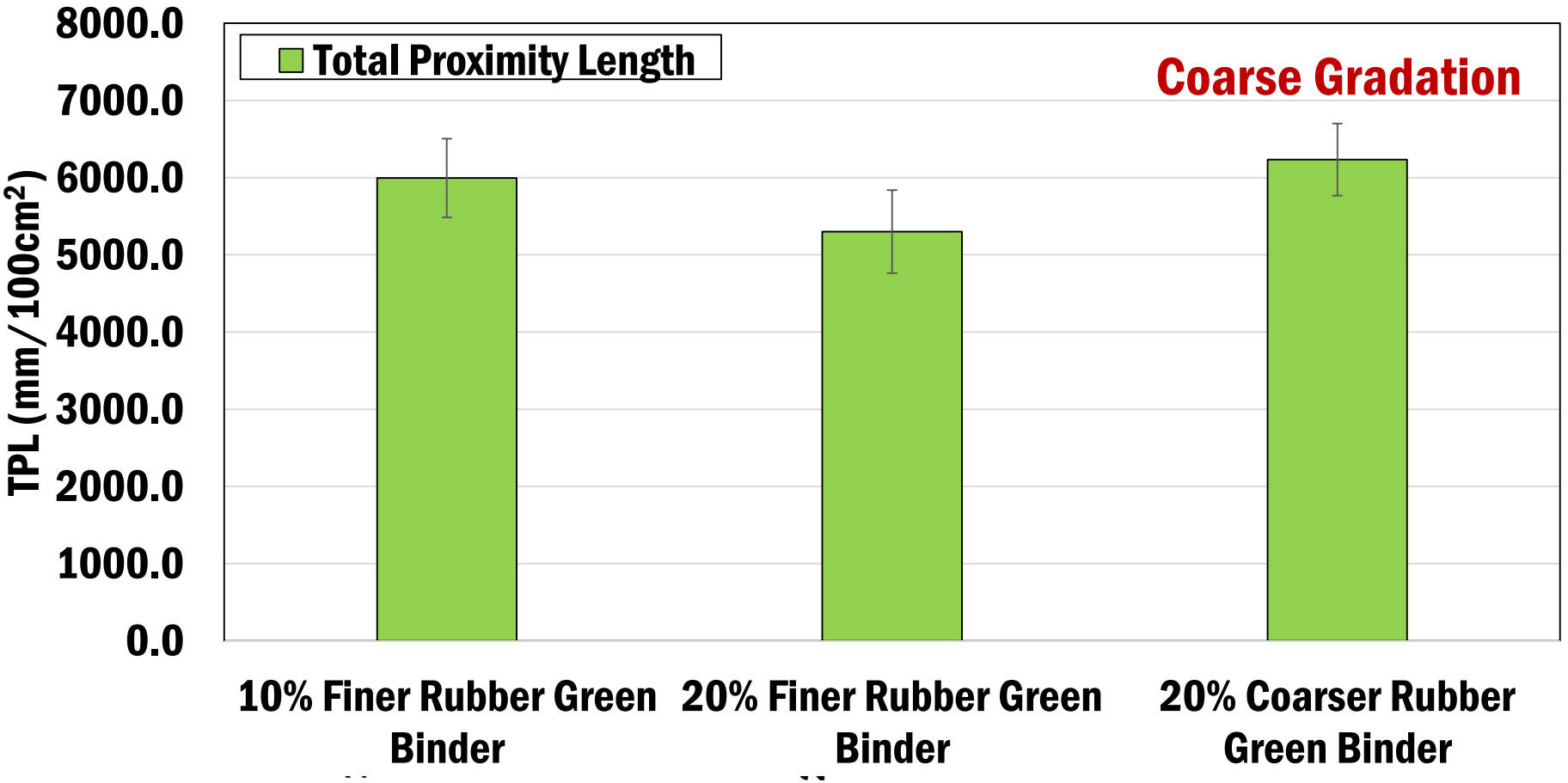
- 20% concentration has highest ER value!
- ER value is less for reacted binder similar to MSCR results

Binder Test Results - LAS



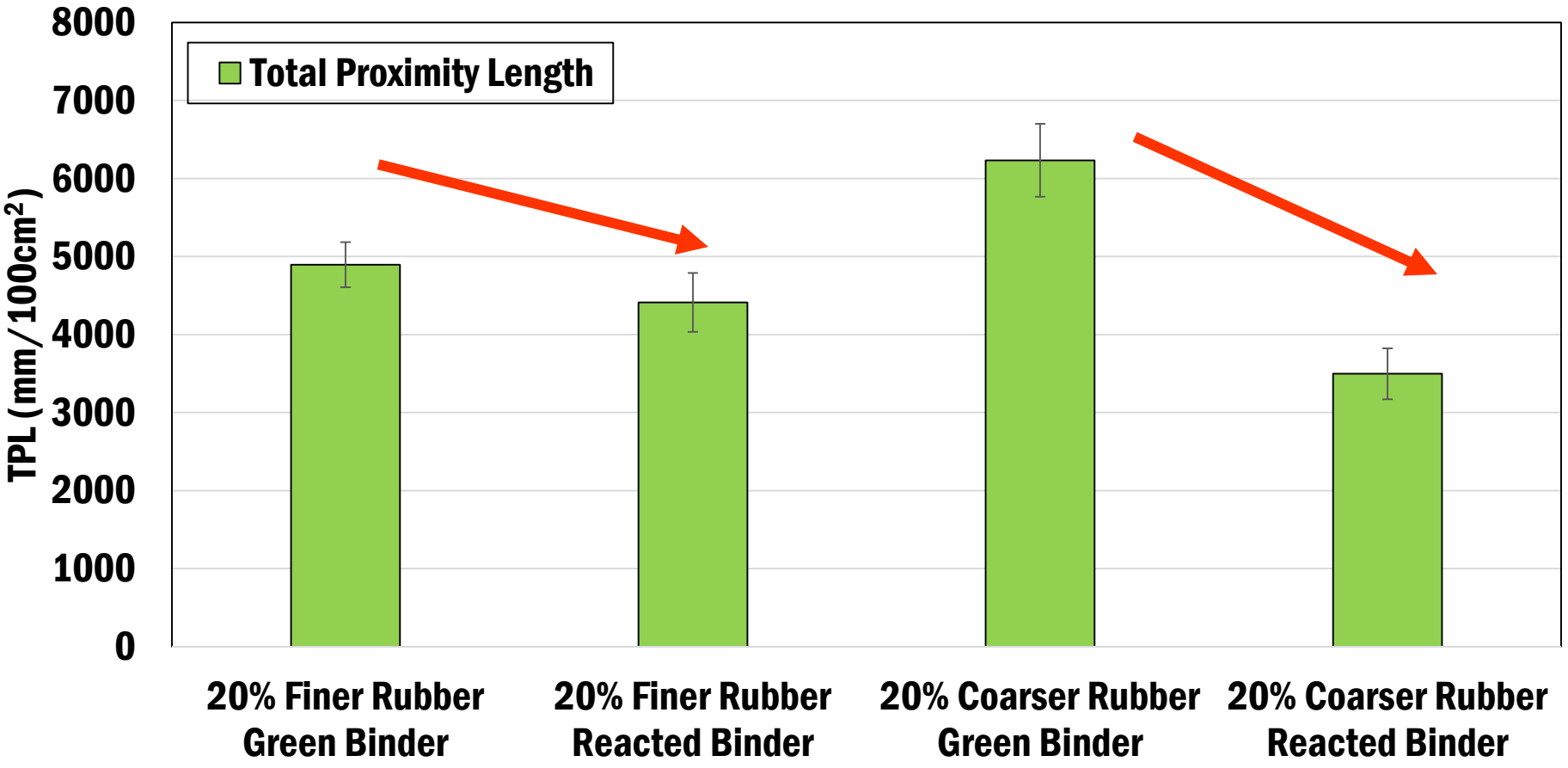
- Coarser rubber performs better in fatigue than finer!
- Nf drops for reacted binder

Aggregate Packing Analysis – On Green Binders



Coarser rubber performs better!

Aggregate Packing Analysis – Green vs. Reacted Binders



Green binder performs better!

Conclusions

- Rubber size, rubber concentration, and reaction time play an important role in the rheological properties of the rubber modified binders
- Binders modified with coarser rubber (0.595-mm) has better rheological properties compared to the finer rubber (0.075-mm)
- Binders modified with higher rubber concentration (20%) performs better for both the sizes of rubber than the lower concentration, and also passes the AASHTO TP-70 MSCR criteria
- Green binders, for both the rubber sizes, show better rheological properties than the reacted binders

Conclusions

- It is found that **rubber size** and **reaction time** could have important effects on aggregate packing during compaction, and thus performance
- **Green binders** for both the size of rubber are found to have **better** aggregate packing than the reacted rubber modified binders.


Thank you!
Questions?