

Evaluation of DSR Creep-Recovery Testing as a Replacement for PG Plus Tests

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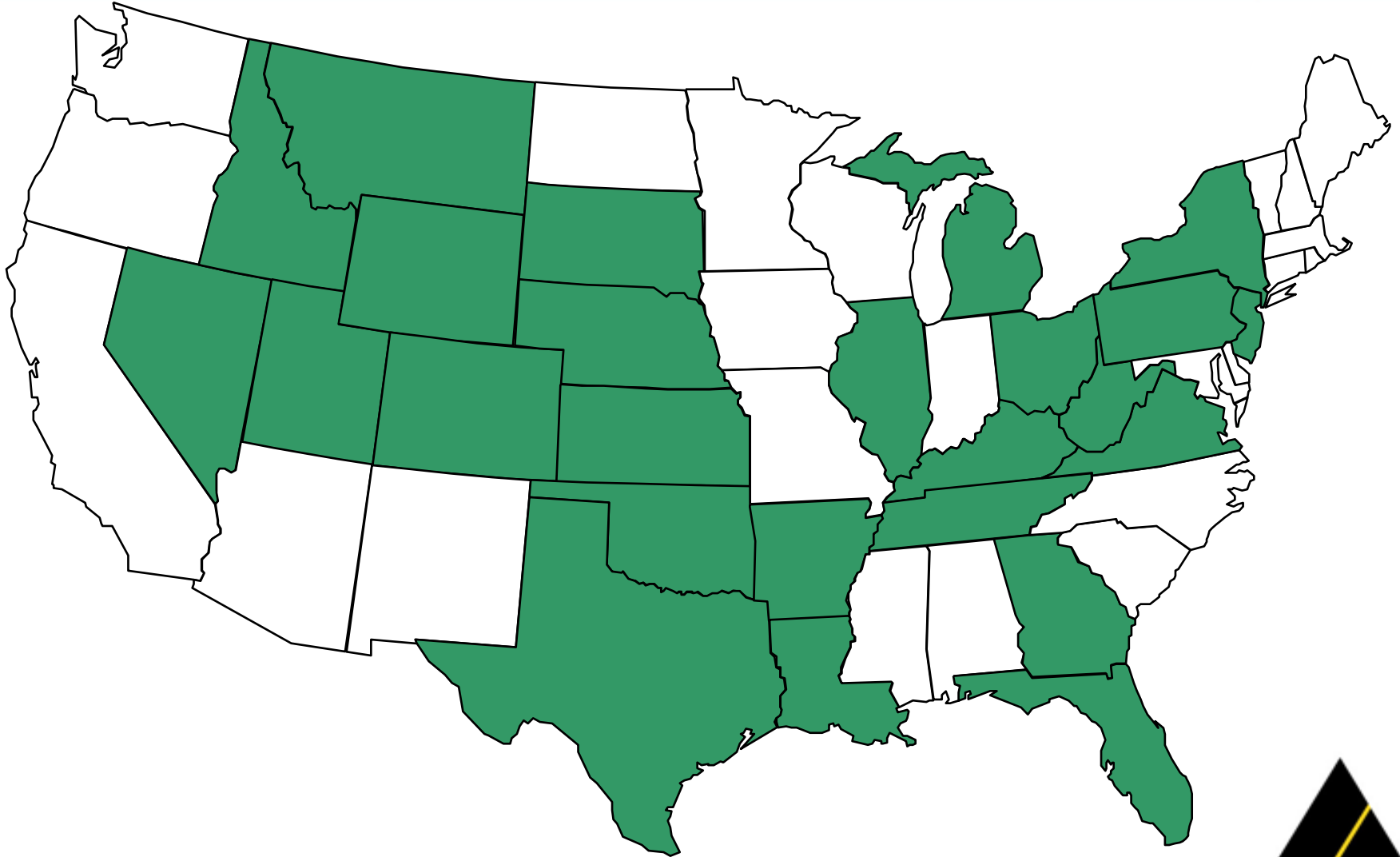
Research Background

- PG+ Tests
 - Commonly used by many agencies in addition to AASHTO M320 specification
 - Ensure polymer modification of “premium” asphalt binders
 - Elastic Recovery
 - Force Ductility
 - Phase Angle
 - Toughness and Tenacity



(2005)

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- Research Objective
 - Can a single test be used to replace the current suite of AASHTO M320+ tests?
 - Evaluate the Multiple Stress Creep Recovery (MSCR) test as potential replacement



MSCR: Multiple Stress Creep Recovery Test

- Modification of Procedure Evaluated by NCHRP 9-10 Research Project
 - “Superpave Protocols for Modified Asphalt Binders”
 - Completed in 2000
 - Repeated Shear Creep Test
 - Low shear stress (30, 100 Pa)
 - Analogous to mixture rutting test developed during SHRP
 - Repeated Shear Test at Constant Height

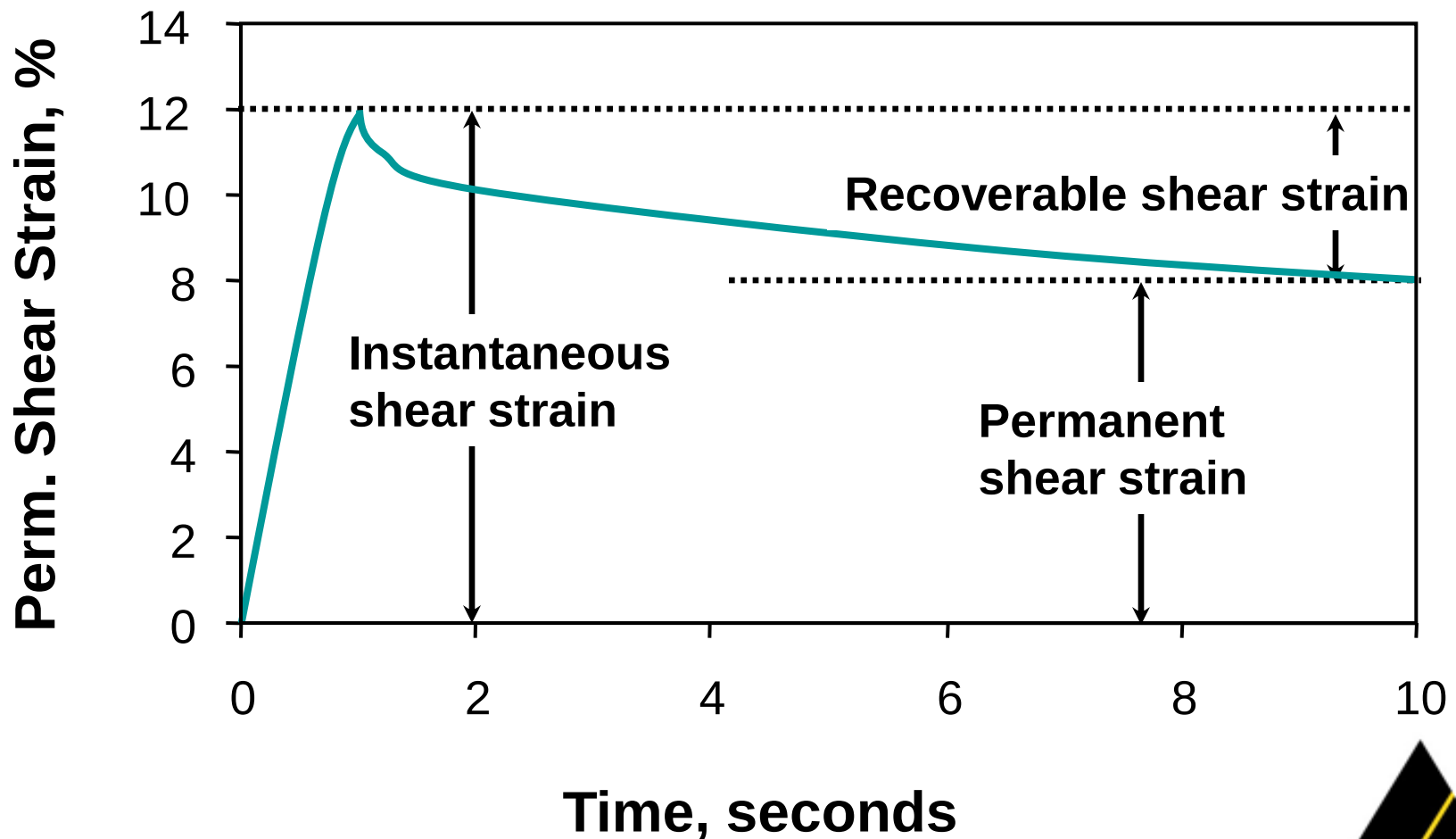


MSCR: Multiple Stress Creep Recovery Test

- Performed on RTFO-aged Binder
- 10 cycles per stress level
 - 1-second loading at specified shear stress
 - 100 Pa
 - 3200 Pa
 - 9-second rest period
- Calculate Recovery for each Cycle, Stress
 - Difference between strain at end of recovery period and peak strain after creep loading



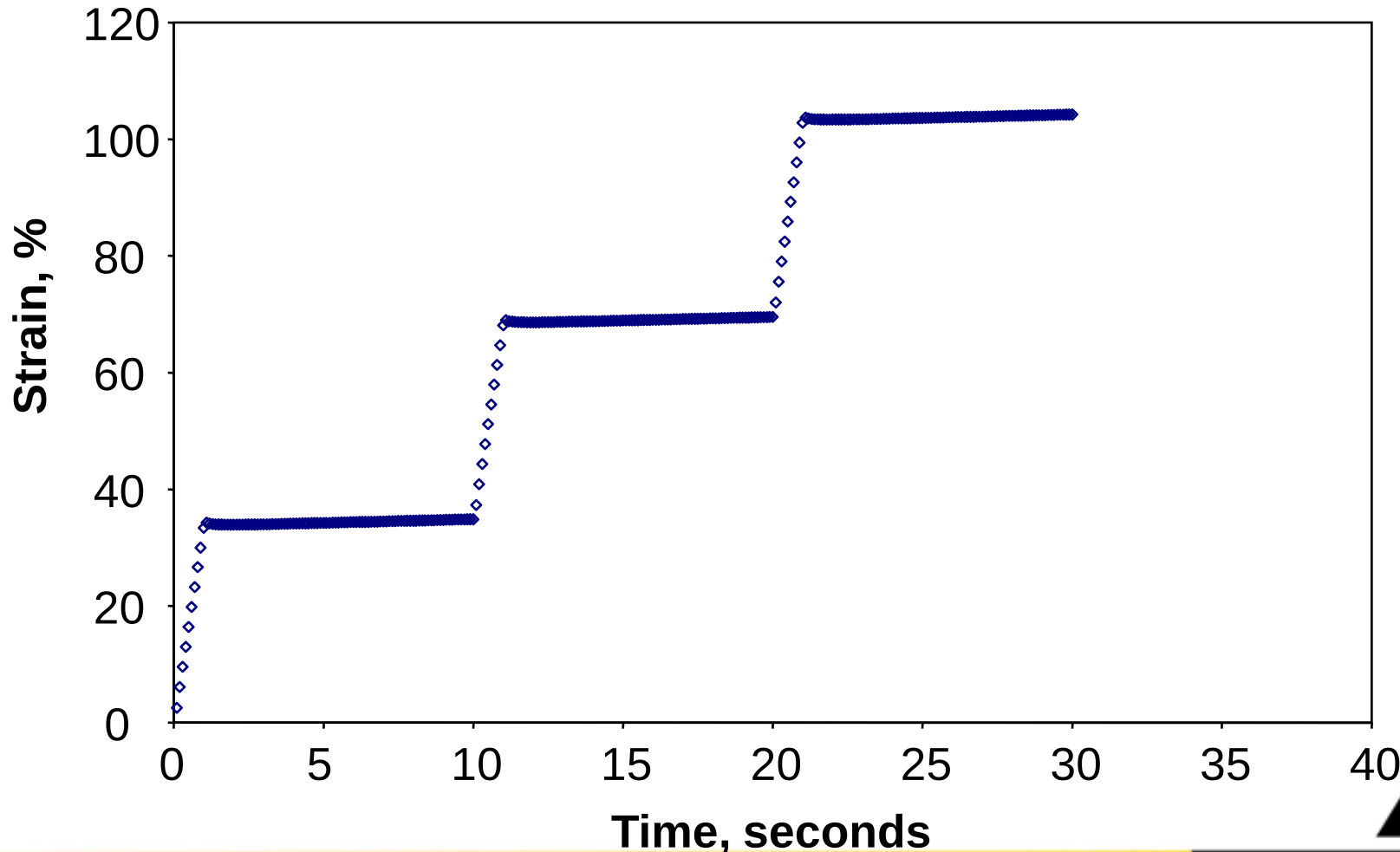
Repeated Shear Creep



Repeated Shear Creep Recovery Test – Unmodified Asphalt Binder

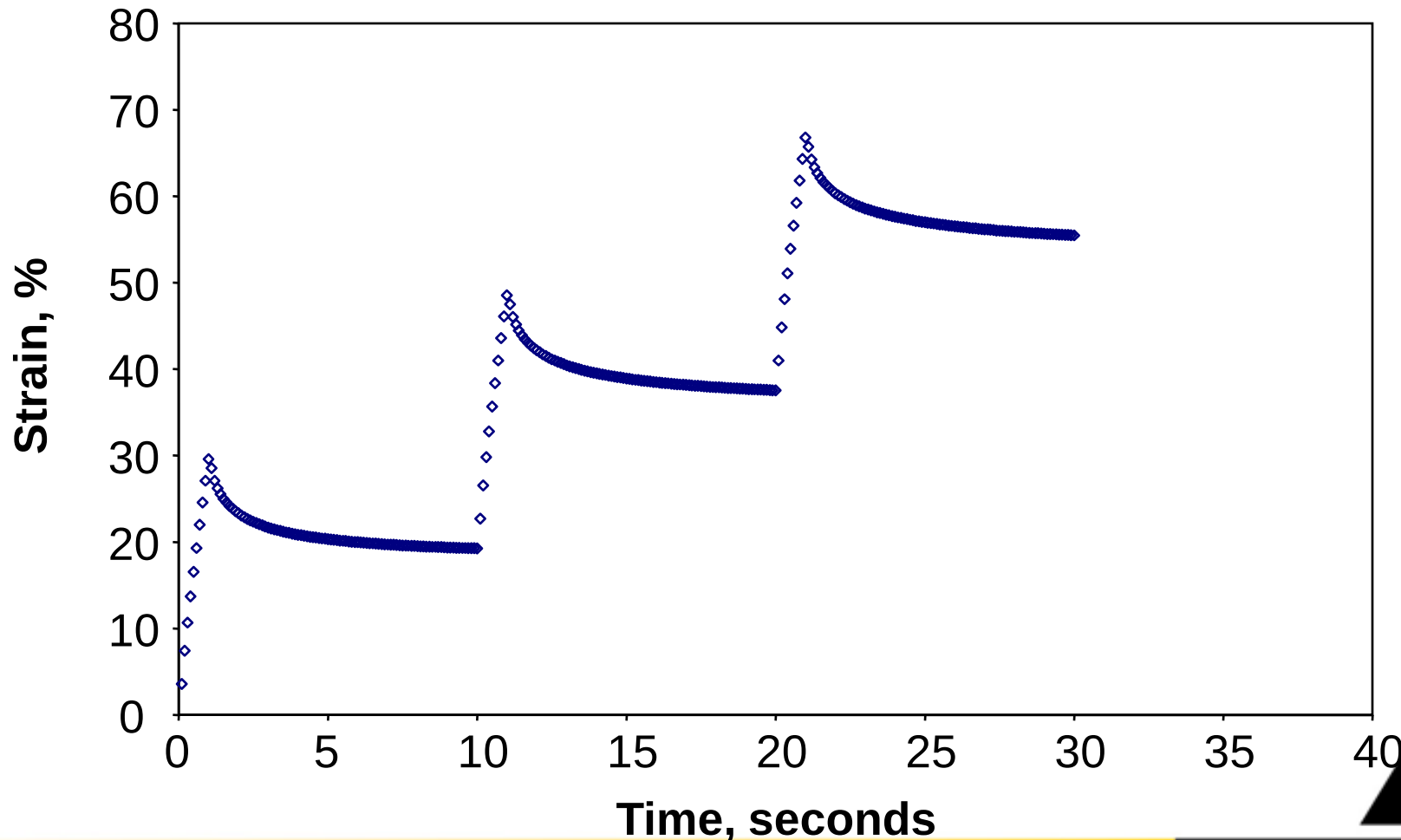
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100 Pa Shear Stress



Repeated Shear Creep Recovery Test – Modified Asphalt Binder

100 Pa Shear Stress



MSCR Calculations

Meas. Pts.	Time [s]	Shear Stress [Pa]	Strain [%]
1	0.1	100	2.69374
2	0.2	100	4.93844
3	0.3	100	6.80793
4	0.4	100	8.44763
5	0.5	100	9.9813
6	0.6	100	11.3947
7	0.701	100	12.7678
8	0.801	100	14.0523
9	0.901	100	15.3203
10	1.001	100	16.5372
11	1.101	1.911E-23	15.1257
12	1.201	0	13.9755
13	1.301	0	13.2543
14	1.401	0	12.6937
15	1.501	0	12.2402
16	1.601	0	11.8613
17	1.701	0	11.5305
18	1.801	0	11.2409
19	1.901	0	10.9871
20	2.001	0	10.7647

95	9.5	0	6.59212
96	9.6	0	6.57239
97	9.701	0	6.55293
98	9.801	0	6.53421
99	9.901	0	6.51511
100	10.001	0	6.49638

γ_0 = initial strain

γ_c = strain at the end of creep

γ_1 = total strain at 1 second

γ_r = strain at the end of recovery

γ_{10} = total strain at 10 seconds

$$\gamma_1 = \gamma_c - \gamma_0$$

$$\gamma_{10} = \gamma_r - \gamma_0$$

$$\text{Recovery} = 100 \times \frac{\gamma_1 - \gamma_{10}}{\gamma_1}$$



MSCR Calculations

Meas. Pts.	Time [s]	Shear Stress [Pa]	Strain [%]
1	0.1	100	2.69374
2	0.2	100	4.93844
3	0.3	100	6.80793
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97	9.701	0	6.55293
98	9.801	0	6.53421
99	9.901	0	6.51511
100	10.001	0	6.49638

γ_0 = initial strain = 0 for 1st cycle

γ_c = strain at the end of creep

γ_r = strain at the end of recovery

$$\gamma_1 = \gamma_c - \gamma_0 = 16.5372 - 0 = \mathbf{16.5372}$$

$$\gamma_{10} = \gamma_r - \gamma_0 = 6.49638 - 0 = \mathbf{6.49638}$$

$$\text{Recovery} = 100 \times \frac{16.5372 - 6.49638}{16.5372}$$

$$\mathbf{Recovery = 60.7\%}$$



MSCR Recovery Calculations

Stress Cycle	100 γ_0	γ_c	γ_1	γ_r	γ_{10}	Recovery
1	0	16.5372	16.5372	6.49638	6.49638	60.7
2	6.49638	22.8361	16.33972	11.9803	5.48392	66.4
3	11.9803	28.2682	16.2879	16.9871	5.0068	69.3
4	16.9871	32.0753	15.0882	21.1416	4.1545	72.5
5	21.1416	37.4008	16.2592	25.8388	4.6972	71.1
6	25.8388	42.0499	16.2111	30.3187	4.4799	72.4
7	30.3187	45.3137	14.995	34.0392	3.7205	75.2
8	34.0392	49.0296	14.9904	37.7441	3.7049	75.3
9	37.7441	53.9674	16.2233	42.0626	4.3185	73.4
10	42.0626	58.2654	16.2028	46.2737	4.2111	74.0
Average						71.0



AI-FHWA MSCR Research

- Sources
 - 23+ different suppliers/locations
- Grades
 - PG 52-34
 - PG 58-28, PG 58-34
 - PG 64-22, PG 64-28, PG 64-34
 - PG 67-22
 - PG 70-22, PG 70-28, PG 70-34
 - PG 76-22, PG 76-28
 - PG 82-22
 - Others (PBA-6A, PBA-6B, PBA-1, PG 94-xx)
- 100+ Binder Samples



AI-FHWA MSCR Research

- Work Plan – Binders
 - DSR
 - Conventional $G^*/\sin \delta$ (Original and RTFO)
 - validate grade, determine phase angle
 - MSCR (Original and RTFO)
 - 100, 3200 Pa
 - 1-second load, 9-second rest per cycle
 - 10 cycles per stress level

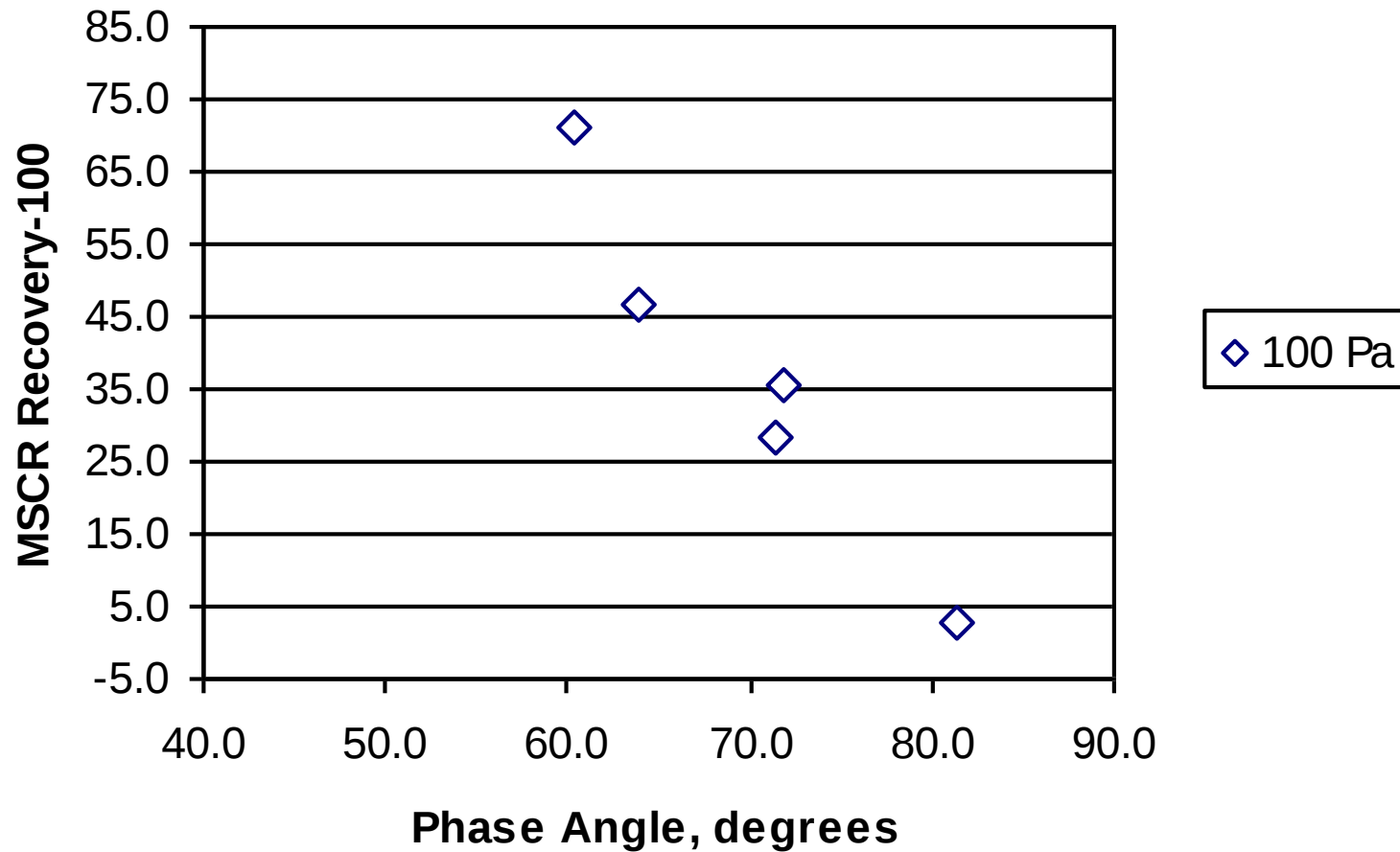


AI-FHWA MSCR Research

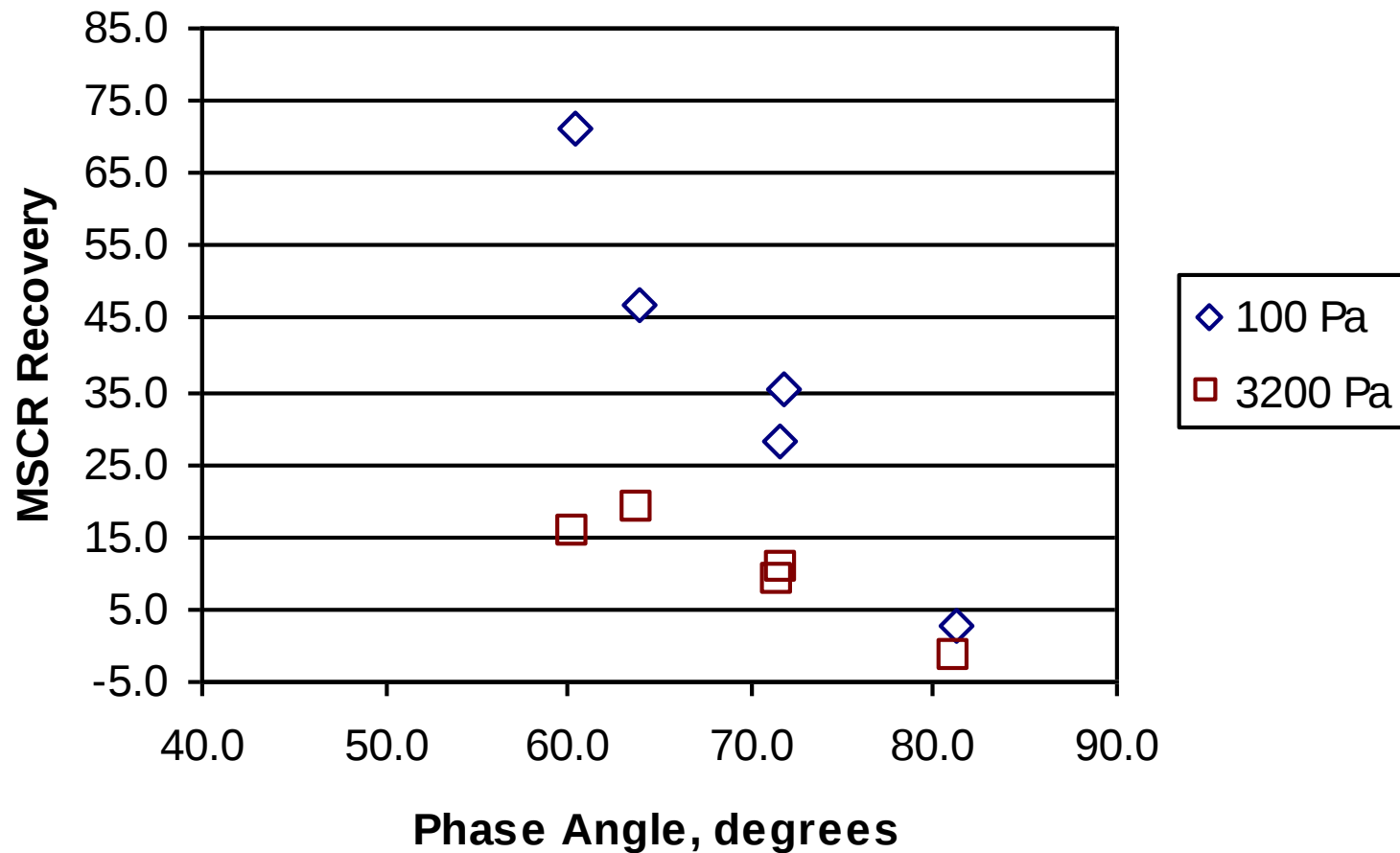
- Work Plan – Binders
 - Elastic Recovery
 - AASHTO T301 at 25 C (Original and RTFO)
 - Force Ductility
 - AASHTO T300 at 4 C (Original)



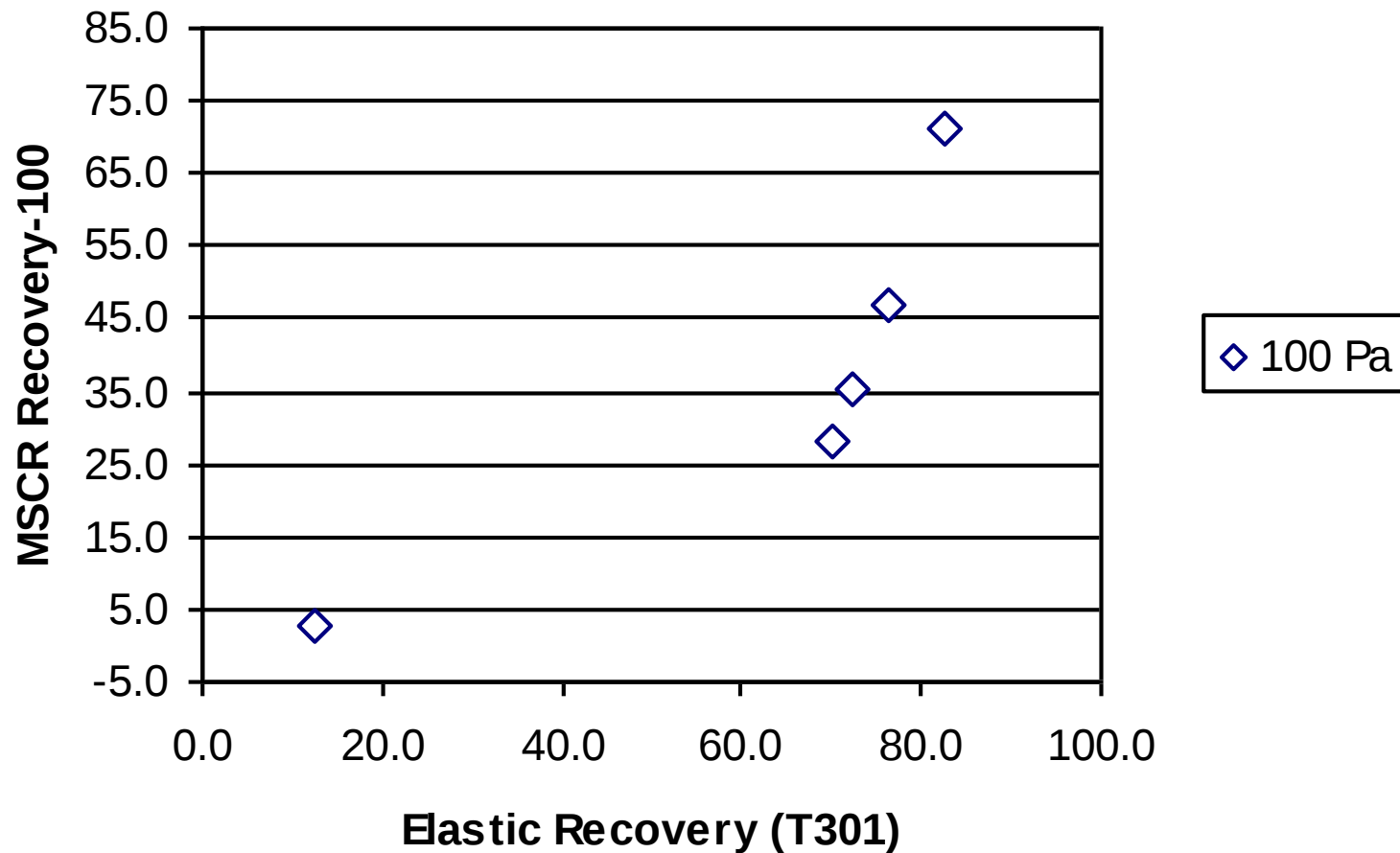
MSCR Results – Single Source



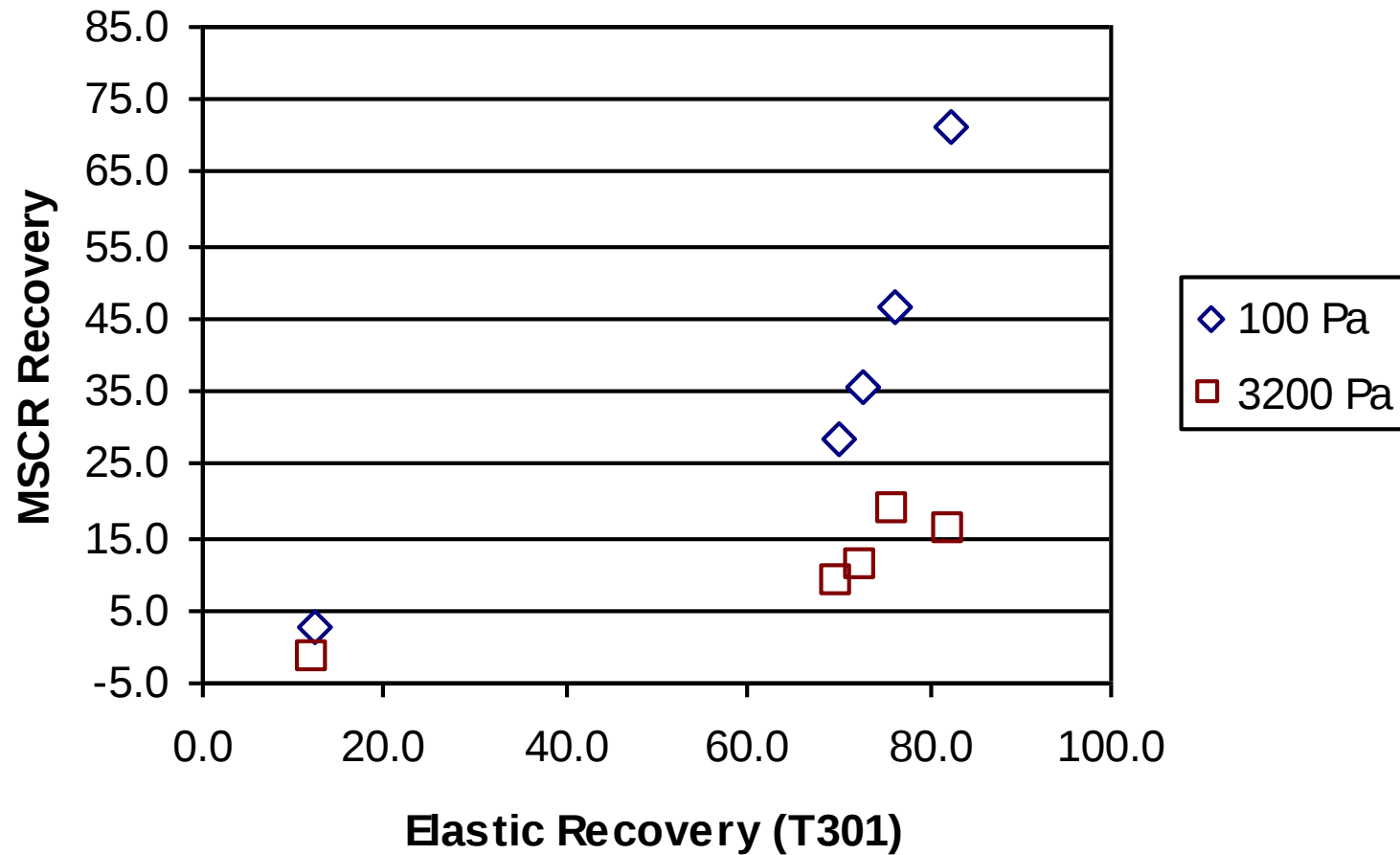
MSCR Results – Single Source



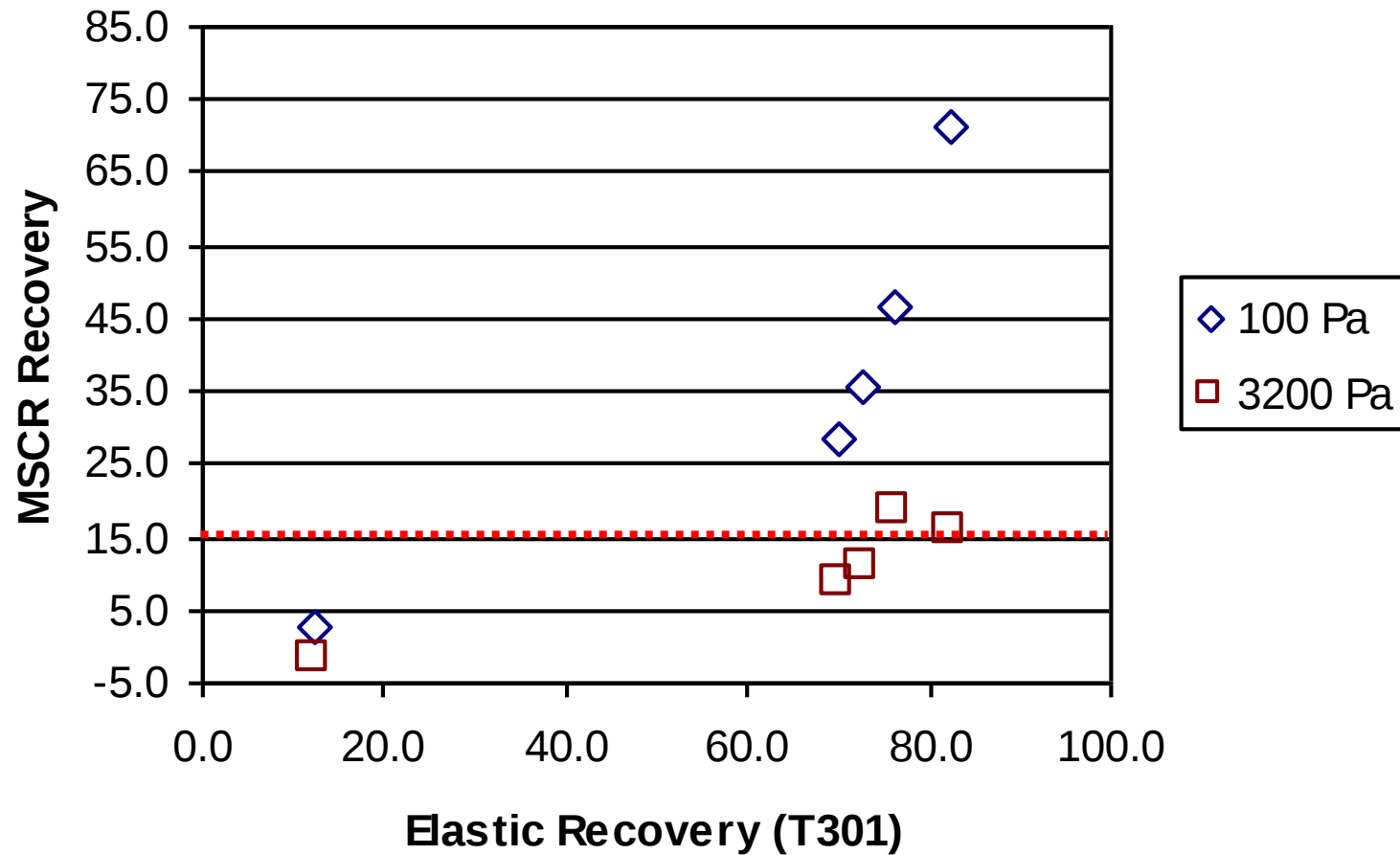
MSCR Results – Single Source



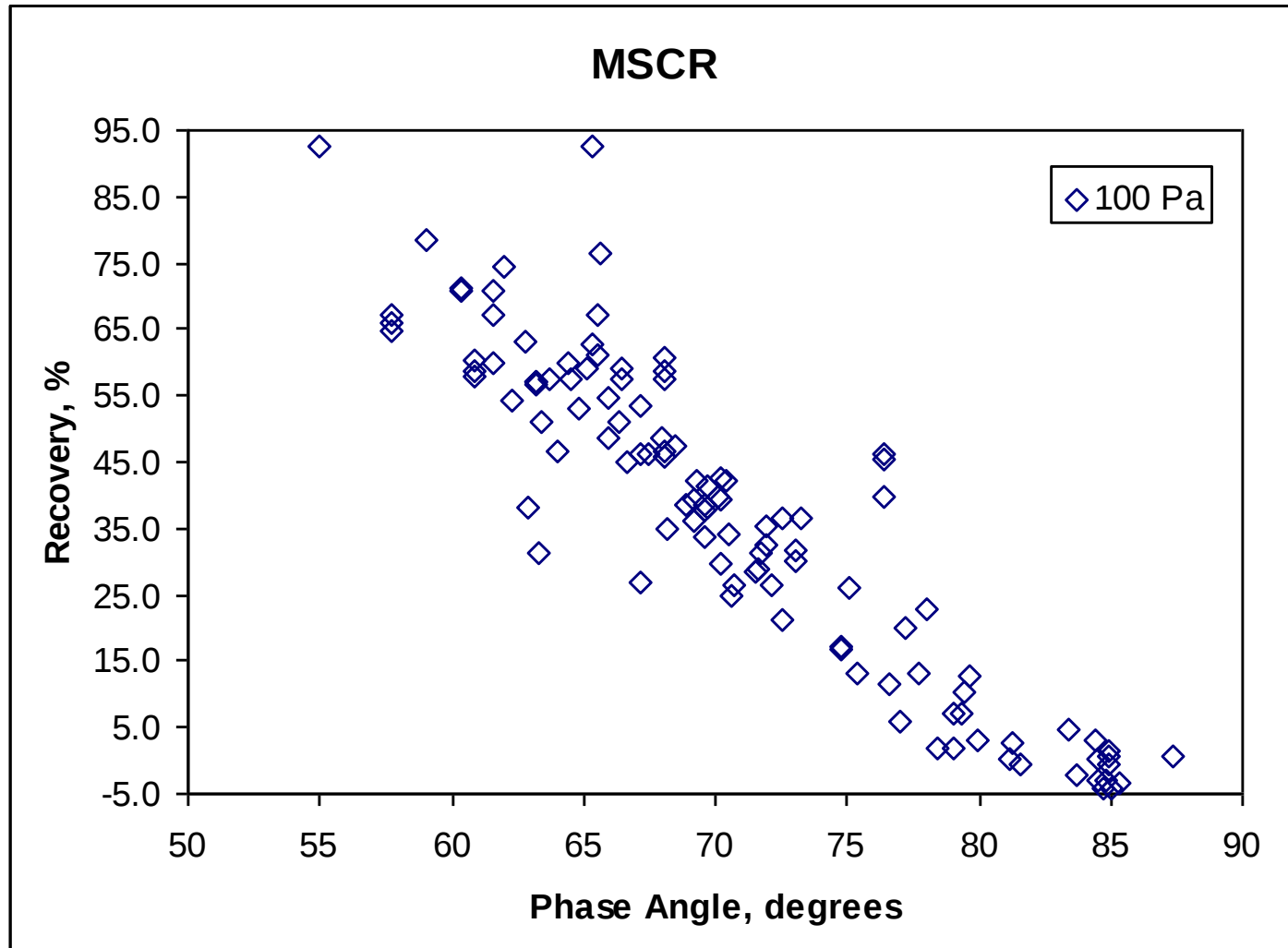
MSCR Results – Single Source



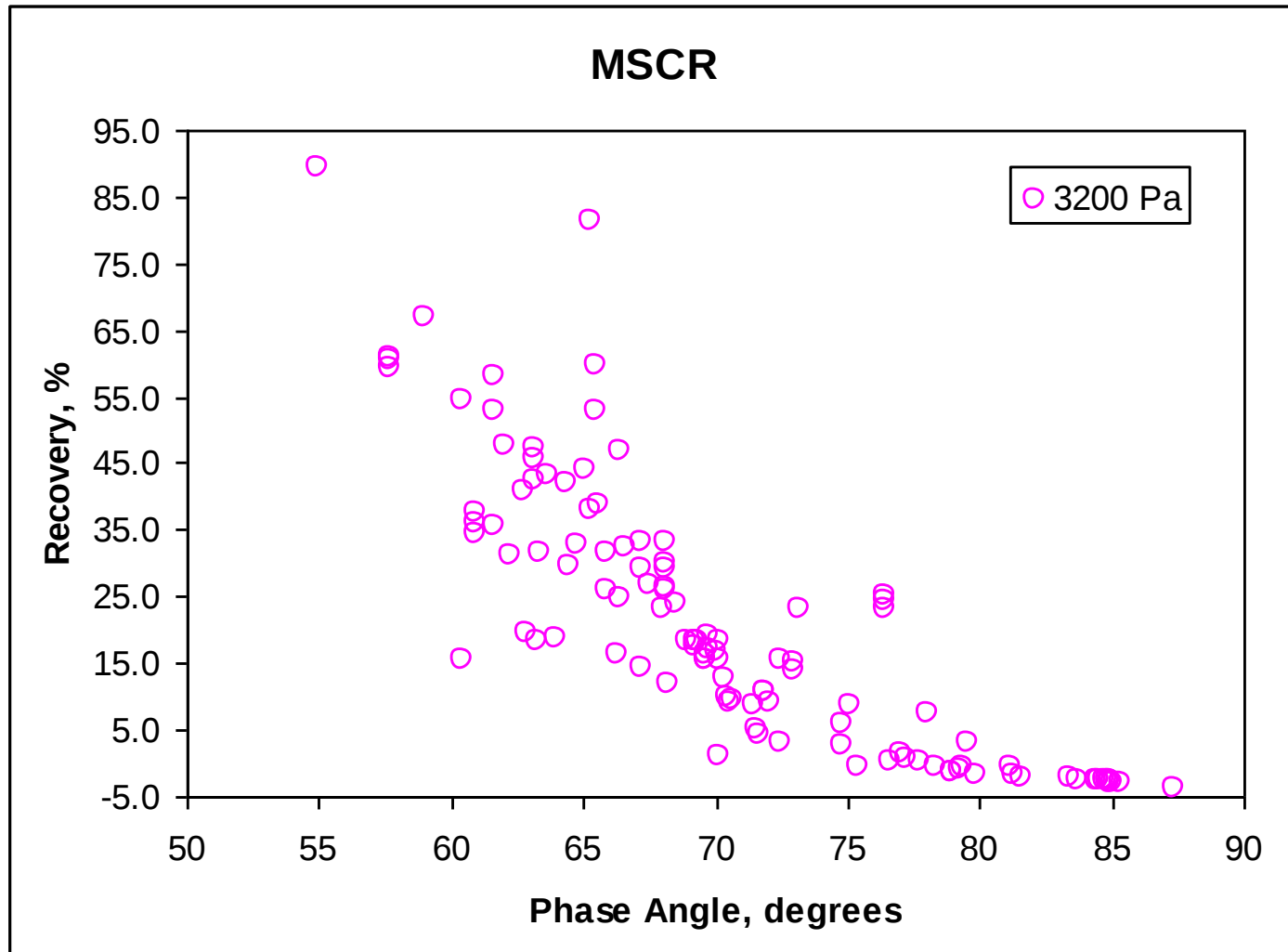
MSCR Results – Single Source



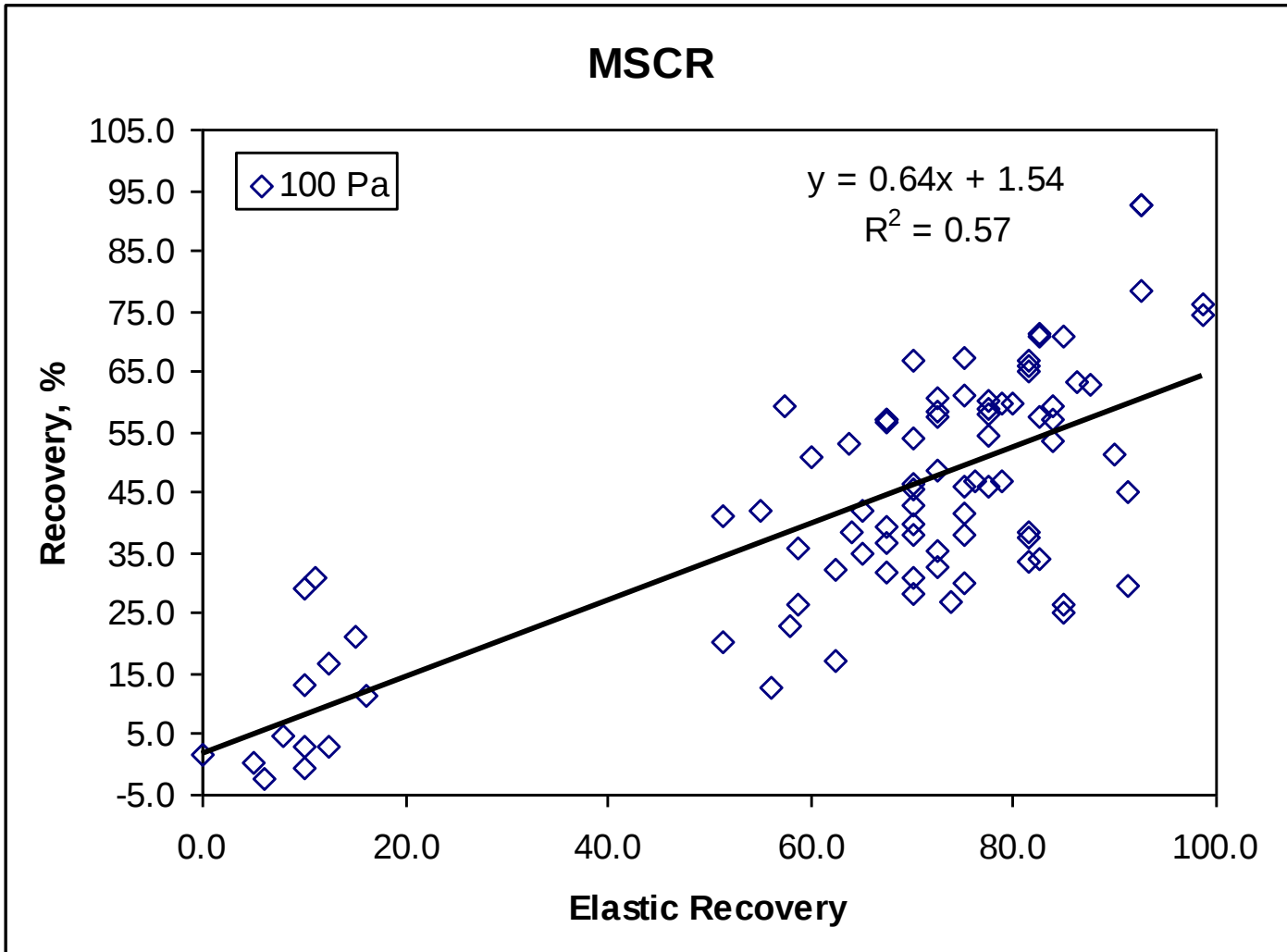
MSCR Recovery: 100 Pa



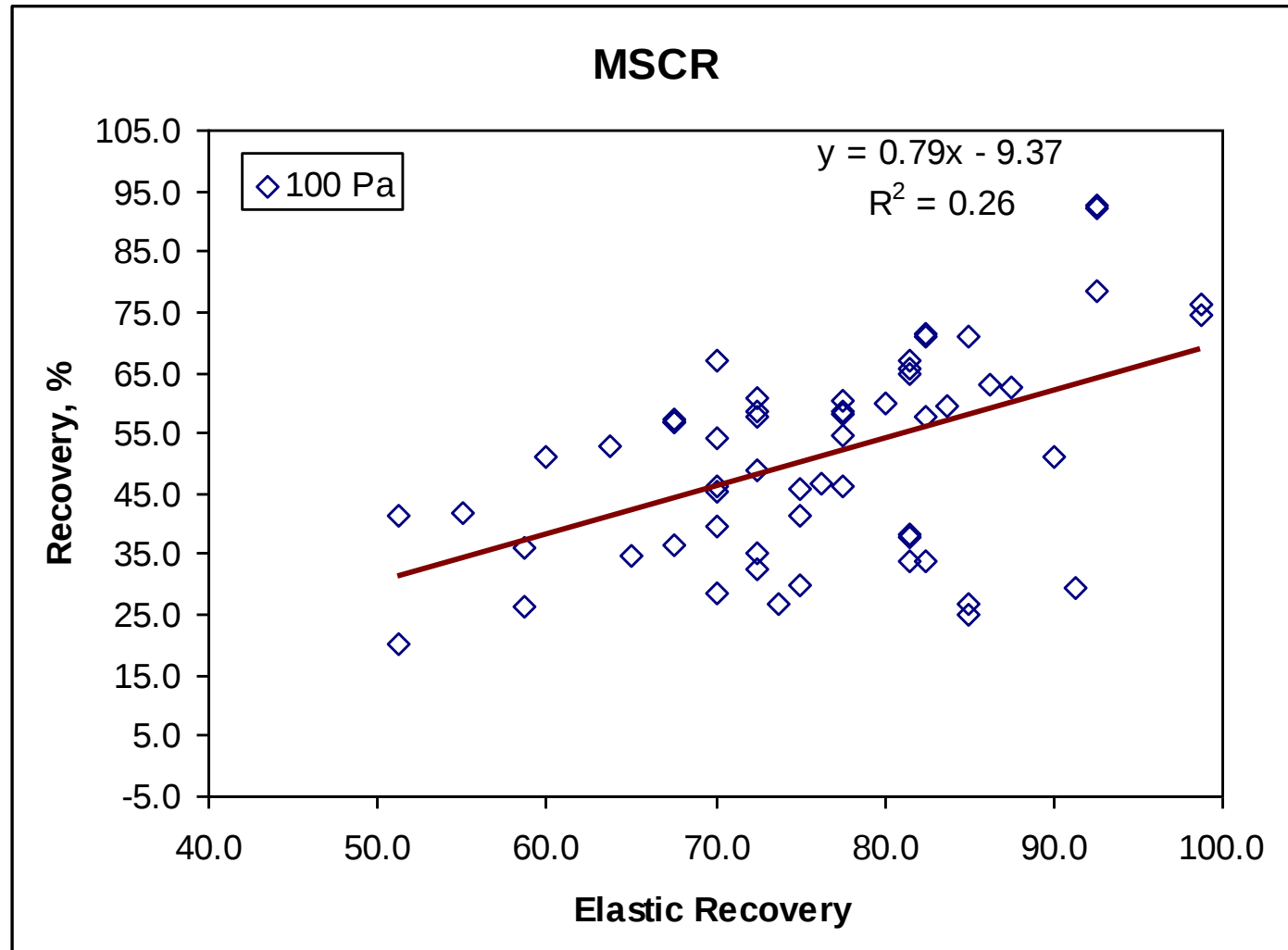
MSCR Recovery: 3200 Pa



Comparison of MSCR-100 Recovery and Elastic Recovery

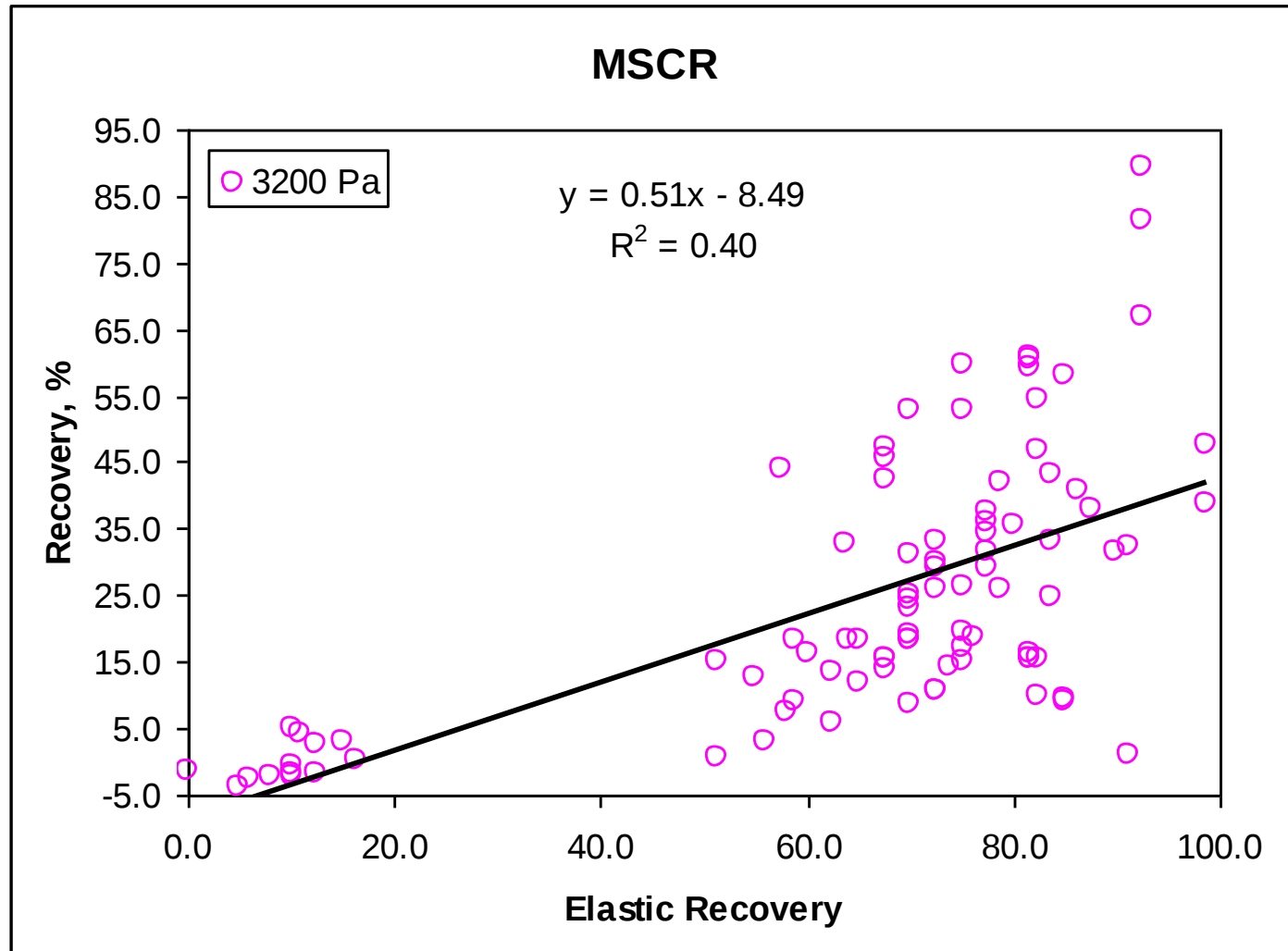


Comparison of MSCR-100 Recovery and Elastic Recovery



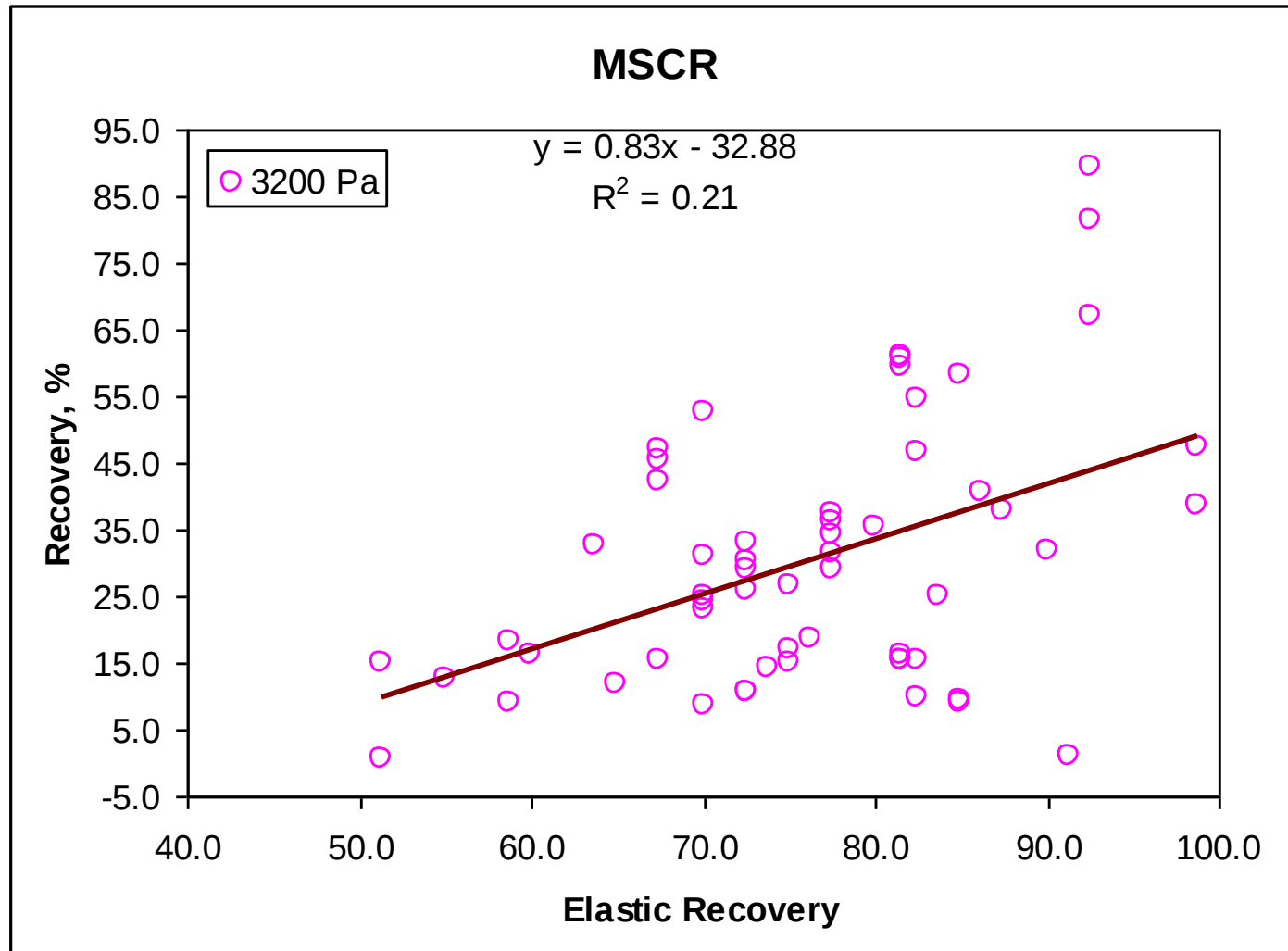
Comparison of MSCR-3200 Recovery and Elastic Recovery

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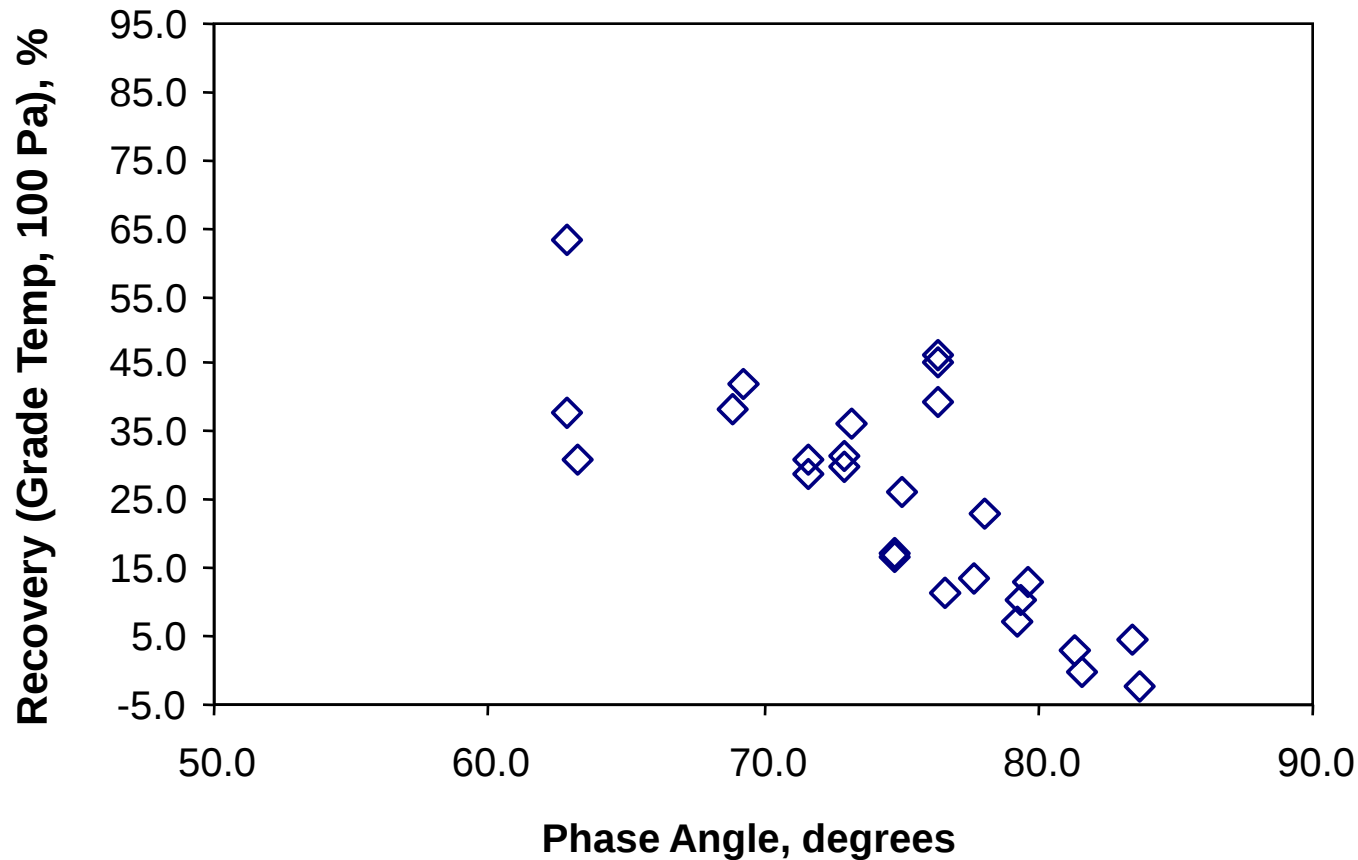
Comparison of MSCR-3200 Recovery and Elastic Recovery

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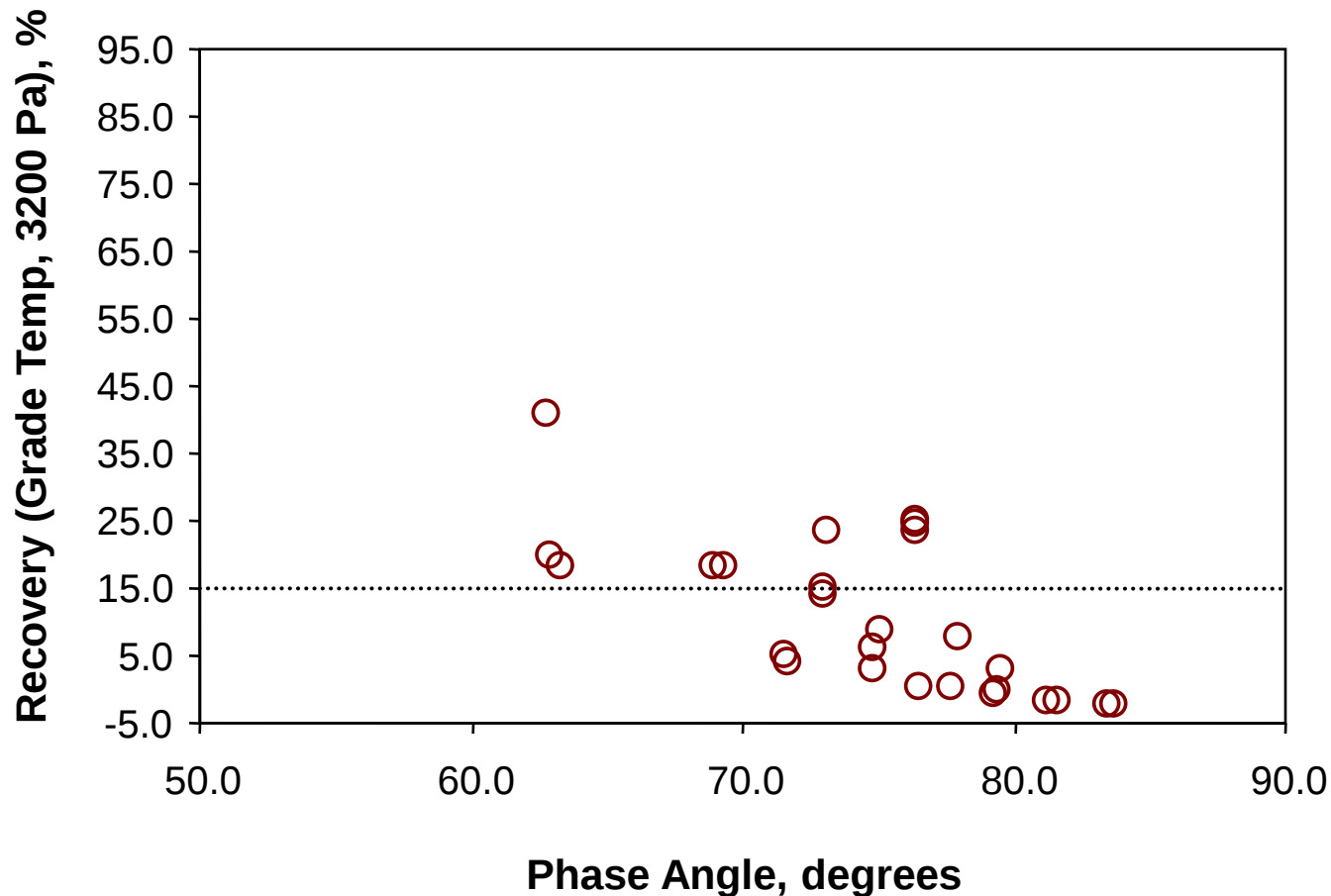
PG 70-22 Binders: MSCR-100 Recovery

MSCR: PG 70-22 Asphalt Binders



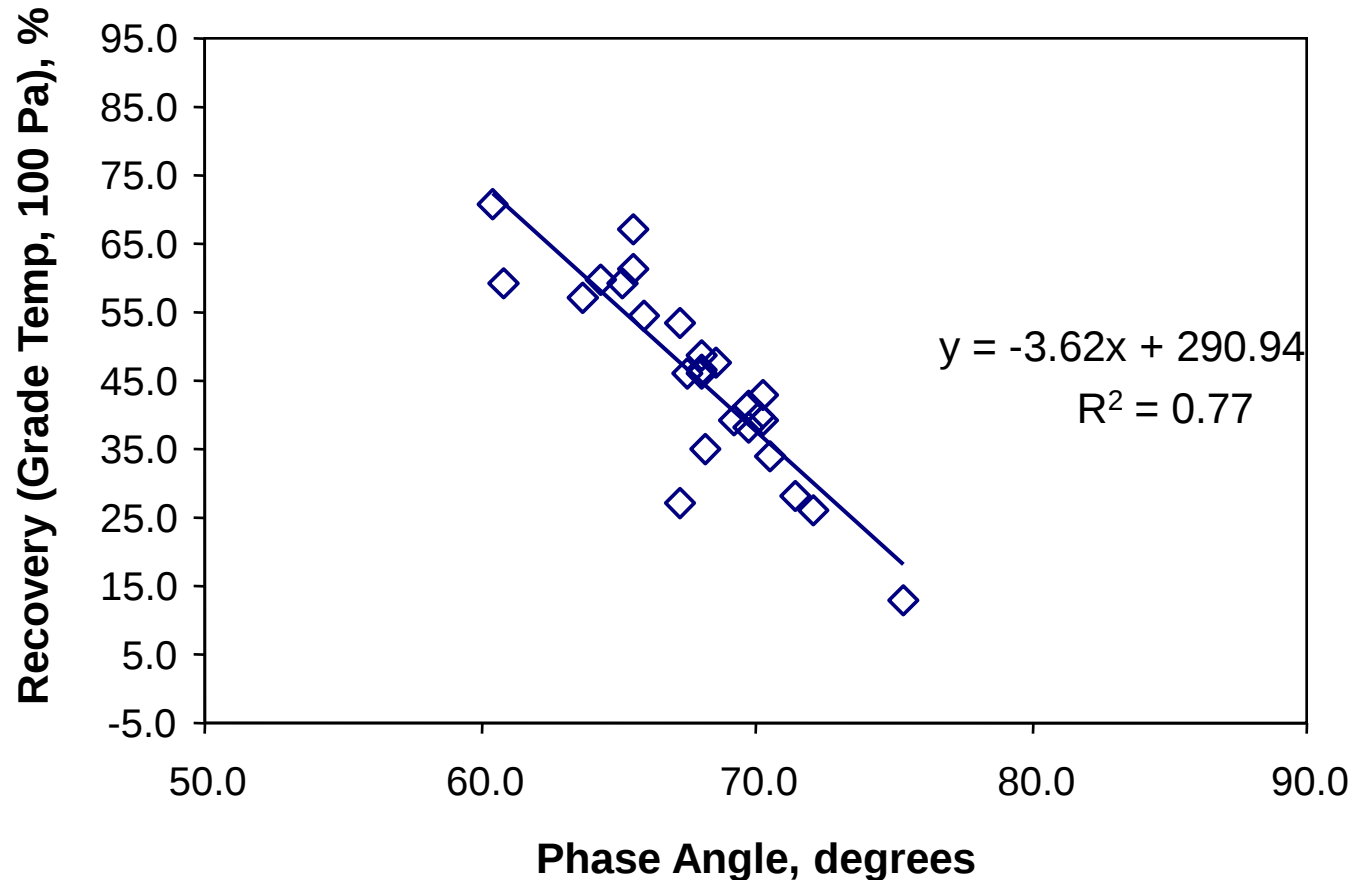
PG 70-22 Binders: MSCR-3200 Recovery

MSCR: PG 70-22 Asphalt Binders



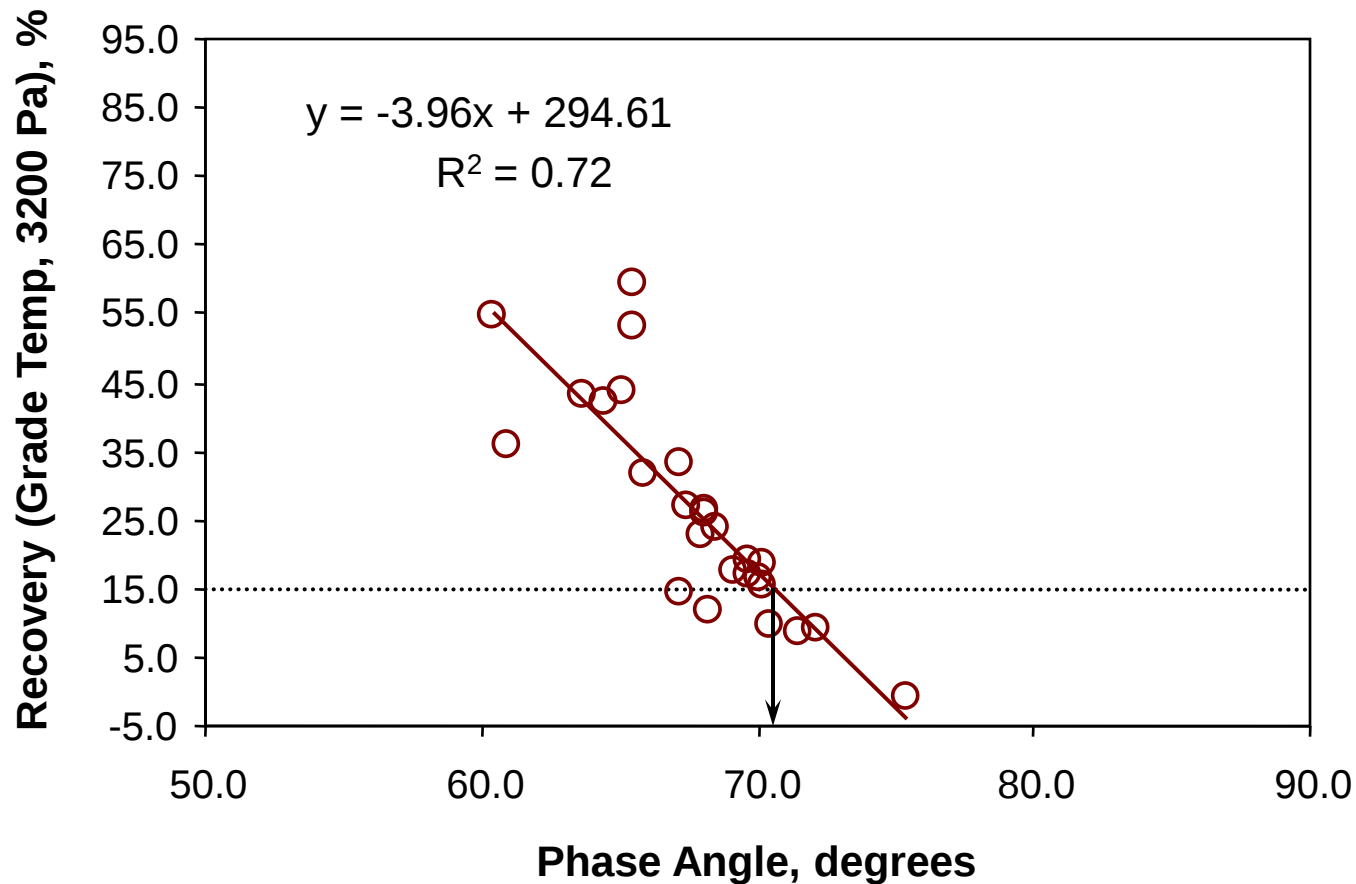
PG 76-22 Binders: MSCR-100 Recovery

MSCR: PG 76-22 Asphalt Binders



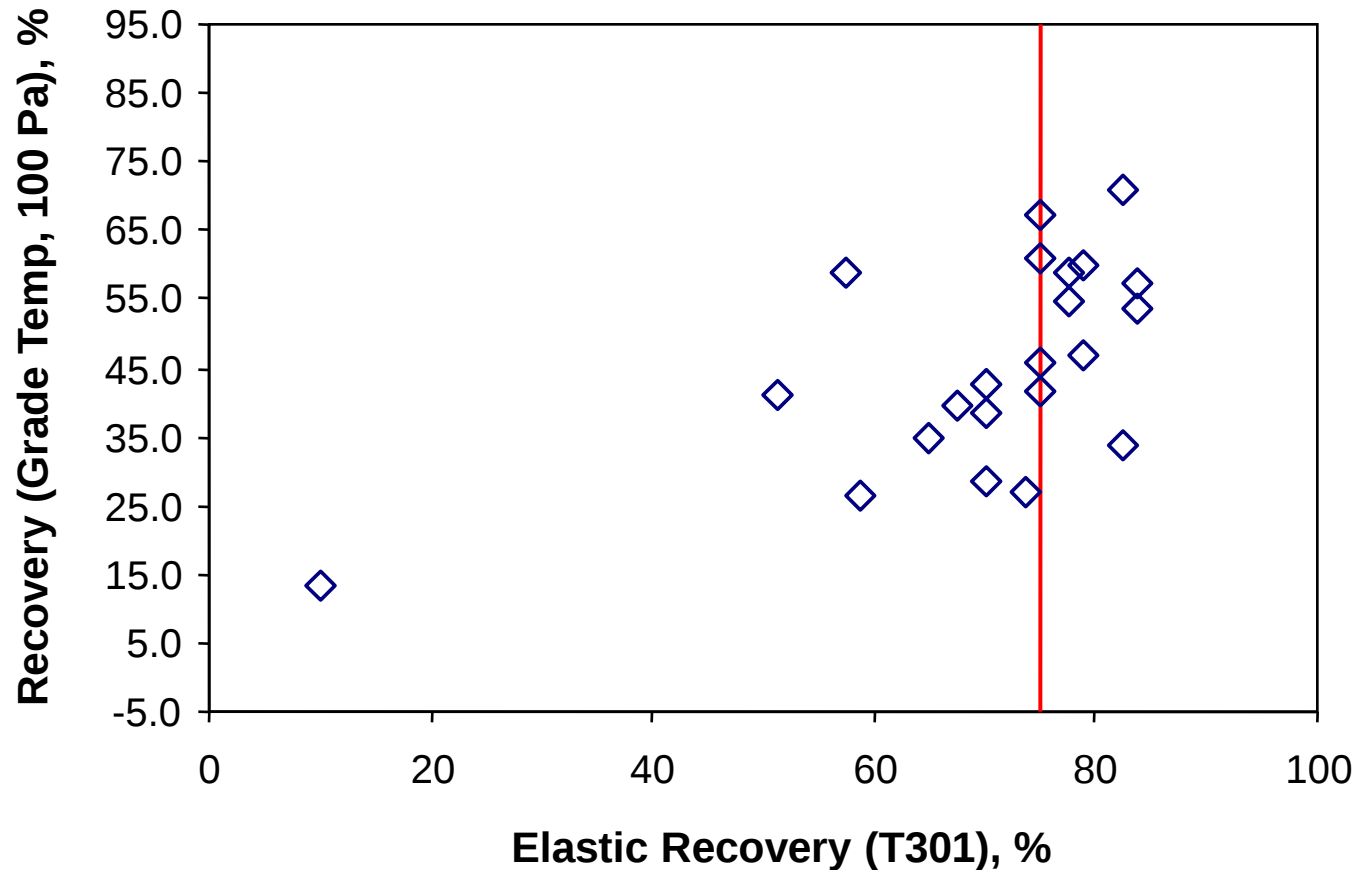
PG 76-22 Binders: 3200 Pa Recovery

MSCR: PG 76-22 Asphalt Binders



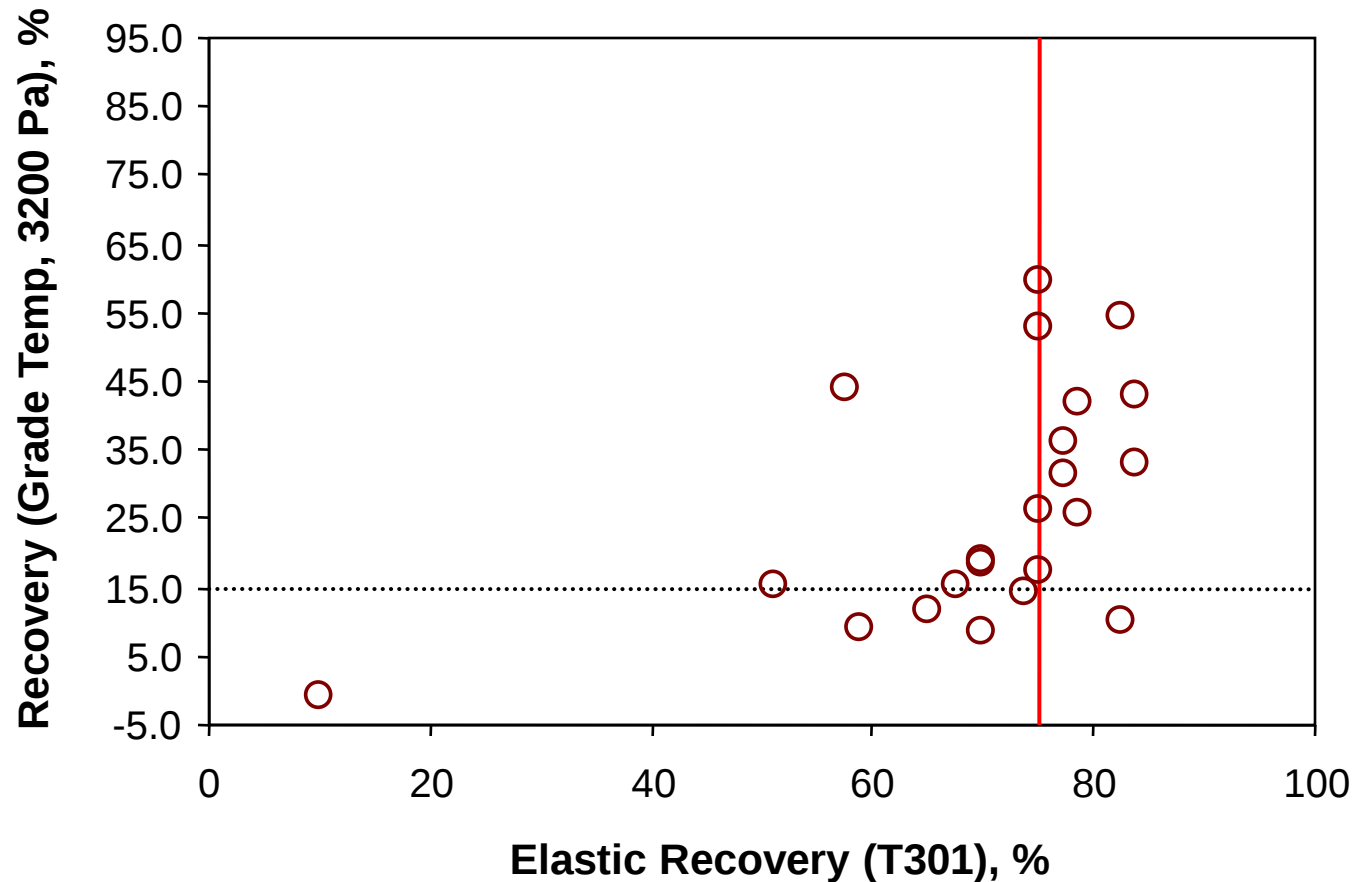
PG 76-22 Binders: MSCR-100 Recovery

MSCR: PG 76-22 Asphalt Binders



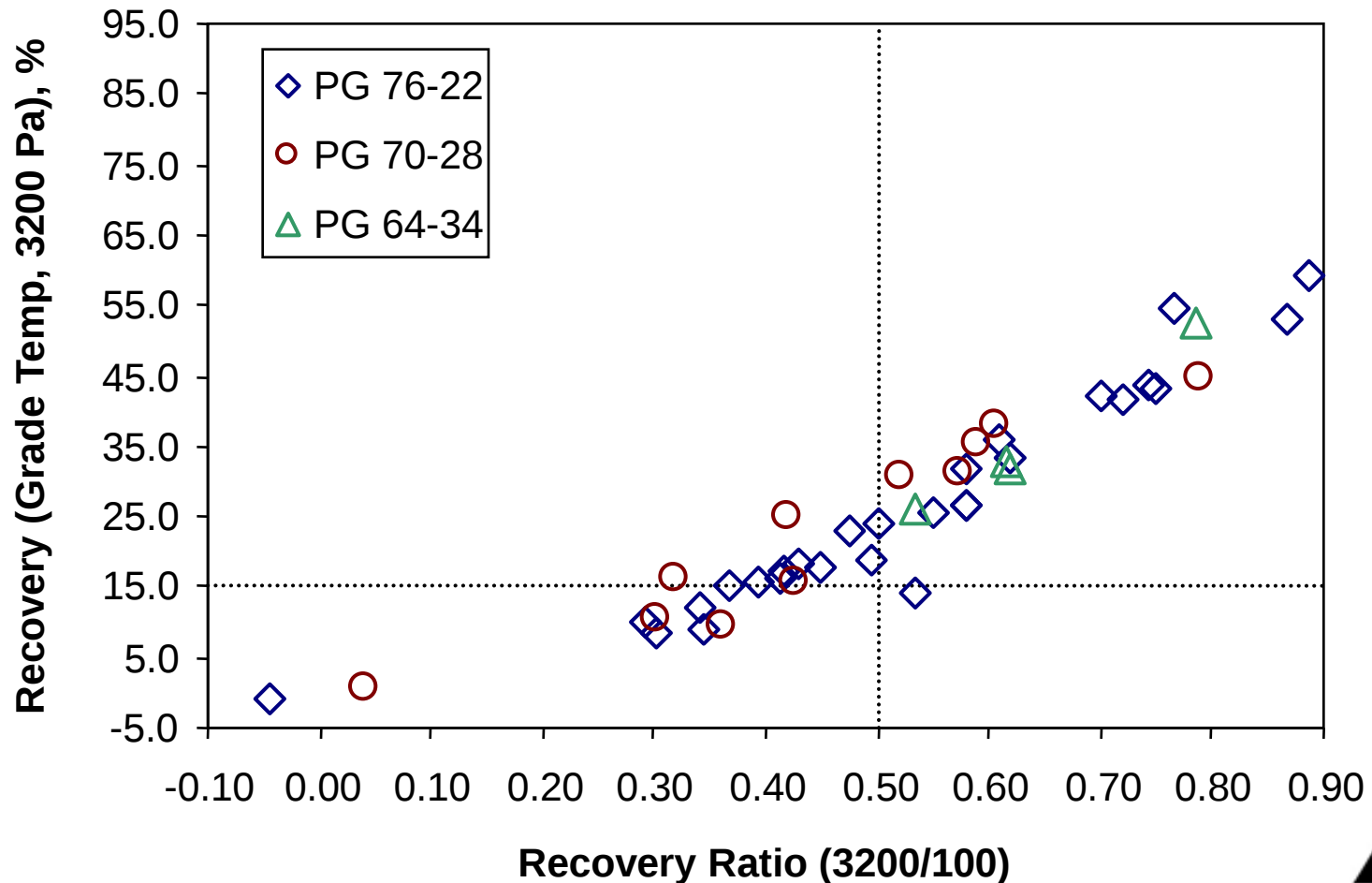
PG 76-22 Binders: 3200 Pa Recovery

MSCR: PG 76-22 Asphalt Binders



Asphalt Binders with 98 C Temperature Interval

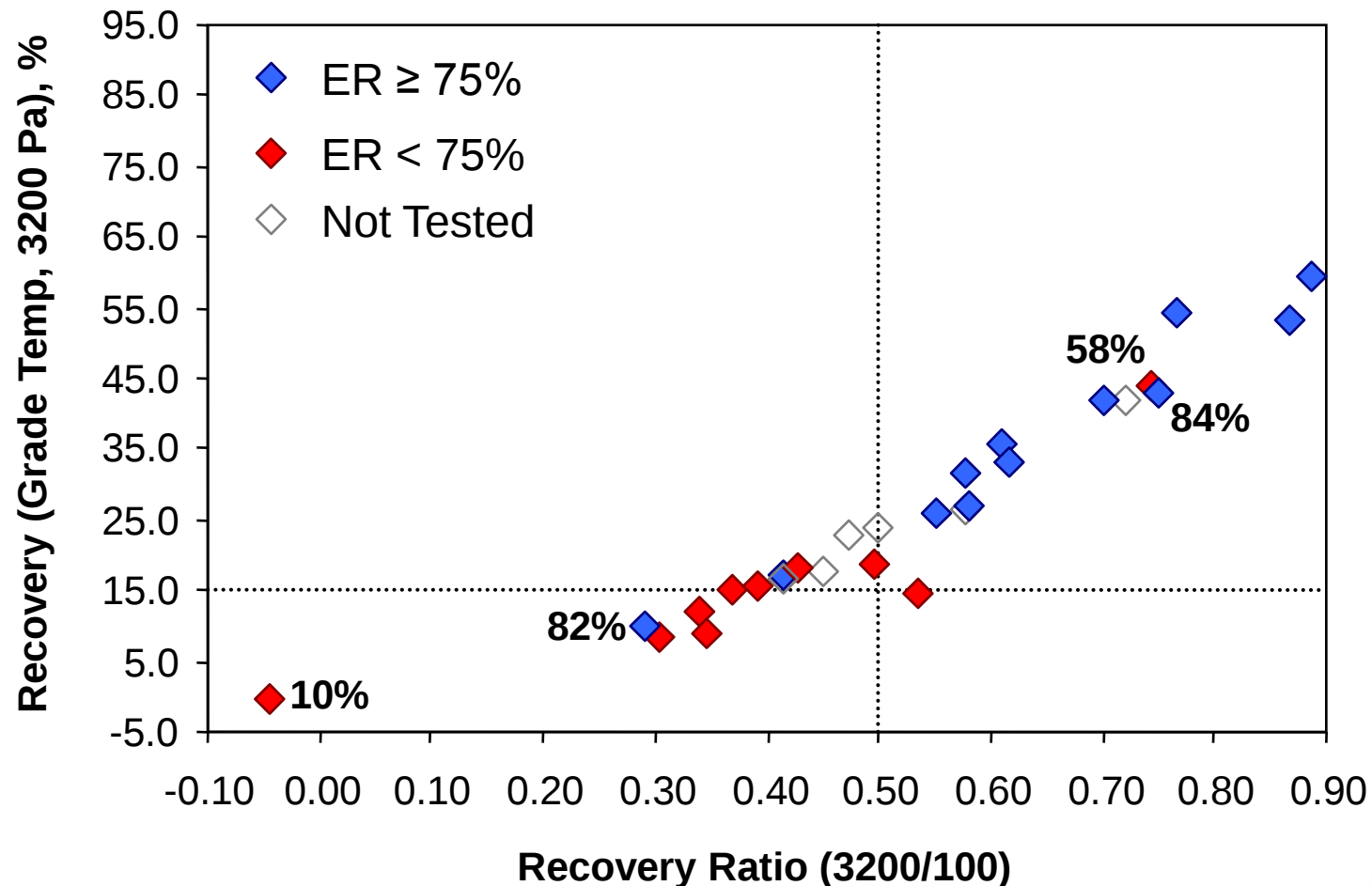
MSCR



Elastic Recovery Compared to MSCR Recovery and Recovery Ratio

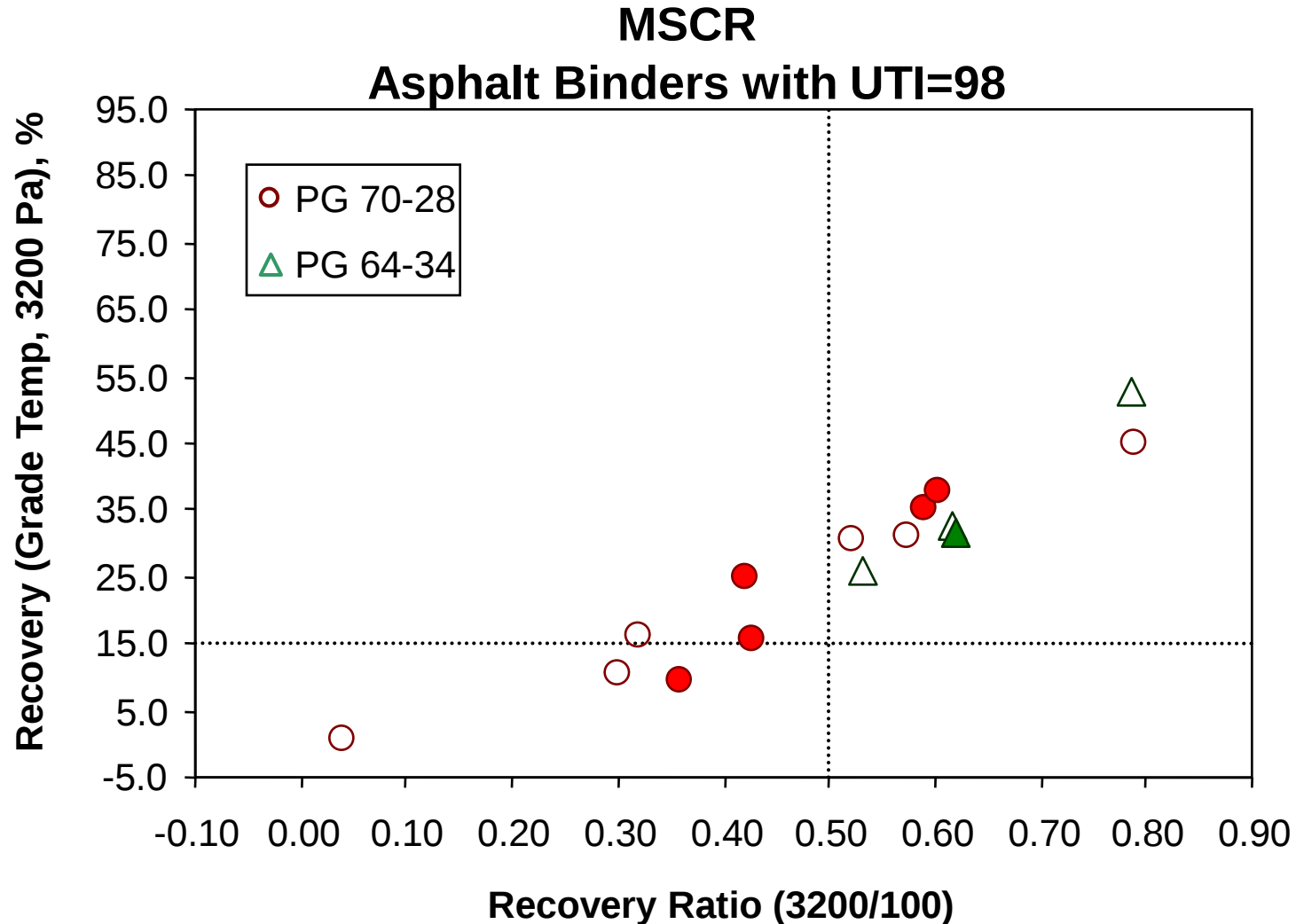
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MSCR: PG 76-22 Asphalt Binders

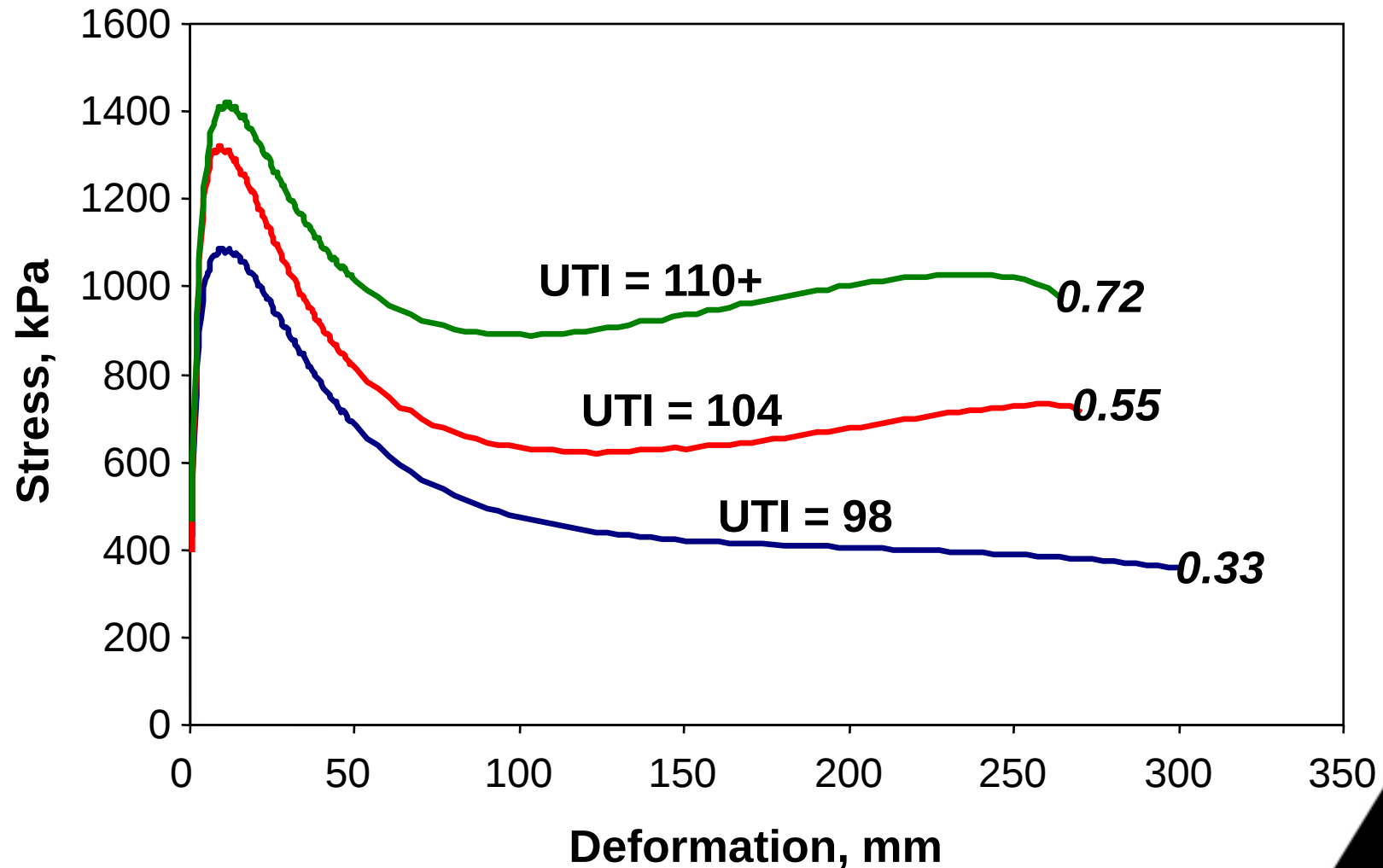


Elastic Recovery Compared to MSCR Recovery and Recovery Ratio

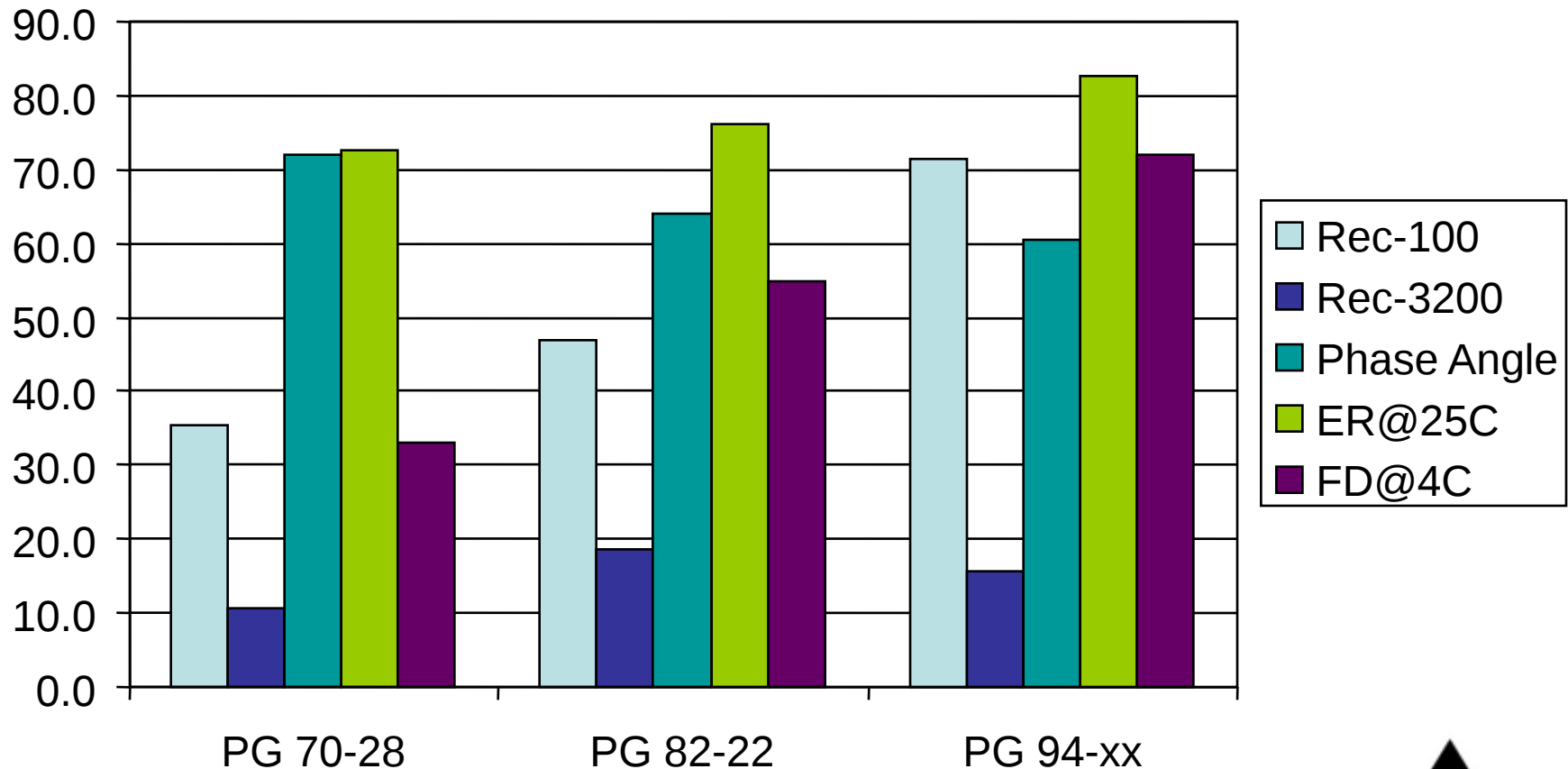
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Force Ductility – Single Source



Single Source – PG+ Comparison



AI Repeatability – 100 Pa

Grade	Recovery - 100 Pa					
	A	B	C	Ave	StDev	CV
PG 52-28	-1.8			-1.8		
PG 64-22	2.0			2.0		
PG 70-22	39.6	45.5	46.4	43.8	3.7	8%
PG 70-22	0.5			0.5		
PG 70-28	57.2	56.7	57.0	57.0	0.3	0%
PG 70-28	37.8	38.5	33.7	36.7	2.6	7%
PG 70-28	60.7	58.6	57.6	59.0	1.6	3%
PG 76-22	58.8	58.1	60.4	59.1	1.2	2%
PG 76-28	67.0	65.9	64.9	65.9	1.1	2%



AI Repeatability – 3200 Pa

Grade	Recovery - 3200 Pa					
	A	B	C	Ave	StDev	CV
PG 52-28	-2.3			-2.3		
PG 64-22	-3.0			-3.0		
PG 70-22	23.2	24.4	25.1	24.2	1.0	4%
PG 70-22	-2.3			-2.3		
PG 70-28	45.5	42.2	47.2	45.0	2.5	6%
PG 70-28	16.2	15.3	15.4	15.6	0.5	3%
PG 70-28	33.1	29.2	30.1	30.8	2.0	7%
PG 76-22	36.1	34.2	37.6	36.0	1.7	5%
PG 76-28	60.9	59.4	60.5	60.3	0.8	1%



Multi-Lab Reproducibility: 100 Pa

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Grade	Recovery - 100 Pa					
	AI	MTE	FHWA	Ave	StDev	CV
PG 52-28	-1.8	4.5	1.8	1.5	3.2	210%
PG 64-22	2.0	3.2	0.7	2.0	1.3	64%
PG 70-22	43.8	54.2	50.2	49.4	5.2	11%
PG 70-22	0.5	6.5	0.3	2.4	3.5	144%
PG 70-28	57.0	59.6	57.3	57.9	1.5	3%
PG 70-28	36.7	42.4	41.9	40.3	3.2	8%
PG 70-28	59.0	47.0	60.2	55.4	7.3	13%
PG 76-22	59.1	64.4	63.9	62.4	2.9	5%
PG 76-28	65.9	68.2	68.0	67.4	1.2	2%



Multi-Lab Reproducibility: 3200 Pa

Grade	Recovery - 3200 Pa					
	AI	MTE	FHWA	Ave	StDev	CV
PG 52-28	-2.3	1.3	0.7	-0.1	1.9	
PG 64-22	-3.0	0.9	0.0	-0.7	2.0	-286%
PG 70-22	24.2	29.2	27.1	26.8	2.5	9%
PG 70-22	-2.3	1.5	0.0	-0.3	1.9	-740%
PG 70-28	45.0	45.6	45.2	45.2	0.3	1%
PG 70-28	15.6	20.0	17.8	17.8	2.2	12%
PG 70-28	30.8	19.2	25.3	25.1	5.8	23%
PG 76-22	36.0	41.4	40.2	39.2	2.8	7%
PG 76-28	60.3	59.8	61.5	60.5	0.8	1%



Effect of RTFO Aging

Lab Aged

Recovery - 100 Pa						
Grade	AI	MTE	FHWA	Ave	StDev	CV
PG 70-28	36.7	42.4	41.9	40.3	3.2	8%
PG 70-28	59.0	47.0	60.2	55.4	7.3	13%

Recovery - 3200 Pa						
Grade	AI	MTE	FHWA	Ave	StDev	CV
PG 70-28	15.6	20.0	17.8	17.8	2.2	12%
PG 70-28	30.8	19.2	25.3	25.1	5.8	23%

MTE RTFO- Aged

Recovery - 100 Pa						
Grade	AI	MTE	FHWA	Ave	StDev	CV
PG 70-28	39.2	43.5	37.0	39.9	3.3	8%
PG 70-28	59.3	60.4	60.0	59.9	0.6	1%

Recovery - 3200 Pa						
Grade	AI	MTE	FHWA	Ave	StDev	CV
PG 70-28	17.5	22.5	18.0	19.3	2.8	14%
PG 70-28	34.6	33.7	31.0	33.1	1.9	6%



Effect of RTFO Aging

Lab Aged

Recovery - 100 Pa						
Grade	AI	MTE	FHWA	Ave	StDev	CV
PG 70-28	36.7	42.4	41.9	40.3	3.2	8%
PG 70-28	59.0	47.0	60.2	55.4	7.3	13%

Recovery - 3200 Pa						
Grade	AI	MTE	FHWA	Ave	StDev	CV
PG 70-28	15.6	20.0	17.8	17.8	2.2	12%
PG 70-28	30.8	19.2	25.3	25.1	5.8	23%

MTE RTFO- Aged

Recovery - 100 Pa						
Grade	AI	MTE	FHWA	Ave	StDev	CV
PG 70-28	39.2	43.5	37.0	39.9	3.3	8%
PG 70-28	59.3	60.4	60.0	59.9	0.6	1%

Recovery - 3200 Pa						
Grade	AI	MTE	FHWA	Ave	StDev	CV
PG 70-28	17.5	22.5	18.0	19.3	2.8	14%
PG 70-28	34.6	33.7	31.0	33.1	1.9	6%



Summary

- MSCR
 - Quicker test than ER
 - Good repeatability, reproducibility
 - Comparison to PG+ Tests
 - Related to phase angle
 - Not directly related to Elastic Recovery
 - Appears to segregate ER values currently meeting specification criterion?
 - Not enough information on Force Ductility



Summary

- Issues
 - Establishment of Criteria
 - Single value for recovery (3200 Pa shear stress) or sliding scale based on UTI of asphalt binder
 - Use of Recovery Ratio
 - Ratio of Recovery at 3200 Pa to Recovery at 100 Pa
 - Is it needed? If so, what is the limit?
 - Test Temperature
 - Grade Temperature versus Climate Temperature
 - i.e., test PG 76-22 at 64C instead of 76C



Thanks!

