Assessing the Performance of Ultrafine Asphalt Mixtures with Recycled Asphalt Pavement (RAP) for Road Rehabilitation

SUNY CANTON

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Topic Outline

- What is RAP?
- Benefit and uses of RAP
- Methodology: Material and Laboratory tests
- Analysis of the results
- Conclusion

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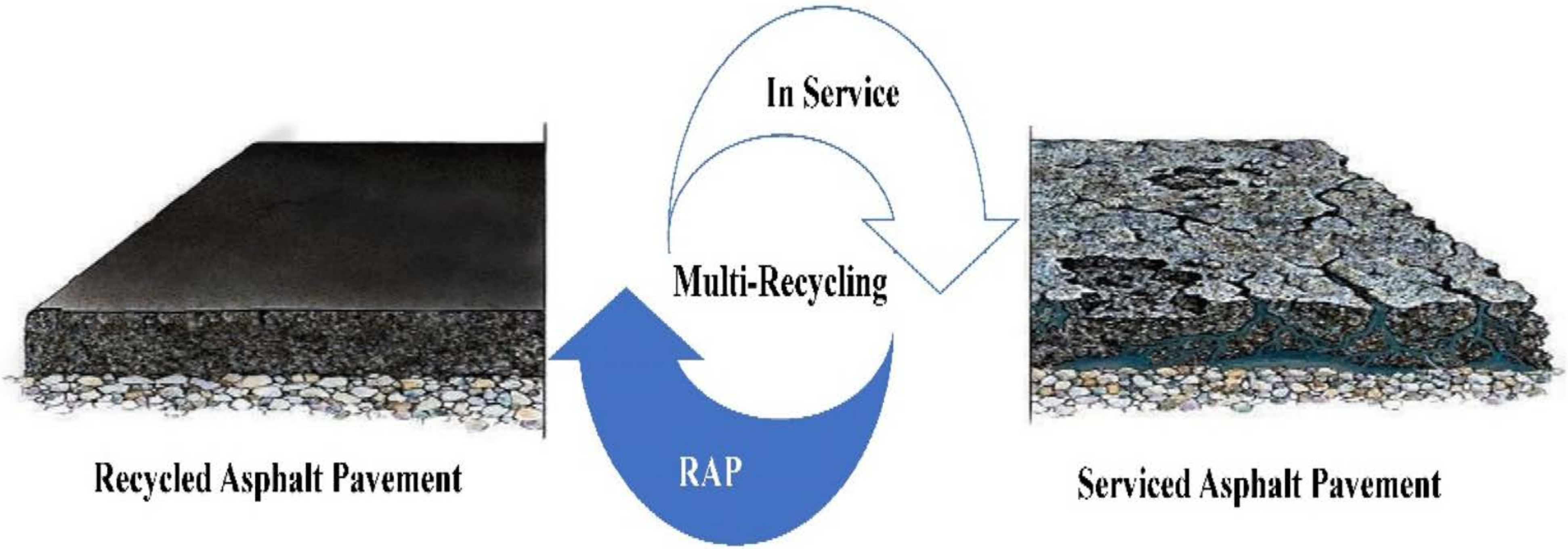
What is RAP?

- A prior pavement structure is made up of aggregate and asphalt binders
- Manufactured by milling, fracturing, and grinding aging pavements
- After then, RAP is mixed with fresh, virgin pavements.

What is RAP?



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History of RAP use

- USDOT: First used in 1915
- Major emphasis started in 1970's
- Oil embargo and increased oil prices
- Improved milling machines
- In several states, became commonplace

Uses

- New Pavement
- Subbase materials
- Repaving already-existing roads
- Repairing the exits roads, Such as cracks

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Table 13-3. State DOT specification requirements for the use of reclaimed asphalt pavement (RAP) in hot mix asphalt paving mixtures.[13]

State	Max. RAP % – Batch Plants			Max. RAP % – Drum Plants			Top Size for RAP
	Base	Binder	Surface	Base	Binder	Surface	
Alabama	40	40	15	50	50	15	2 in
Alaska	–	–	–	–	–	–	–
Arizona	30	30	30	30	30	30	1.5 in
Arkansas	70	70	70	70	70	70	3 in
California	50	50	50	50	50	50	2 in
Colorado	15	15	15	15	15	15	1.5
Connecticut	40	40	40	40	40	40	2 in
Delaware	35	35	25	50	50	30	2 in
Florida	60	50	None	60	50	None	Specs
Georgia	25	25	25	40	40	40	2 in
Hawaii	30	None	None	40	None	None	1.5 in
Idaho	Open	Open	Open	Open	Open	Open	2 in
Illinois	50	25	15	50	25	15	Specs
Indiana	50	50	20	50	50	20	2 in
Iowa	Open	Open	Open	Open	Open	Open	1.5 in
Kansas	50	50	50	50	50	50	2 in
Kentucky	30	30	30	30	30	30	Specs
Louisiana	30	30	None	30	30	None	2 in
Maine	40	40	None	40	40	None	1 in
Maryland	Open	Open	Limit	Open	Open	Limit	Specs
Massachusetts	20	20	10	40	40	10	.75 in
Michigan	50	50	50	50	50	50	Specs
Minnesota	59	50	30	50	50	30	3 in
Mississippi	30	30	15	30	30	15	2 in
Missouri	50	50	50	50	50	50	1.5 in
Montana	50	50	10	50	50	10	2 in
Nebraska	Not Used	Not Used	Not Used	Open	Open	Open	2 in
Nevada	50	50	15	50	50	15	1.5 in
New Hampshire	35	35	15	50	50	15	Specs
New Jersey	25	25	10	25	25	10	2 in
New Mexico	Open	Open	Open	Open	Open	Open	1.5 in
New York	50	50	None	70	70	None	2 in
North Carolina	60	60	60	60	60	60	2 in
North Dakota	50	50	50	50	50	50	1 in
Ohio	50	35	20	50	35	20	2 in
Oklahoma	25	25	None	25	25	None	2 in
Oregon	30	20	20	30	20	20	1 in
Pennsylvania	Open	Open	Open	Open	Open	Open	2 in
Rhode Island	30	30	None	30	30	None	1.25 in
South Carolina	30	25	20	30	25	20	2 in
South Dakota	Not Used	Not Used	Not Used	50	50	50	1.5 in
Tennessee	15	Open	None	Open	Open	None	Open
Texas	15	Open	Open	Open	Open	Open	2 in
Utah	Not Used	Not Used	Not Used	25	25	25	2 in
Vermont	Specs.	Specs.	Specs	Specs	Specs	Specs	Specs
Virginia	25	25	25	25	25	25	2 in Open
Washington	Open	Open	Open	Open	Open	Open	Open
West Virginia	Open	Open	Open	Open	Open	Open	Open
Wisconsin	Open	35	20	Open	35	20	Open
Wyoming	50	50	50	50	50	50	2 in

The benefit of using RAP

- Environment and the Economy
- Maintenance and rehabilitation activities consist of periodic placement of the surface layer of asphalt concrete and involve costly activities
- Cost-effective materials, including ultra-fine mixture mixes, suitable replacements for applications involving pavement maintenance.

Cost Savings

- Decreases the need to mine additional aggregate
- Reduces aggregate production, processing, and transportation energy/costs
- Reduces the need for asphalt

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Environmentally Friendly

- Reducing waste
- Conserving resources: reusing RAP materials, can reduce the need for new resources such as virgin asphalt, aggregates, and petroleum products
- Saving energy: RAP materials often use less energy than manufacturing new materials, lower greenhouse gas emissions

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Materials and laboratory tests

- Aggregate gradations, recycled material properties, and characteristics of the asphalt mixtures
- Tests conducted to improve the sustainability of construction materials, and environmentally friendly
- Extraction binder evaluation, Cantabro mass loss, dynamic modulus, indirect tensile asphalt cracking, repeated permanent load deformation, and asphalt pavement analyzer.

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Table 1 Mix Designs for Ultra fine Asphalt Mixtures

Production Year	2014	2015	2015	2015	2015	2015
Lab ID	A	B	C	D	E	F
Mix	SM-4.75 A	SM-4.75D	SM-4.75 A	SM-4.75A	SM-4.75A	SM-4.75D
Asphalt Content (%)	6.2%	6.3%	6.3%	6.0%	5.7%	6.0%
RAP Content (%)	20%	20%	30%	30%	30%	30%
Natural Sand	-	23%	24%	-	15%	-
Virgin binder Grade	PG 64S-22	PG 64H-22	PG 64S-22	PG 64S-22	PG 64S-22	PG 64S-22

Table 2 Mixture Volumetric Properties and Gradation for Ultra fine Asphalt Mixtures

	Mix ID						
Property	**A**	**B**	**C**	**D**	**E**	**F**	**VDOT Specification**
% AC	6.39	6.63	6.38	6.42	5.75	6.24	
Rice Specific Gravity (G_{mm})	2.532	2.590	2.453	2.630	2.649	2.475	
% Air Voids (V_a)	4.6	4.6	4.7	3.9	5.8	4.4	
% VMA	18.4	20.5	18.4	19.4	19.3	17.8	16.5
% VFA	75.2	77.6	74.6	80	70	75.4	70-80*
Fines/Asphalt Ratio	1.24	1.17	1.42	1.48	1.61	1.39	1.0 – 2.0+
Bulk Specific Gravity (G_{mb})	2.416	2.471	2.338	2.528	2.496	2.367	
Aggregate Specific Gravity (G_{sb})	2.773	2.902	2.683	2.936	2.916	2.700	
% Binder Absorbed (P_{ba})	0.52	0.00	0.34	0.10	0.17	0.42	
Effective % Binder (P_{be})	5.91	6.63	6.06	6.33	5.59	5.84	
Effective Film Thickness, (F_{be})	7.1	8.2	6.8	7.4	6.6	6.9	

Table 3 Gradation for Ultra fine Asphalt Mixtures

Sieve Size							Maximum	Minimum
3/4 in (19.0 mm)	100.0	100.0	100.0	100.0	100.0	100.0		
1/2 in (12.5 mm)	99.6	100.0	99.8	100.0	100.0	100.0	-	100
3/8 in (9.5 mm)	97.6	98.8	97.5	99.0	100	99.7	100	95
No. 4 (4.75 mm)	85.7	92.0	86.9	86.9	93.2	84.9	100	90
No. 8 (2.36 mm)	60.4	71.3	67.2	58.5	66.9	62.8	-	-
No.16 (1.18 mm)	46.2	52.0	52.4	41.2	44.7	47.4	55	30
No. 30 (600 μm)	35.8	36.2	39.0	30.0	31.2	34.4	-	-
No. 50 (300 μm)	24.8	20.3	24.1	21.5	20.7	22.7	-	-
No. 100 (150 μm)	13.8	11.9	13.3	14.5	13.2	14.0	-	-
No. 200 (75 μm)	7.35	7.74	8.61	9.35	9.0	8.10	13	6

*During the production of an approved job mix, the VFA shall be controlled within these limits.

+Fines/Asphalt Ratio is based on effective asphalt content.

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Extracted Binder Evaluation Tests

The extraction of binder from the loose mixture followed the guidelines outlined in **AASHTO T 164**, using n-propyl bromide as the solvent. The Rotavap recovery procedure, specified in **AASHTO T 319**, was then employed to recover the binder from the solvent for performance grading, as per **AASHTO M 320**

Cantabro Mass Loss

- Test specimens were compacted to N_{design} and tested three times.
- These specimens were then placed into a Los Angeles abrasion machine and rotated at a speed of 30 rotations per minute for 300 rotations. The degree of relative mass loss observed in the specimens measures the durability of dense-graded asphalt mixtures.

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Dynamic Modulus Test

- The AASHTO R84 guidelines
- Gyratory-compacted asphalt samples were tested at six frequencies (0.1 Hz to 25 Hz) and four temperatures (4.4°C to 54°C), as per AASHTO R83, with a target air void content of 7 ± 0.5% for each specimen.
- Tests were conducted in the uniaxial mode without confinement, and stress versus strain values was continuously recorded to calculate the dynamic modulus. The results for each mixture type at each temperature-frequency combination are reported in triplicate

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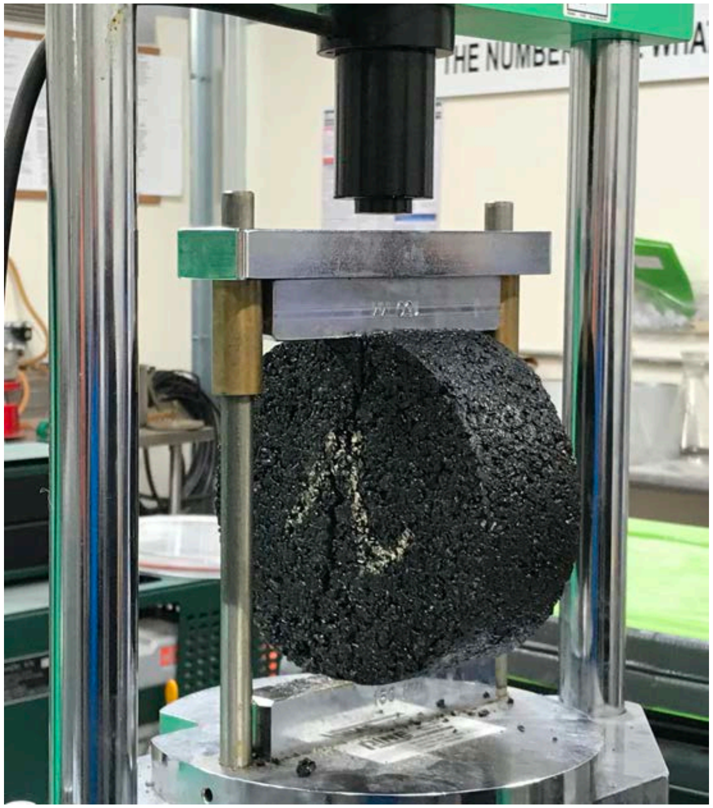
N_{flex} Factor

- The cracking resistance of asphalt mixtures, was performed using the 2017 AASHTO method
- Specimens were compacted to N_{design} using a gyratory compactor, then cut to a size of 50 ± 5 mm before being tested using an Instrotek Auto-SCB load frame equipped with a 50 kN load cell.

Indirect Tensile Asphalt Cracking Test

- This test aims to assess the cracking resistance of asphalt mixtures at intermediate temperatures.
- A cylindrical specimen, typically 150 mm in diameter, is subjected to a monotonic load at a constant displacement rate of 50 mm/min. The corresponding load-displacement curve is analyzed to obtain the crack performance index of the asphalt mixtures, referred to as the CT_{index}.



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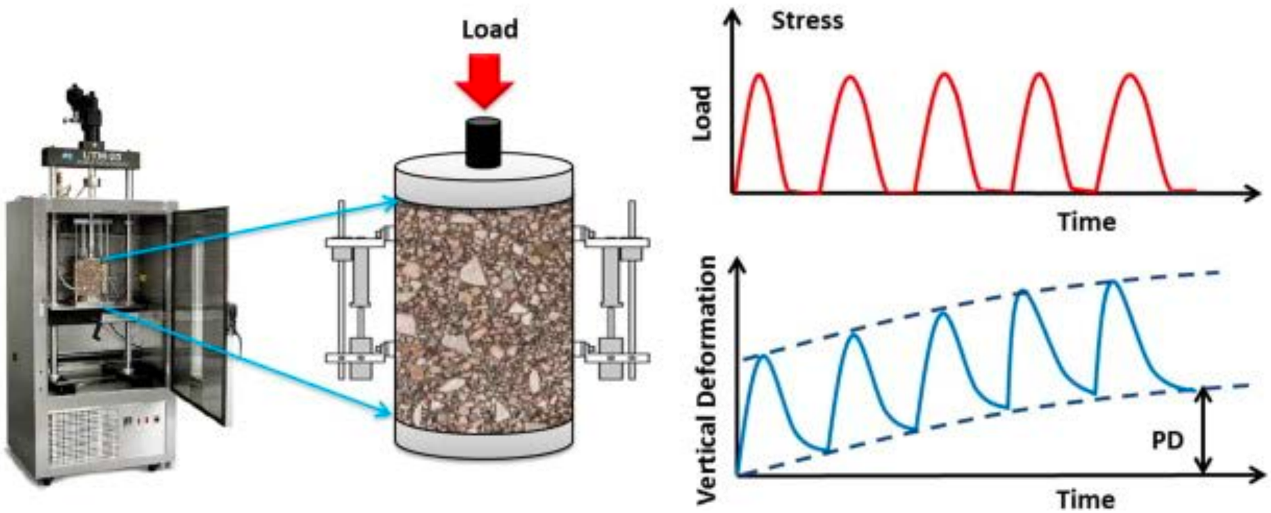
Repeated Load Permanent Deformation

- The repeated load permanent deformation (RLPD) test, also known as the flow number test, was employed per AASHTO T 378. Sample preparation and air void content were similar to |E*| tests.
- Proper calibration of the MEPDG rutting model requires selecting appropriate testing temperatures and suitable triaxial stresses in the RLPD test.



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Asphalt Pavement Analyzer

- The APA test complied with Virginia Test Method 110
- The gyratory compactor was used to compact the specimens, targeting 8 ± 0.5% air voids.
- A vertical load of 533 N was applied to the specimens through a rubber hose filled with compressed air at a pressure of 830 kPa. Rutting depths were measured after subjecting the specimens to 8,000 load cycles at the left, middle, right, and average rut depth positions.

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RESULTS

Binder Tests

Table 4 Extracted Binder Data Results

Property	Mix ID					
	A	B	C	D	E	F
RTFO* failure temperature	74.36	78.03	76.5	77.4	82.83	71.93
ΔT_c, ºC	-13.6	-4.7	-3.8	-1.4	-2.0	-1.7
Stiffness failure temperature	-32.6	-25.9	-27.5	-26.0	-24.7	-26.0
M-value failure temperature	-19.0	-21.3	-23.7	-24.5	-22.8	-24.4
Performance grade	70-16	76-16	76-22	76-22	82-22	70-22

*RTFO = rolling thin film oven

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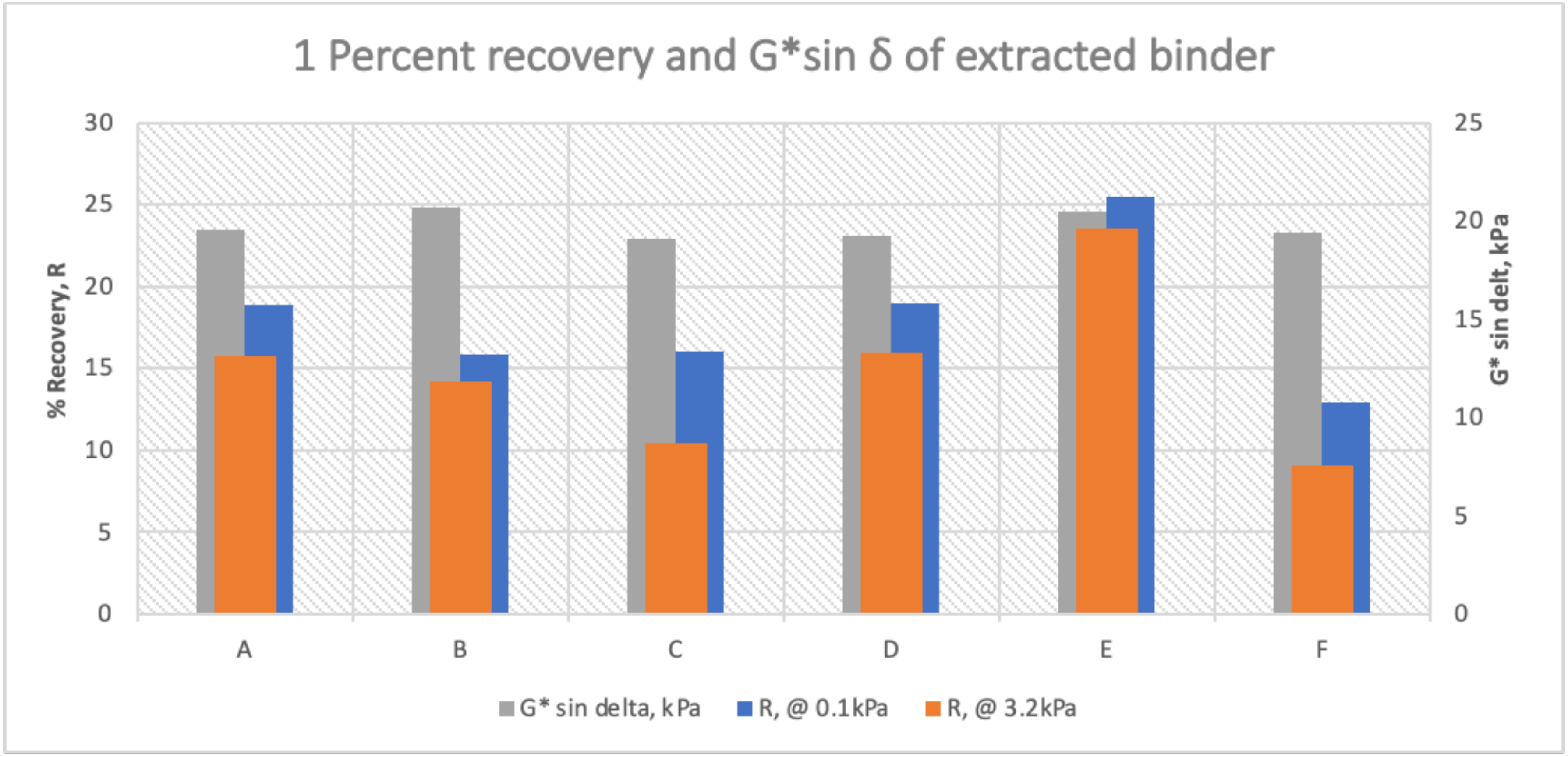
RESULTS

Binder Tests



Graph. 1 Percent recovery and G*sin δ of extracted binders.

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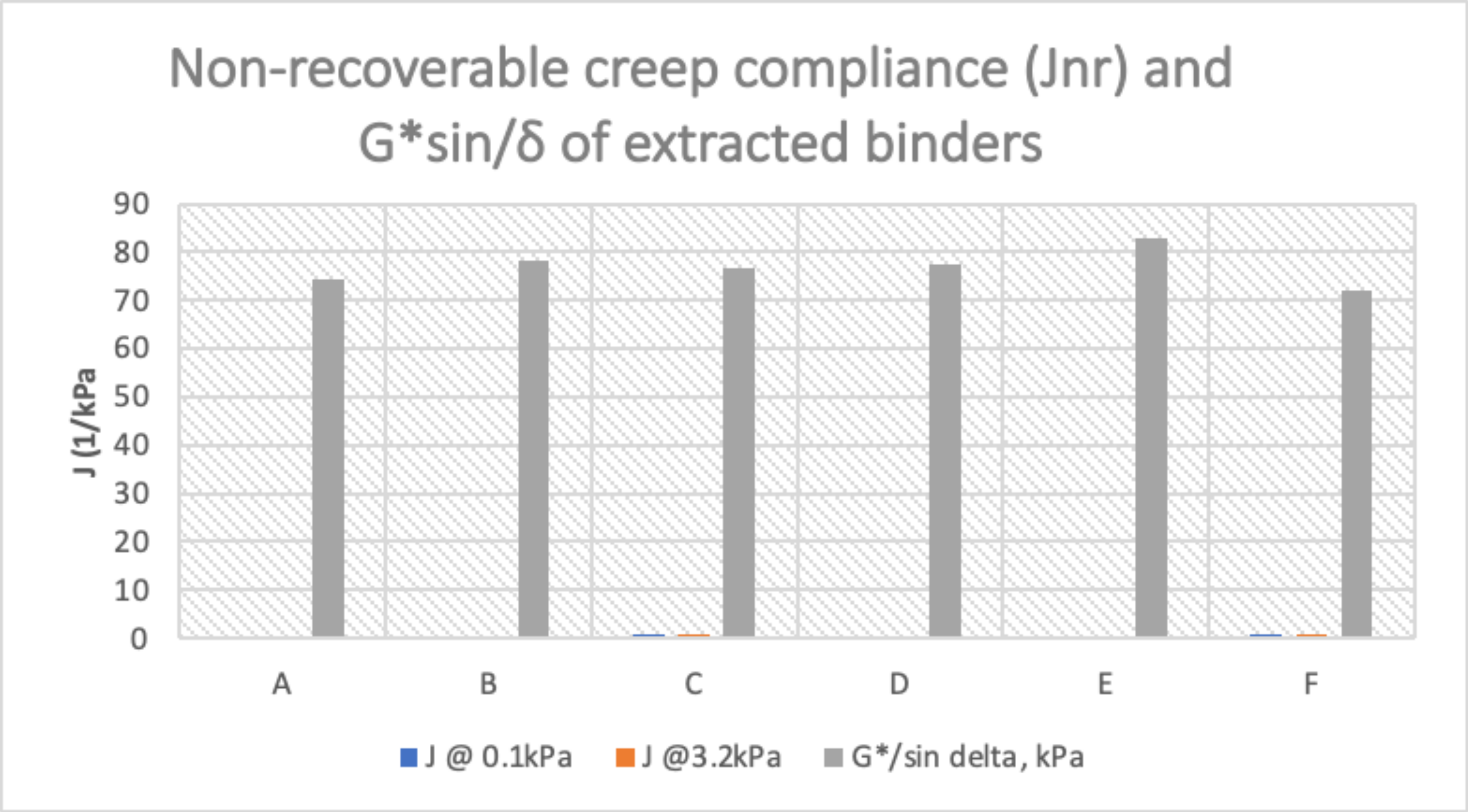
RESULTS

Binder Tests



Graph. 2 Non-recoverable creep compliance (J_{nr}) and G*sin/δ of extracted binders.

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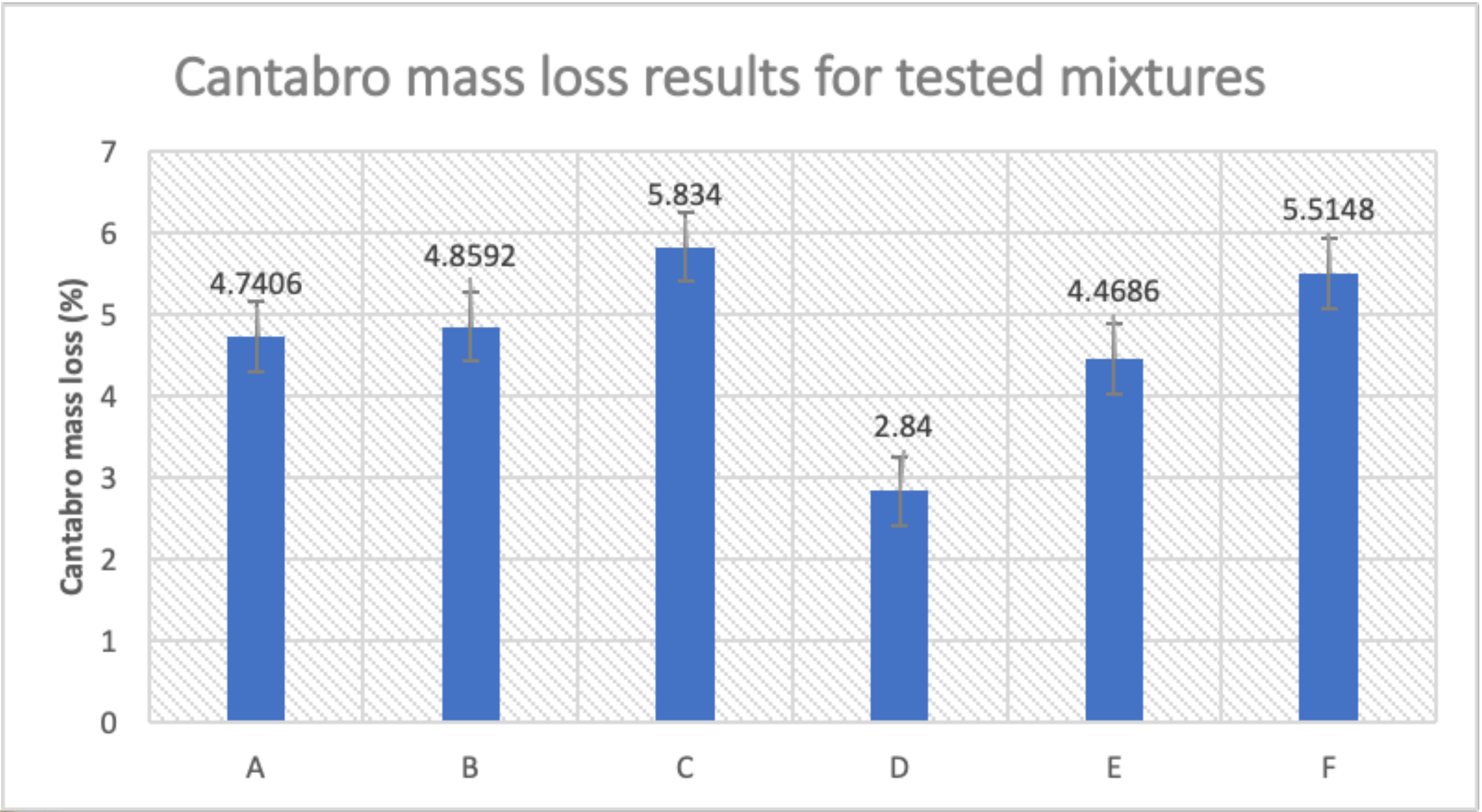
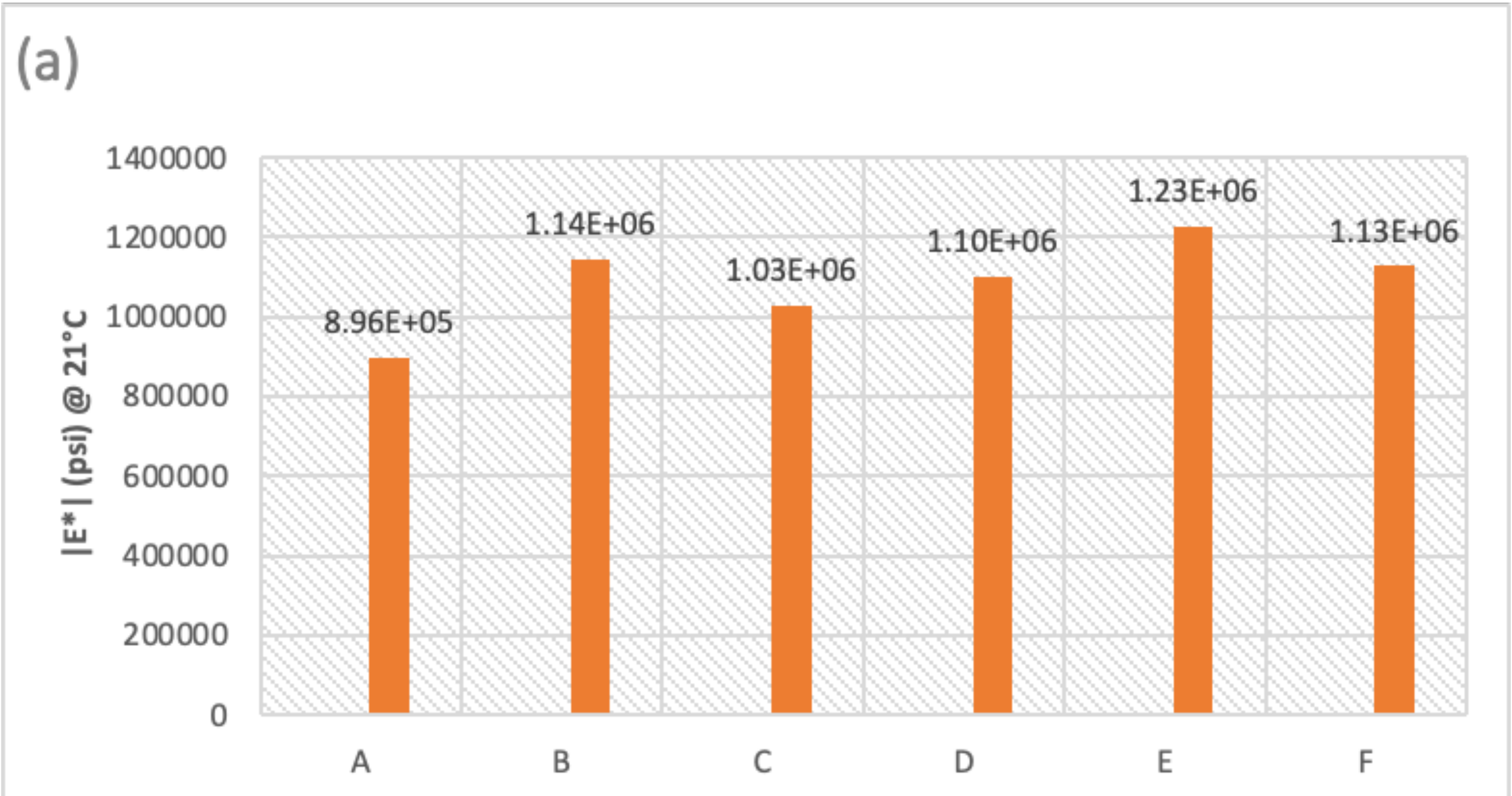
Cantabro test results



Graph. 3 Cantabro mass loss results for tested mixtures.

Dynamic Modulus Test



Graph.4 Dynamic modulus results: (a) measured dynamic modulus values at T = 21°C and (b) T = 54°C; (c) log-log scale dynamic modulus master curves and (d) linear-log scale dynamic modulus master curves

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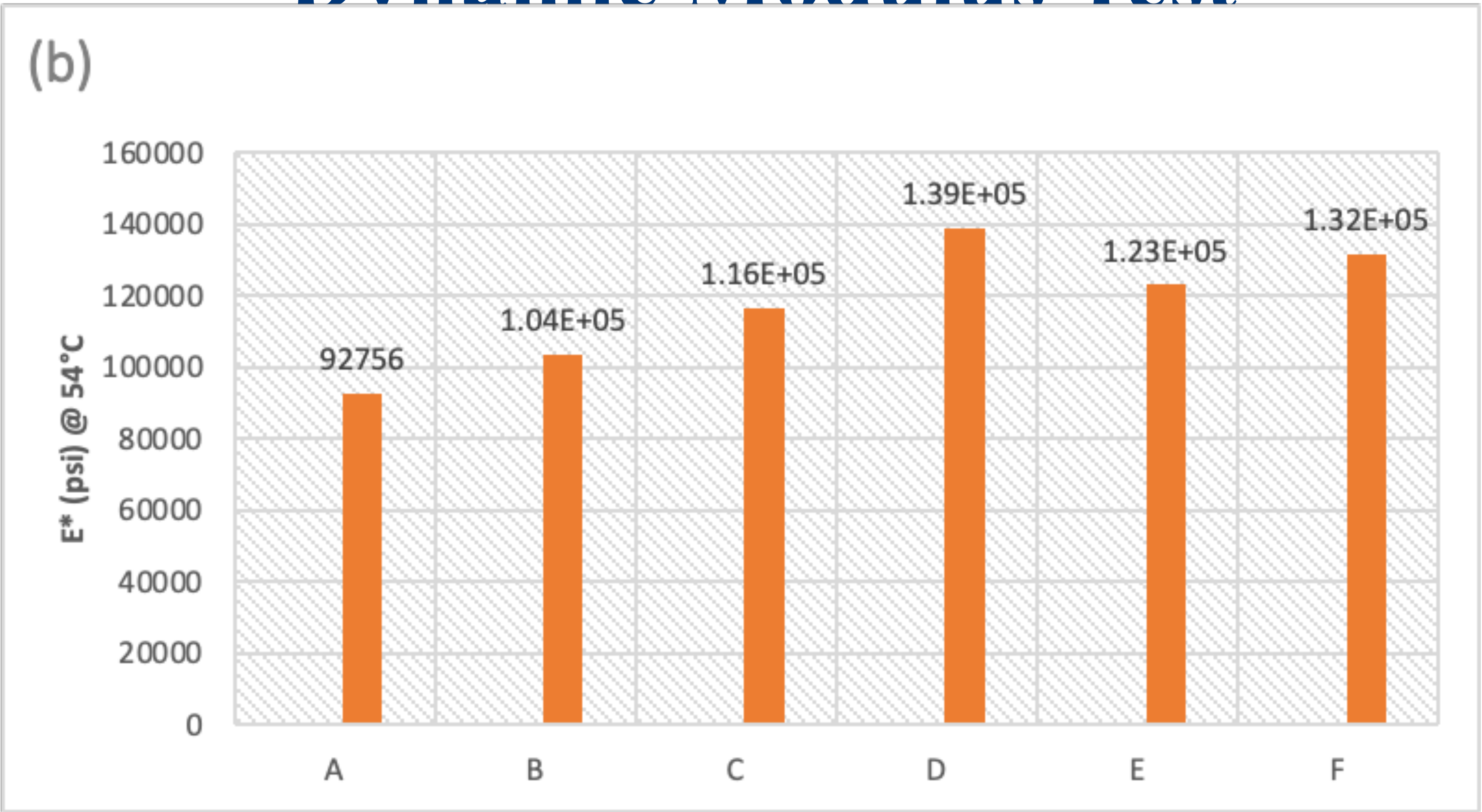
Dynamic Modulus Test



Graph 4. Dynamic modulus results: (a) measured dynamic modulus values at T = 21°C and (b) T = 54°C; (c) log-log scale dynamic modulus master curves and (d) linear-log scale dynamic modulus master curves

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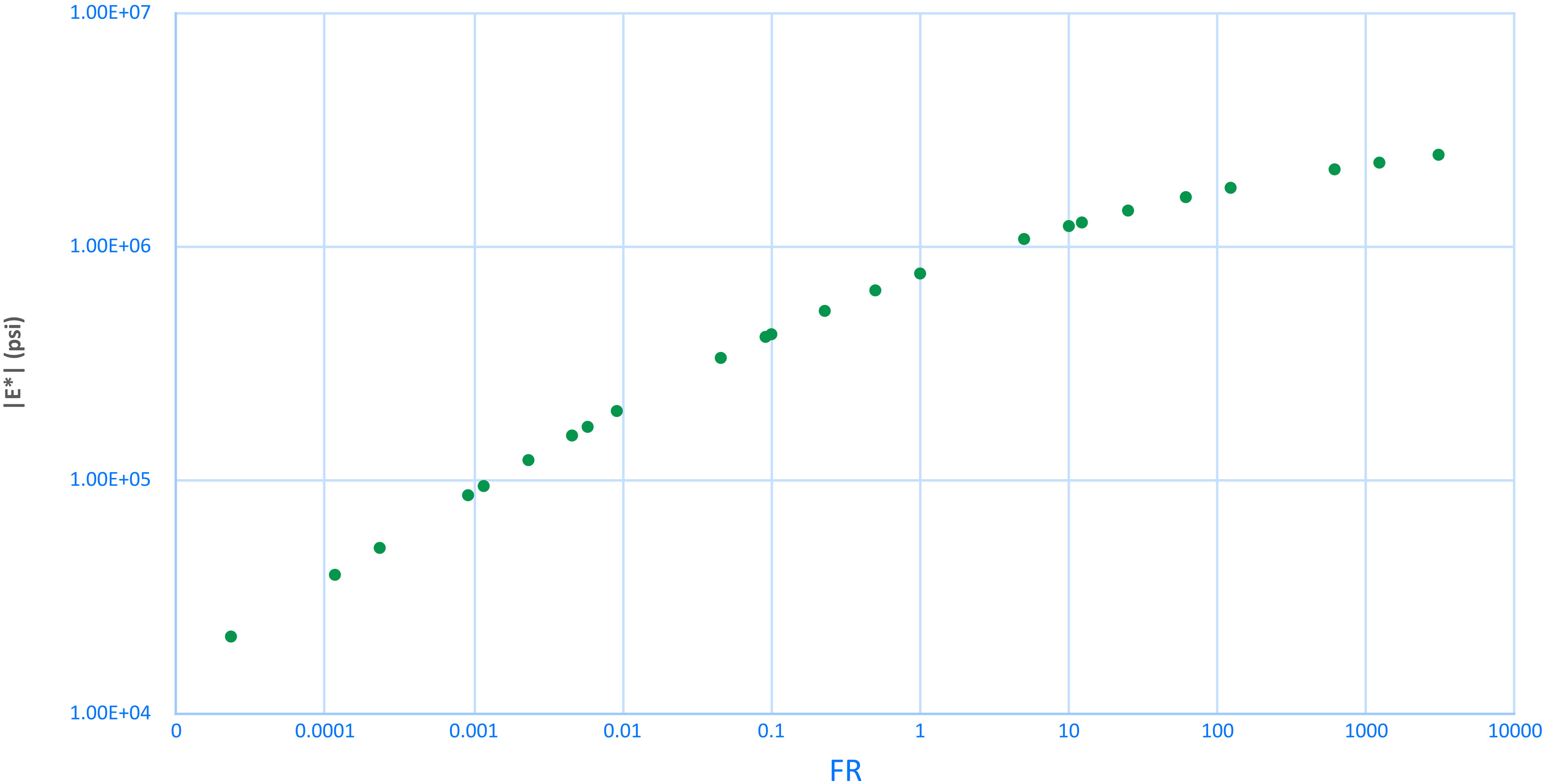
Dynamic Modulus Test



Graph. 4 Dynamic modulus results: (a) measured dynamic modulus values at T = 21°C and (b) T = 54°C; (c) log-log scale dynamic modulus master curves and (d) linear-log scale dynamic modulus master curves

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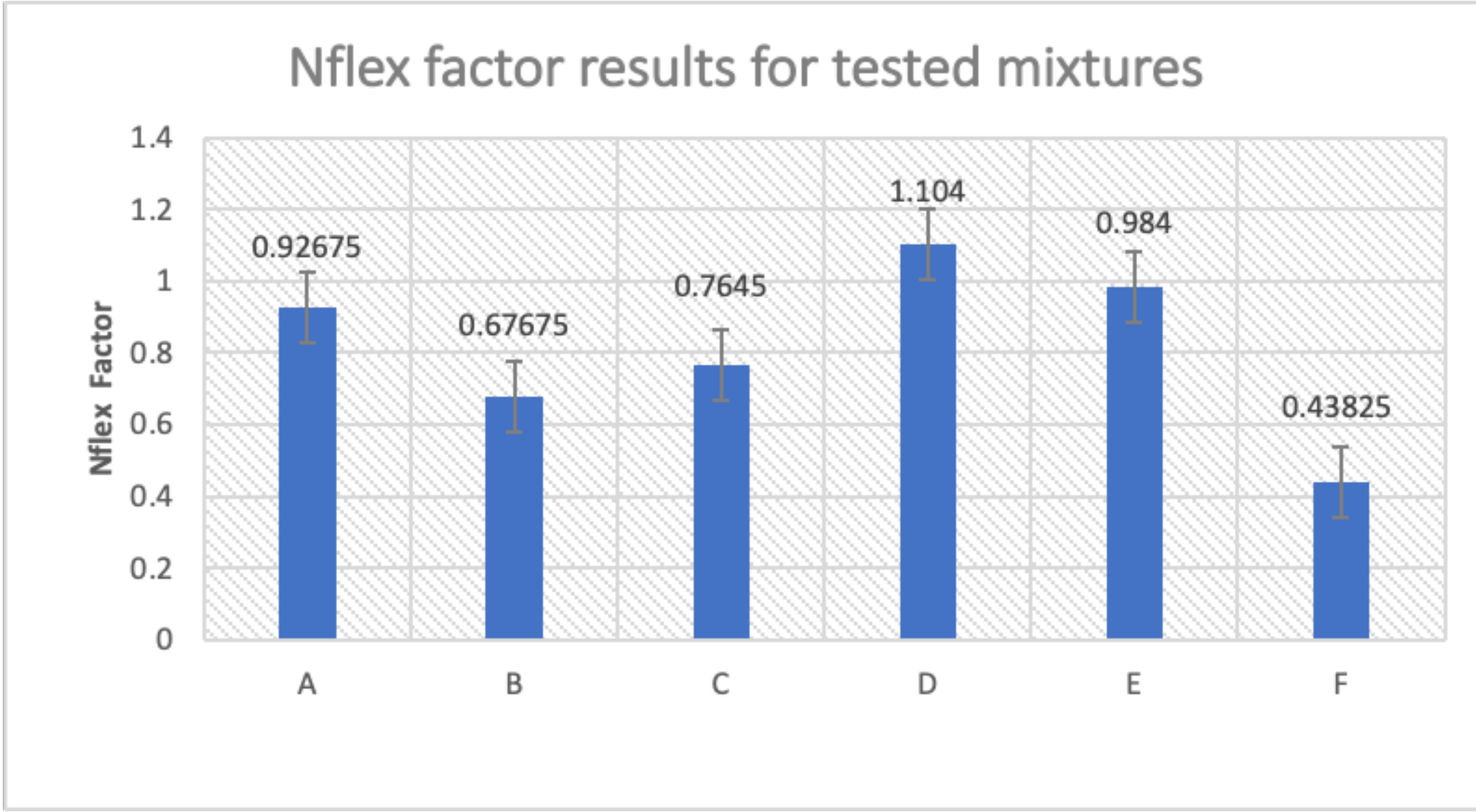
N_{flex} Factor



Graph. 5 N_{flex} factor results for tested mixtures.

Indirect Tensile Asphalt Cracking Test

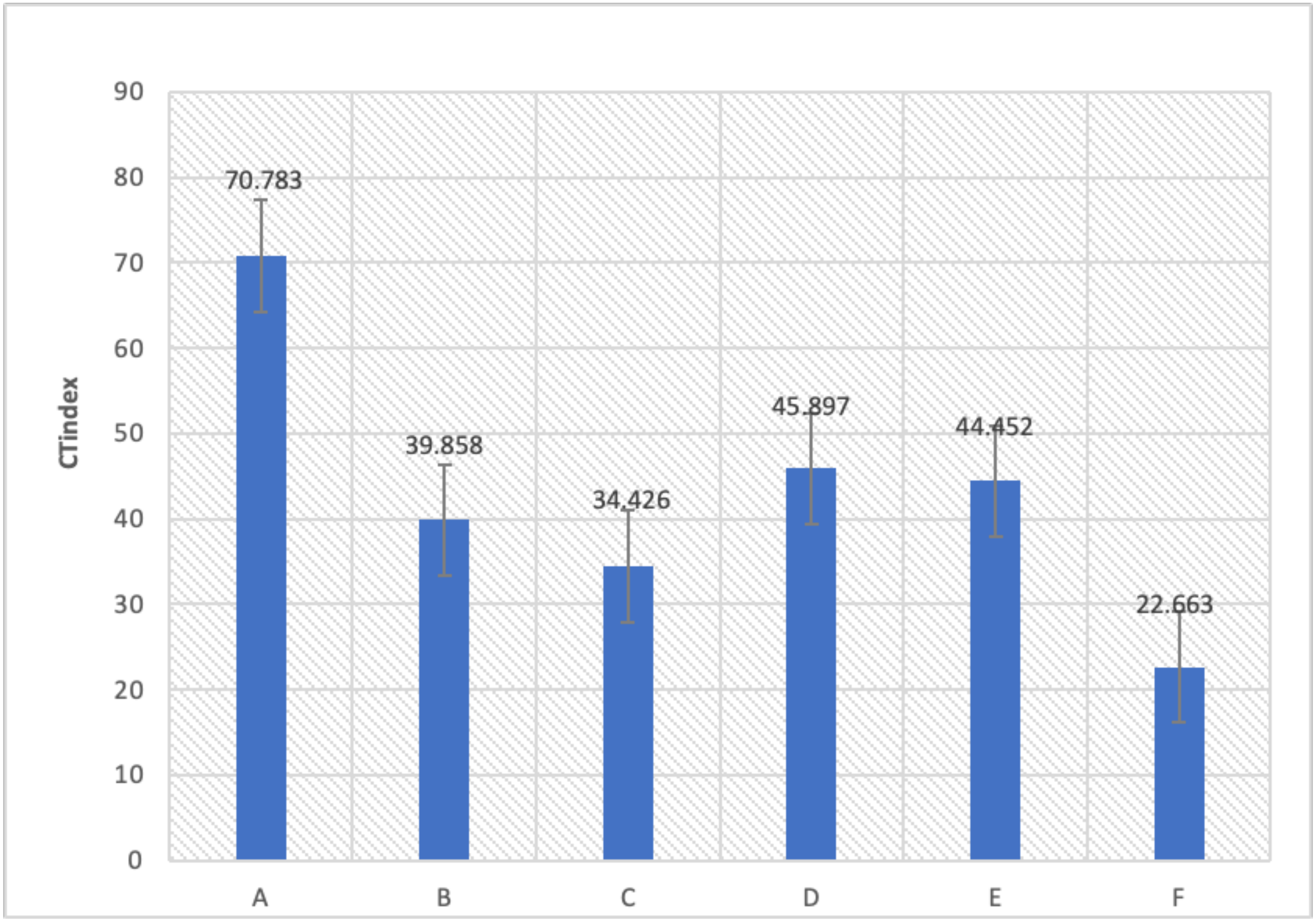


Fig. 6 CT_{index} results for tested mixtures.

Repeated Load Permanent Deformation

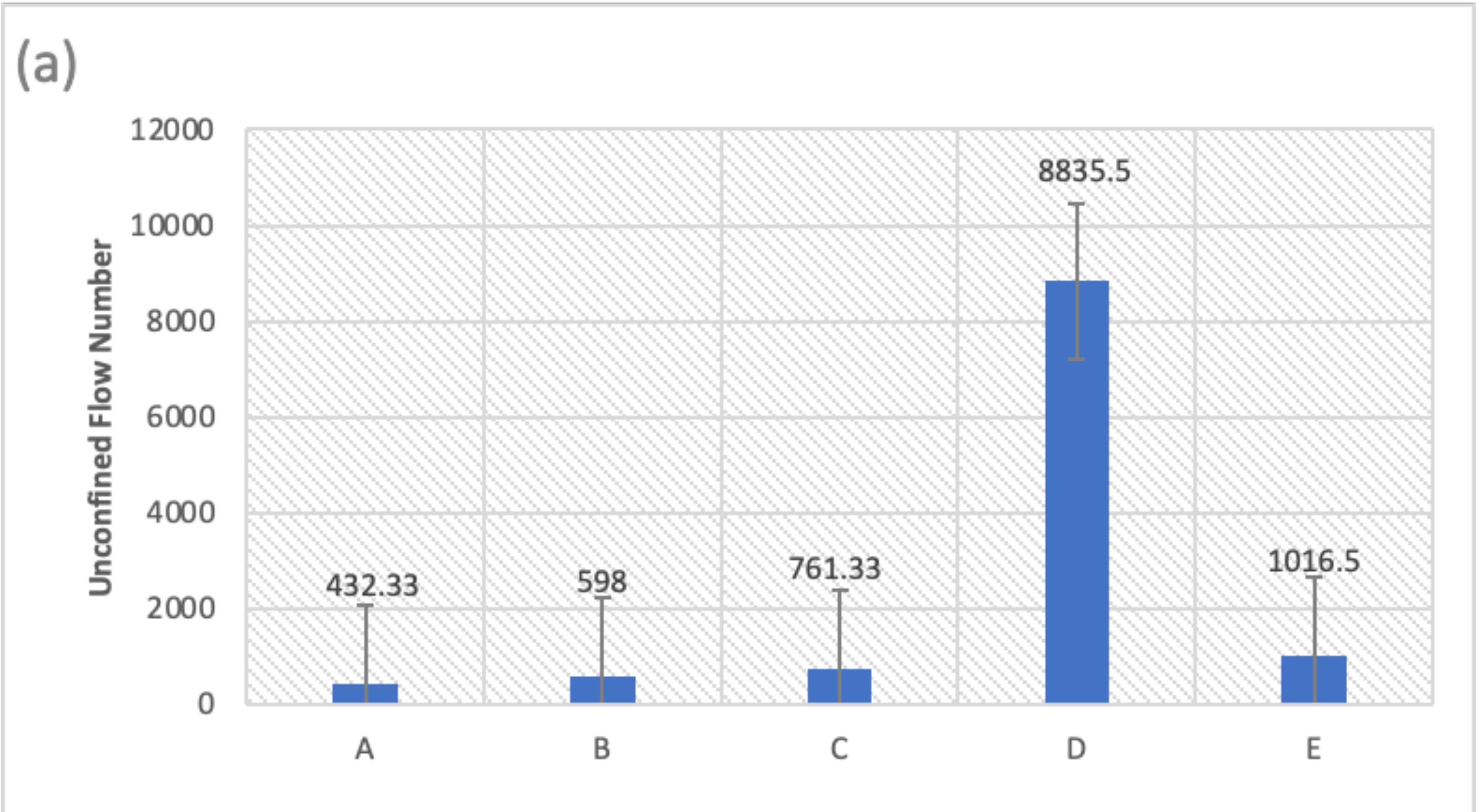
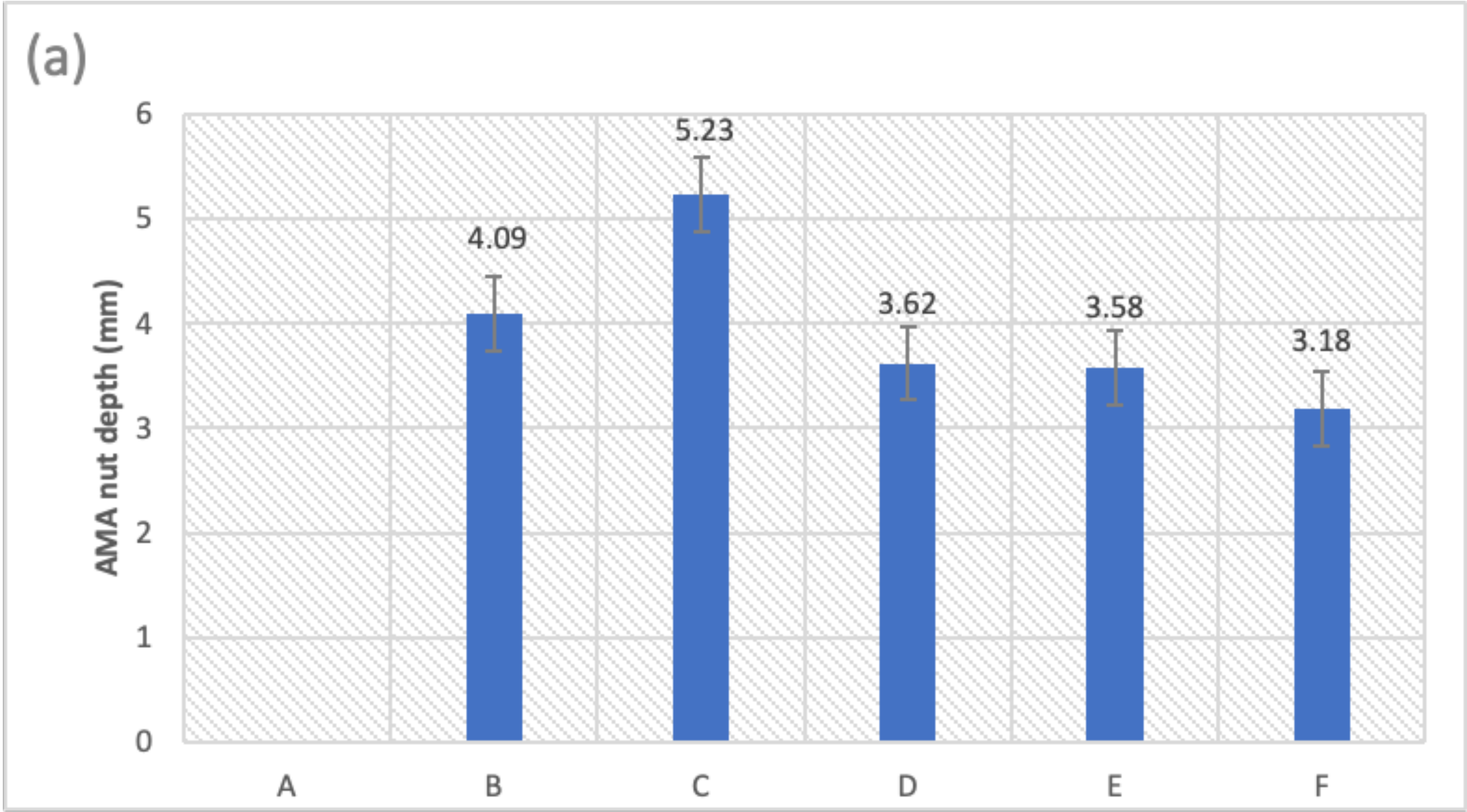


Fig. 7 Flow number results for (a) unconfined condition; (b) confined condition.

Asphalt Pavement Analyzer



Graph 7. Average APA rut depth test results.

Statistical Comparison of Asphalt Mixture Performance Tests

Table 5 Tukey Pairwise Comparison of Cracking Tests

Test	Evaluation Parameter	Mix ID					
		A	B	C	D	E	F
Cantabro	Mass loss	A	A	A	B	A	A
IDT	N_{flex} factor	A, B	C	B, C	A	A	D
IDEAL-CT	CT_{index}	A	B	B, C	B	B	C
APA	Rut depth	_[b]	A	A	A	A	A
Unconfined RLPD	Flow number	B	B	B	A	B	B
Confined RLPD	Flow number	A	A	B	A	A, B	A

[b] No rutting deformation was experienced by mixture A.

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Conclusions

- RAP can be used in new asphalt pavements as well as maintenance and rehabilitation projects for existing pavements
- lower construction costs
- conserve natural resources
- avoid using landfills, and improve sustainability
- Possible to achieve cracking resistance for high RAP mixtures that is similar to the cracking resistance of non-RAP mixes by using a lower-grade virgin binder to counteract the aged binder in high RAP combinations.

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