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

AASHTO M320+ (2005)

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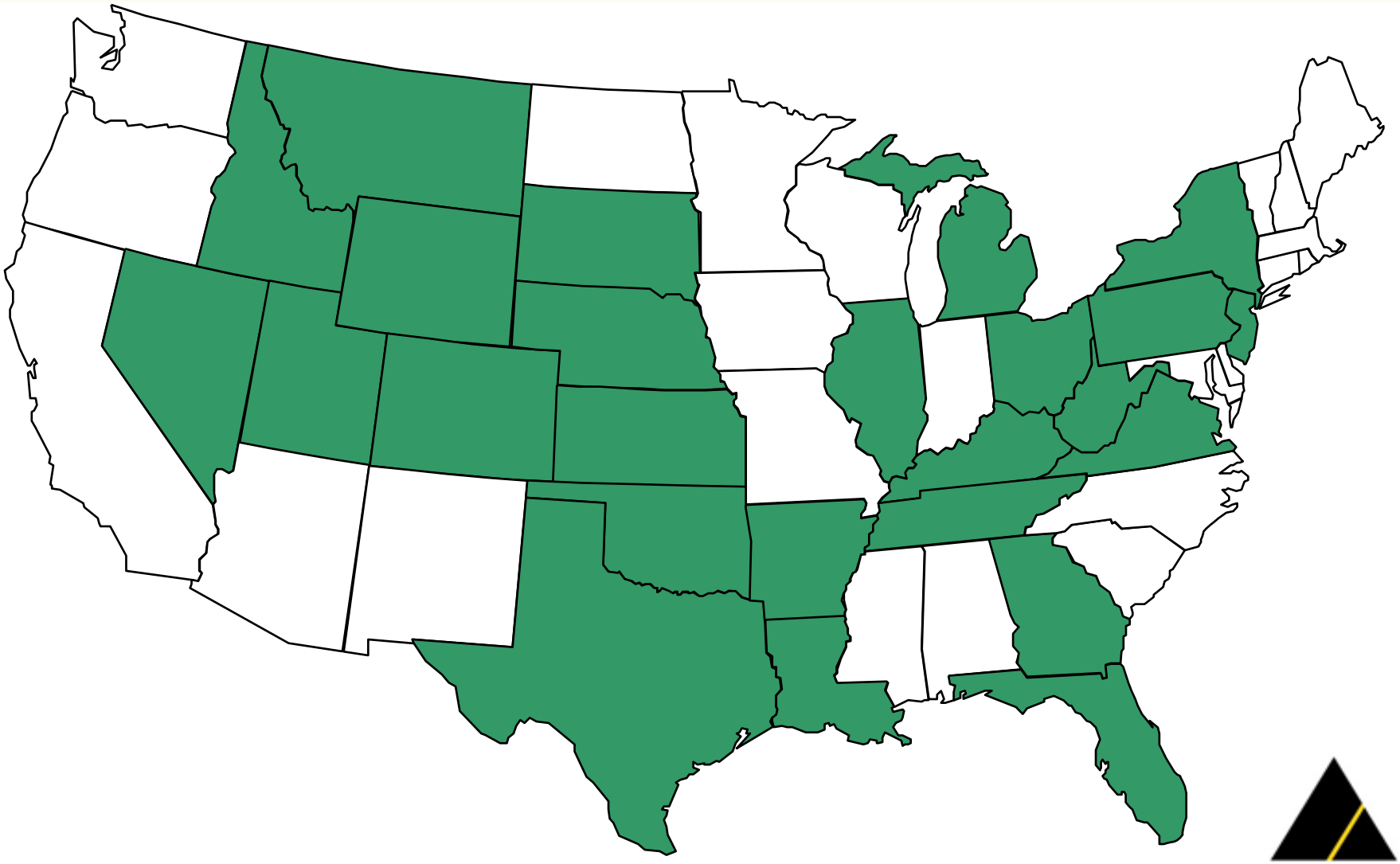


Asphalt Institute – FHWA Research

- 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

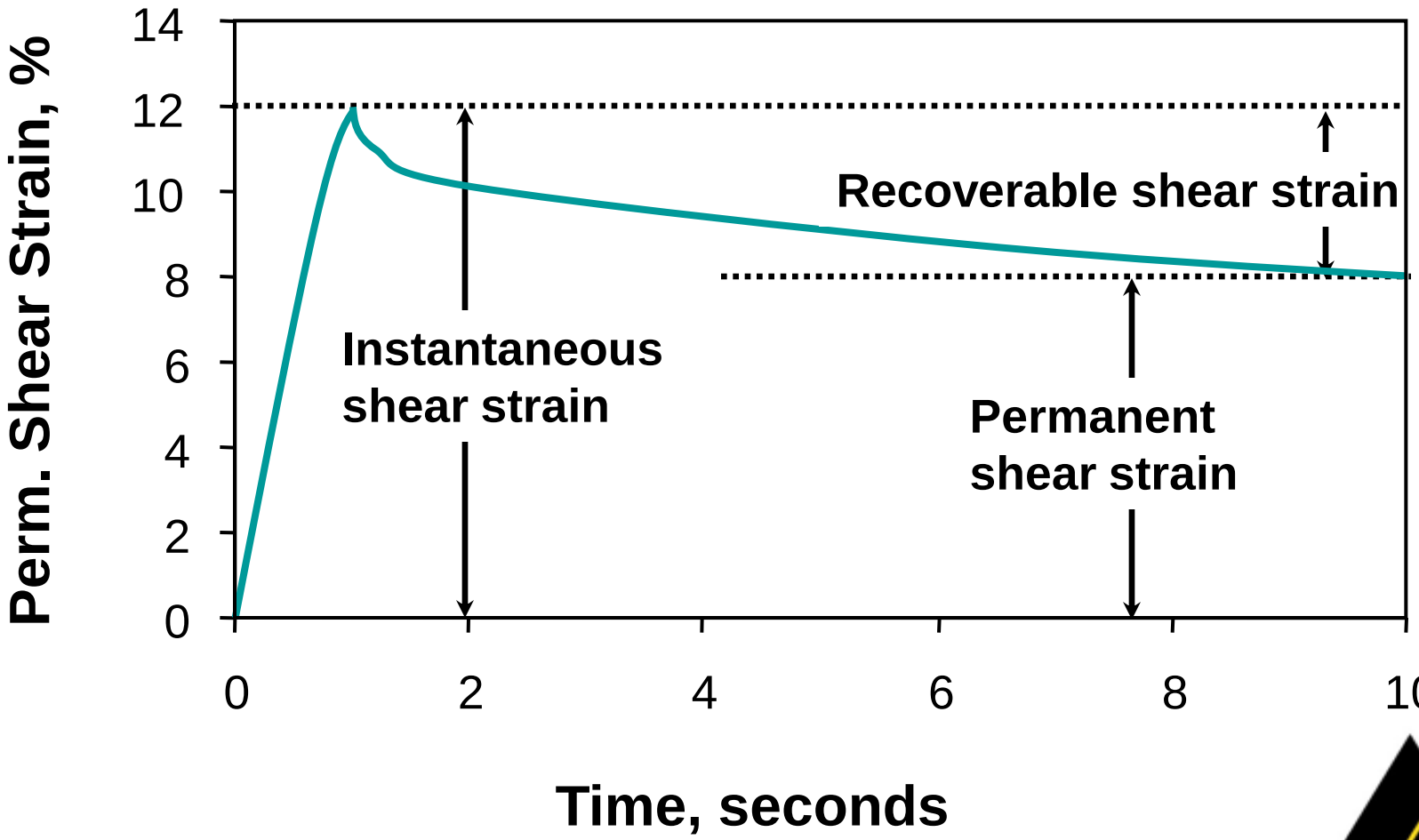
MSCR: Multiple Stress Creep Recovery Test

- 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

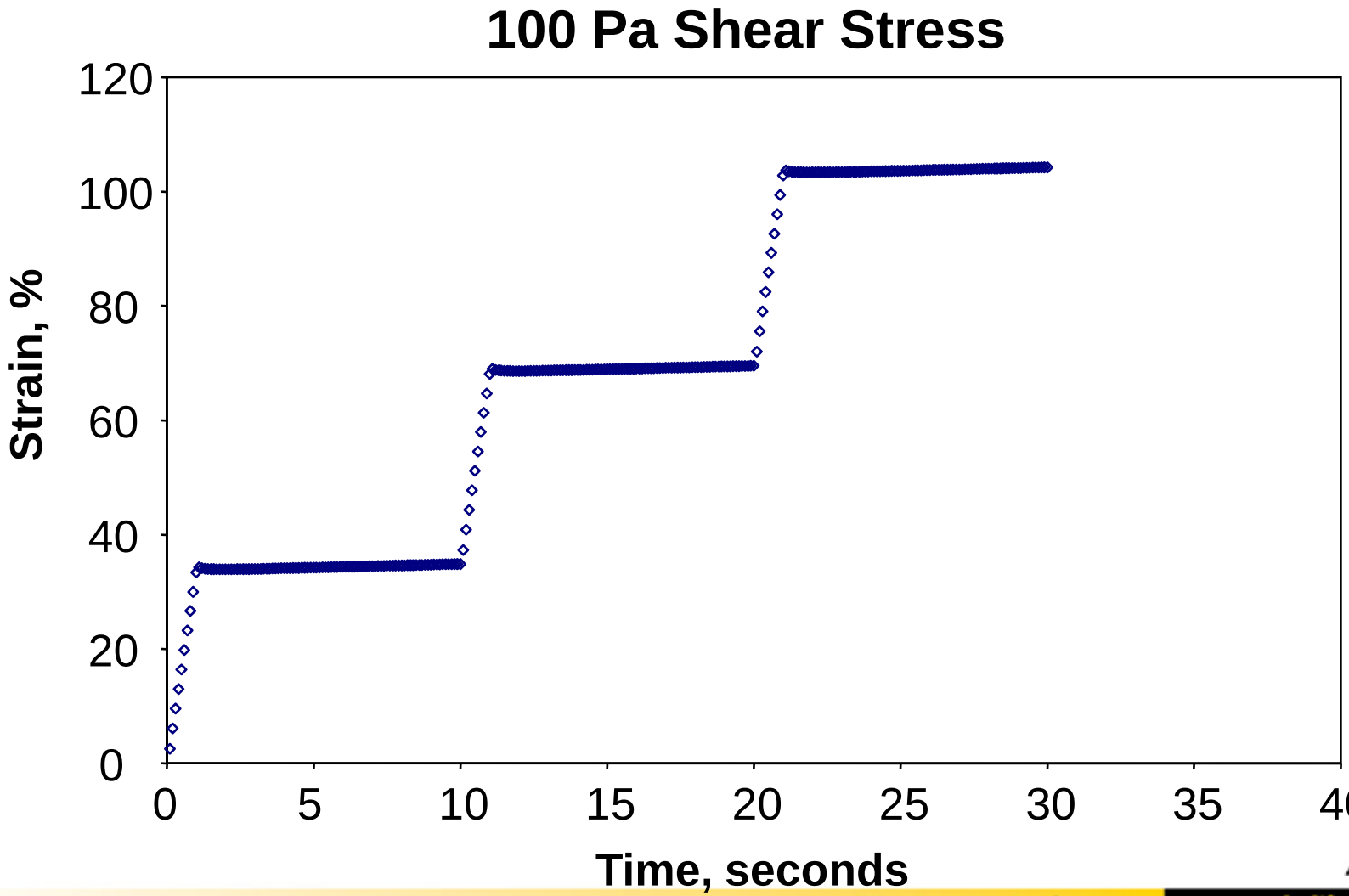
MSCR: Multiple Stress Creep Recovery Test

- 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

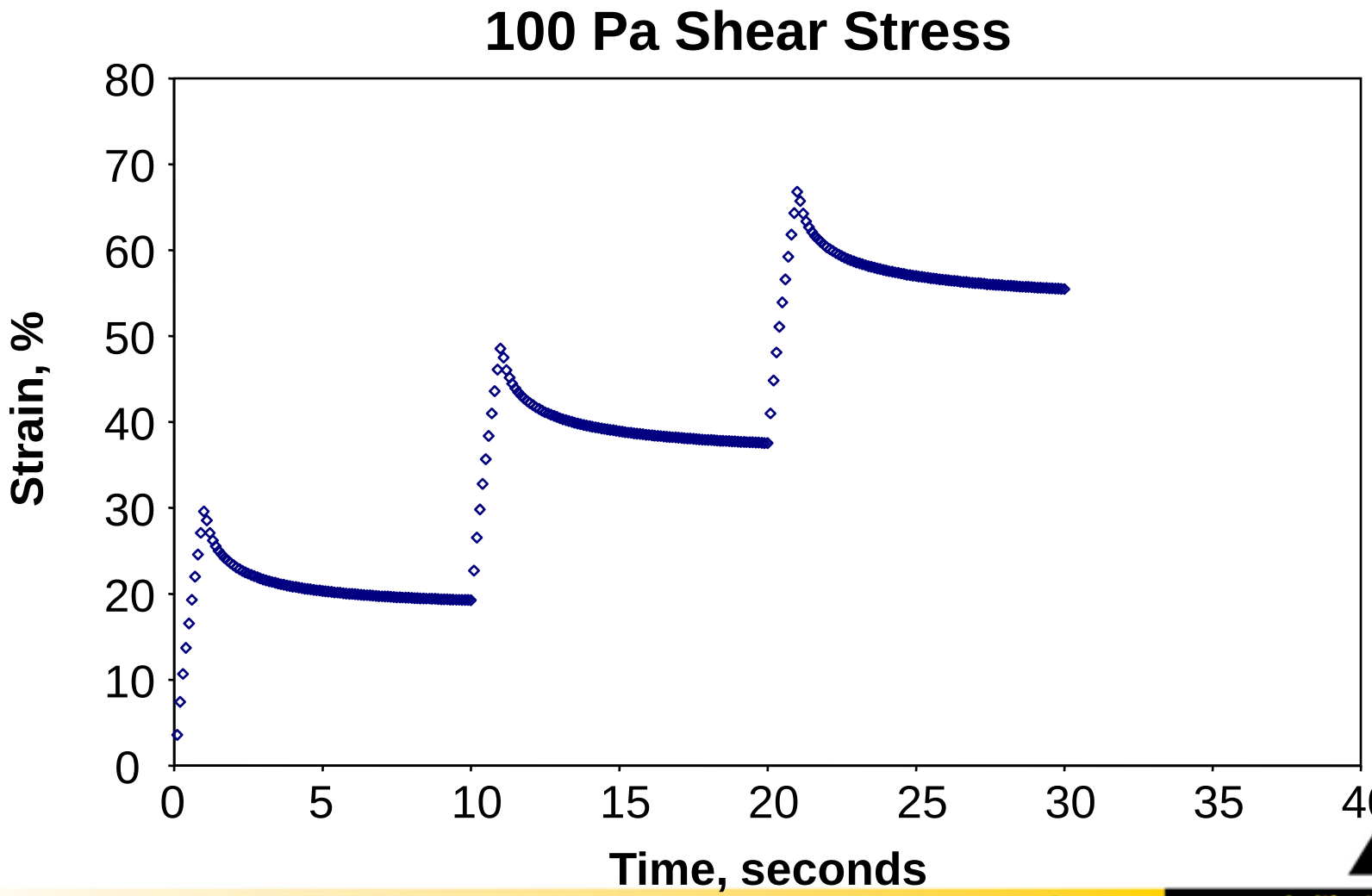
Repeated Shear Creep



Repeated Shear Creep Recovery Test – Unmodified Asphalt Binder



Repeated Shear Creep Recovery Test – Modified Asphalt Binder



MSCR Calculations

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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
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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

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

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

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

Recovery = 60.7%

MSCR Recovery Calculations

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Stress	100					
Cycle	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

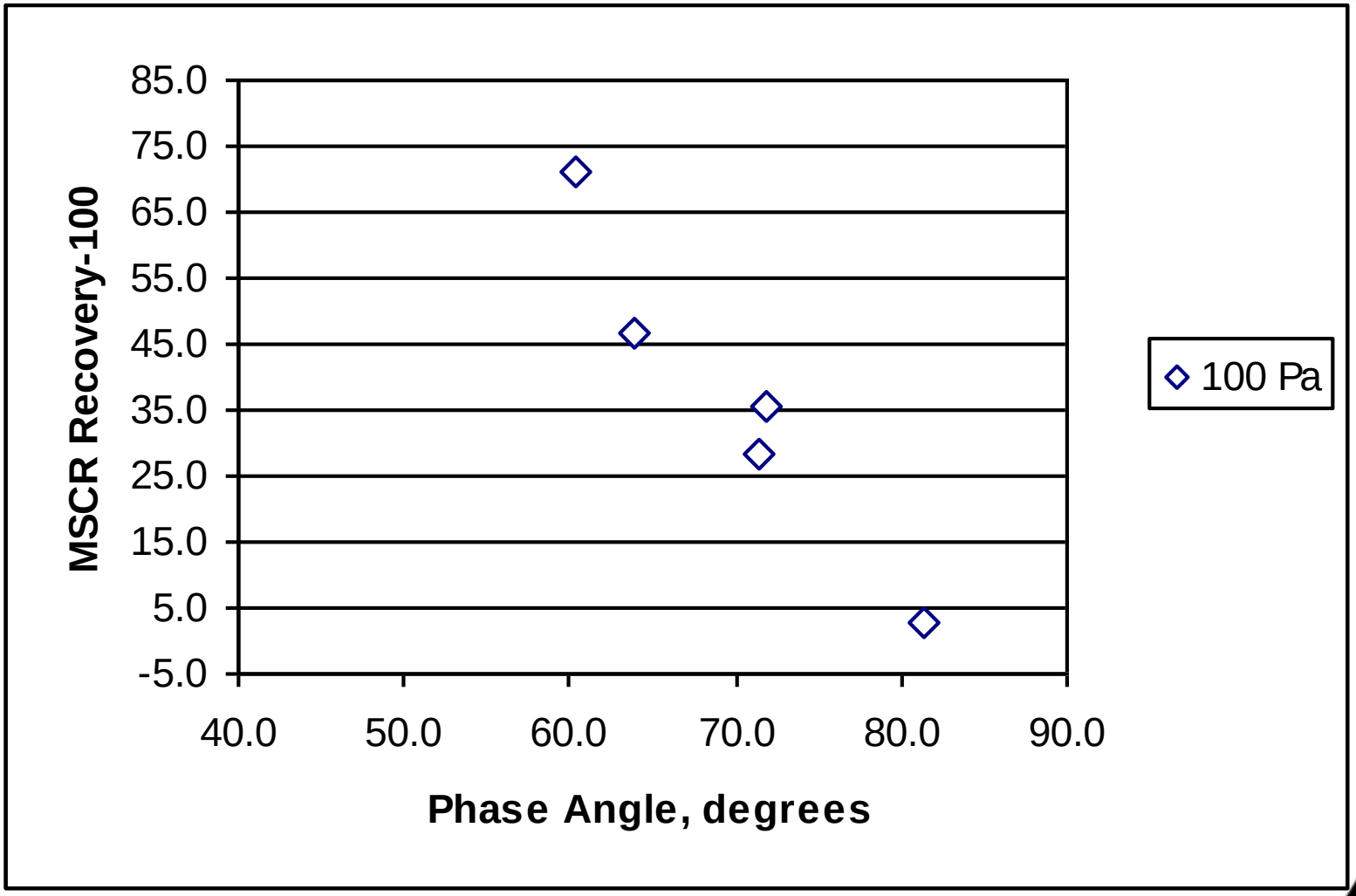
AI-FHWA MSCR Research

- Work Plan – Binders
  - DSR
    - Conventional G*/sin δ (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

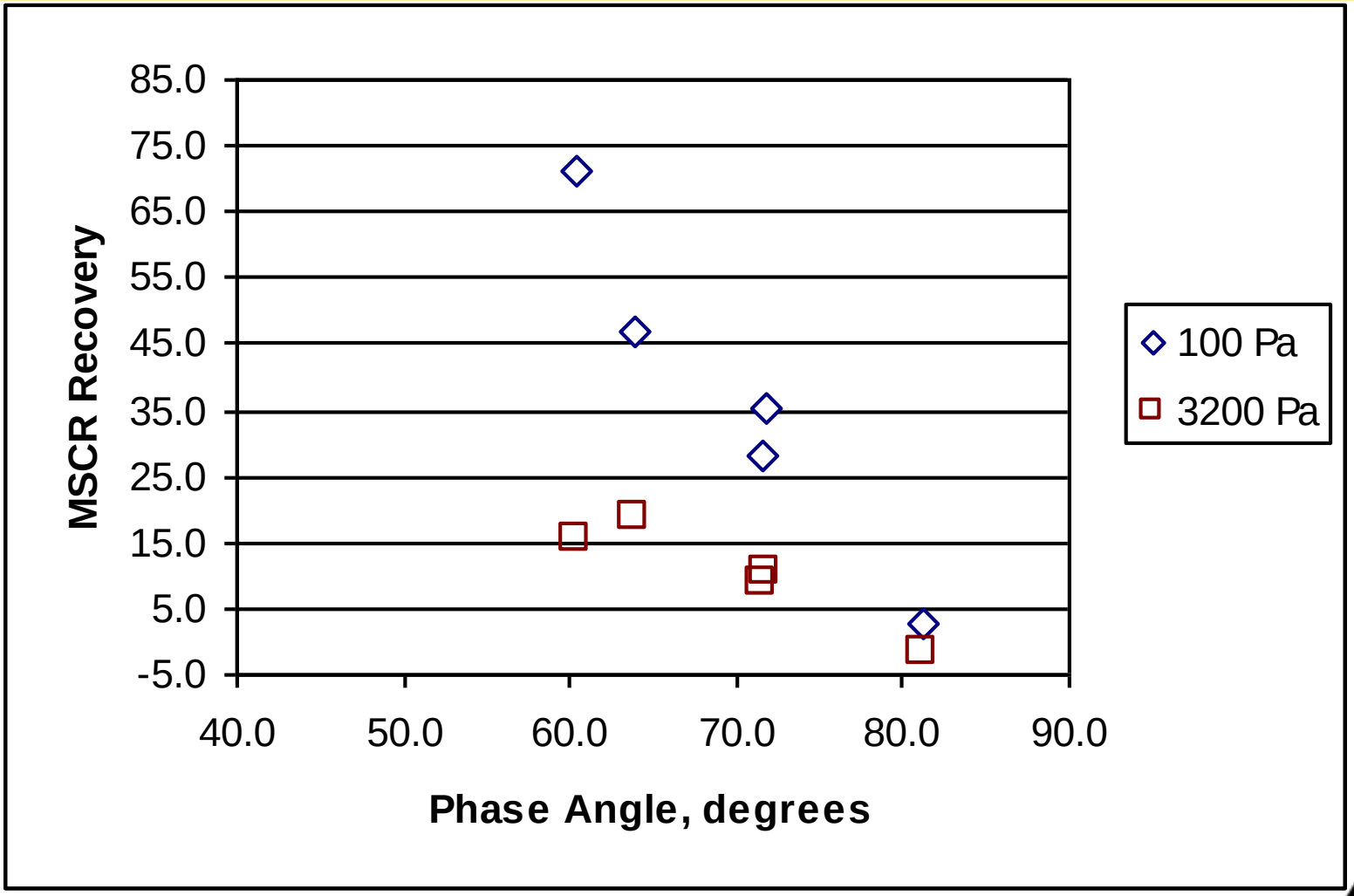
AI-FHWA MSCR Research

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

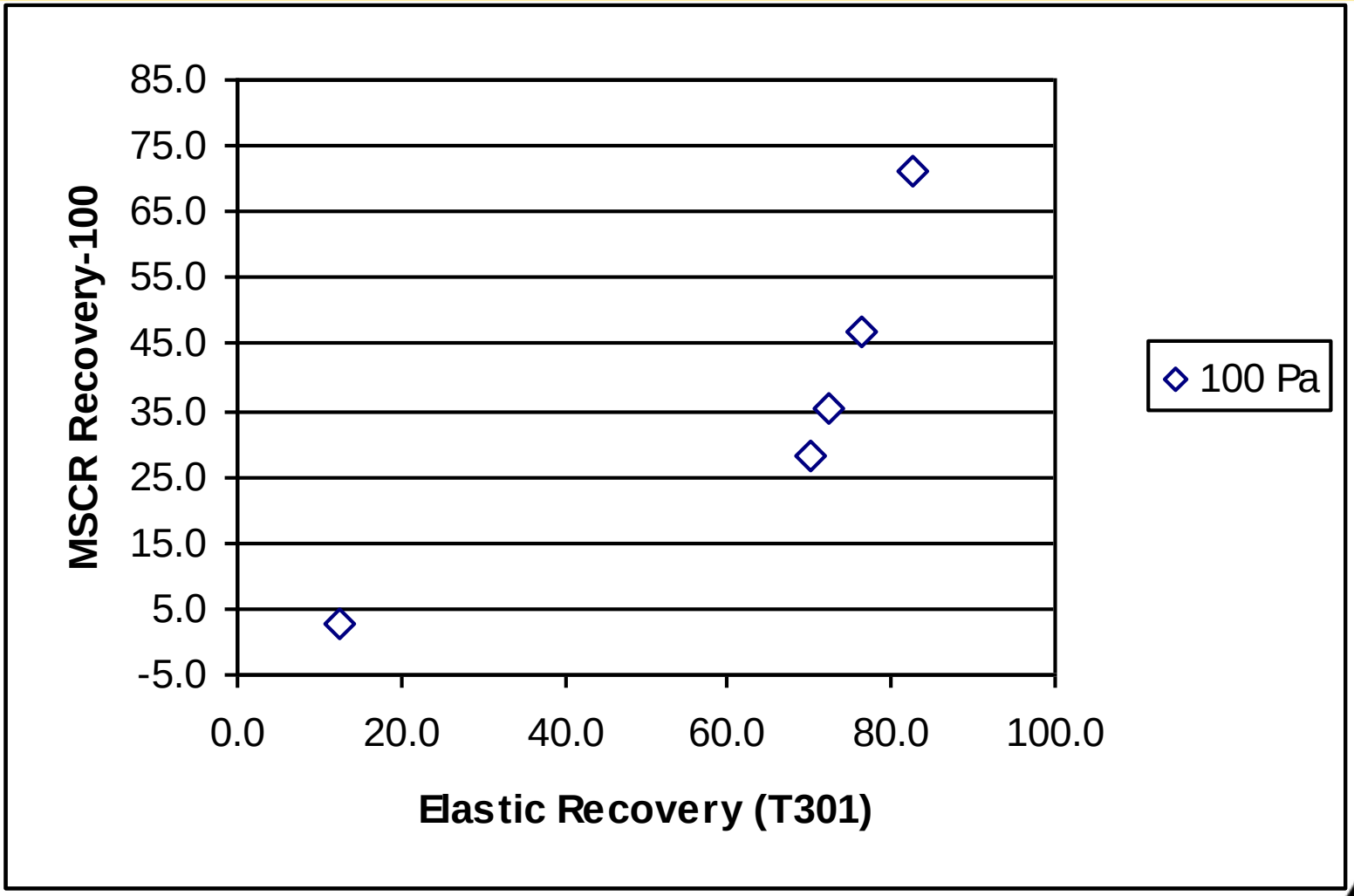
MSCR Results – Single Source



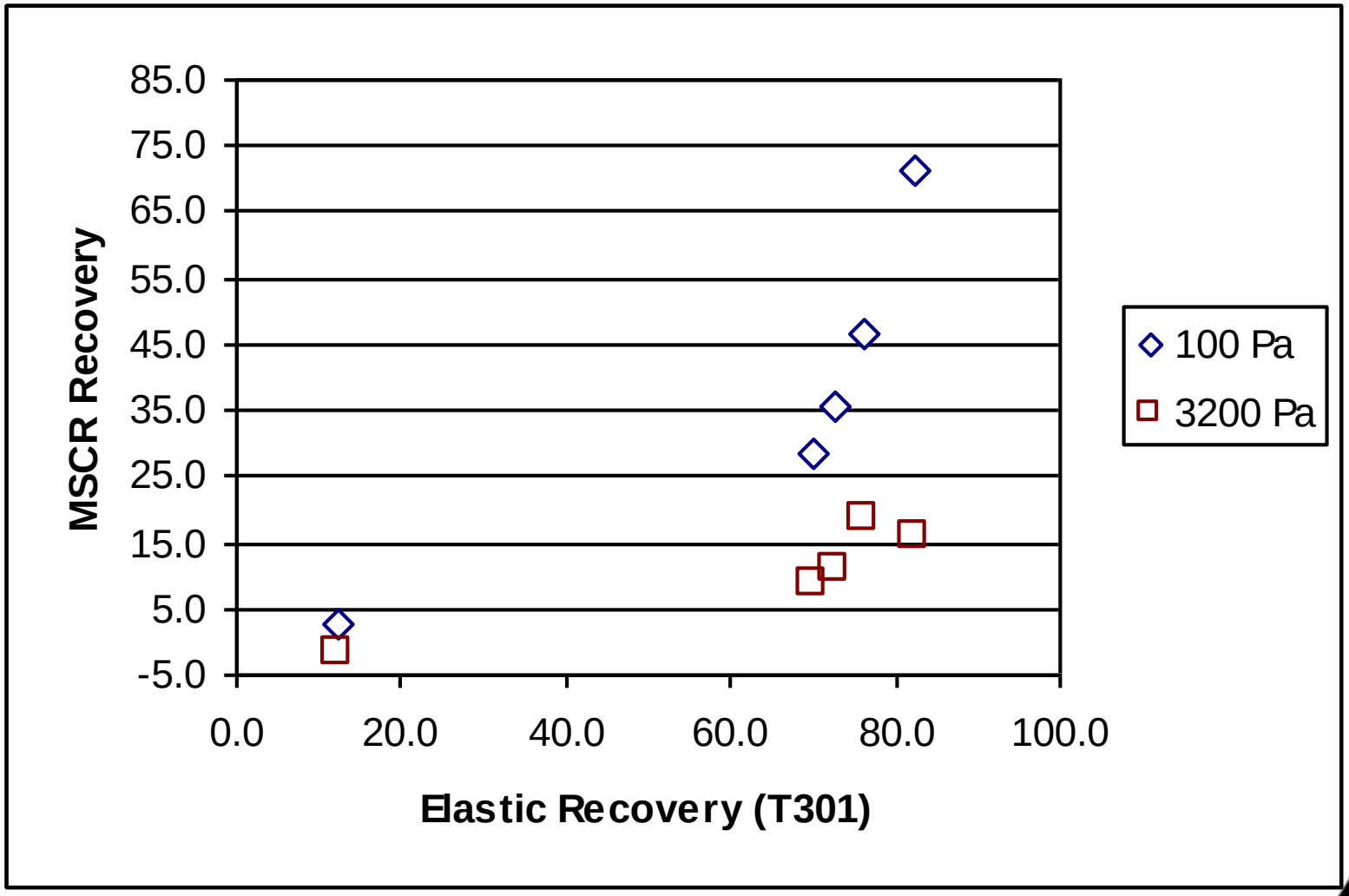
MSCR Results – Single Source



MSCR Results – Single Source



MSCR Results – Single Source



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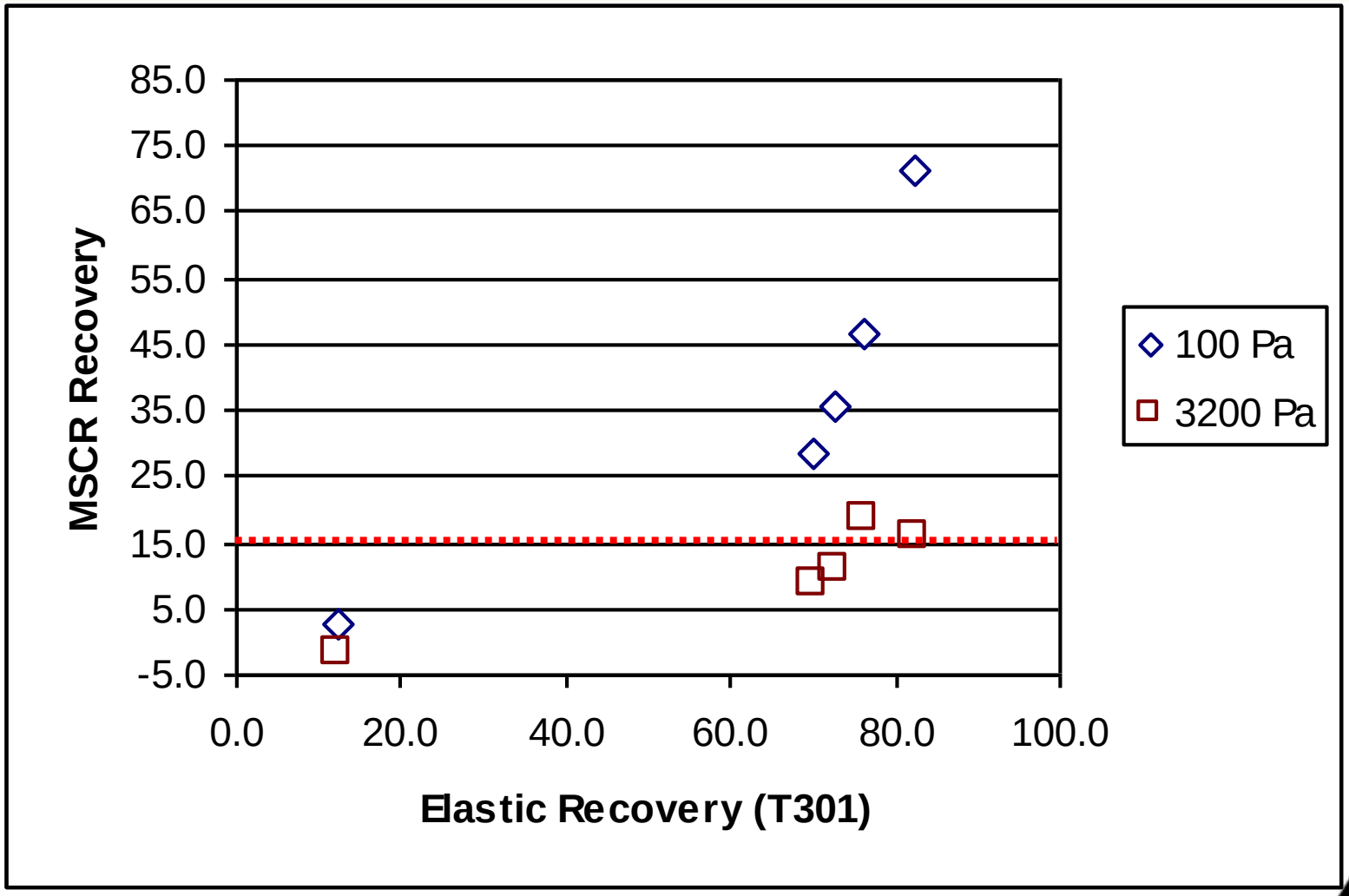
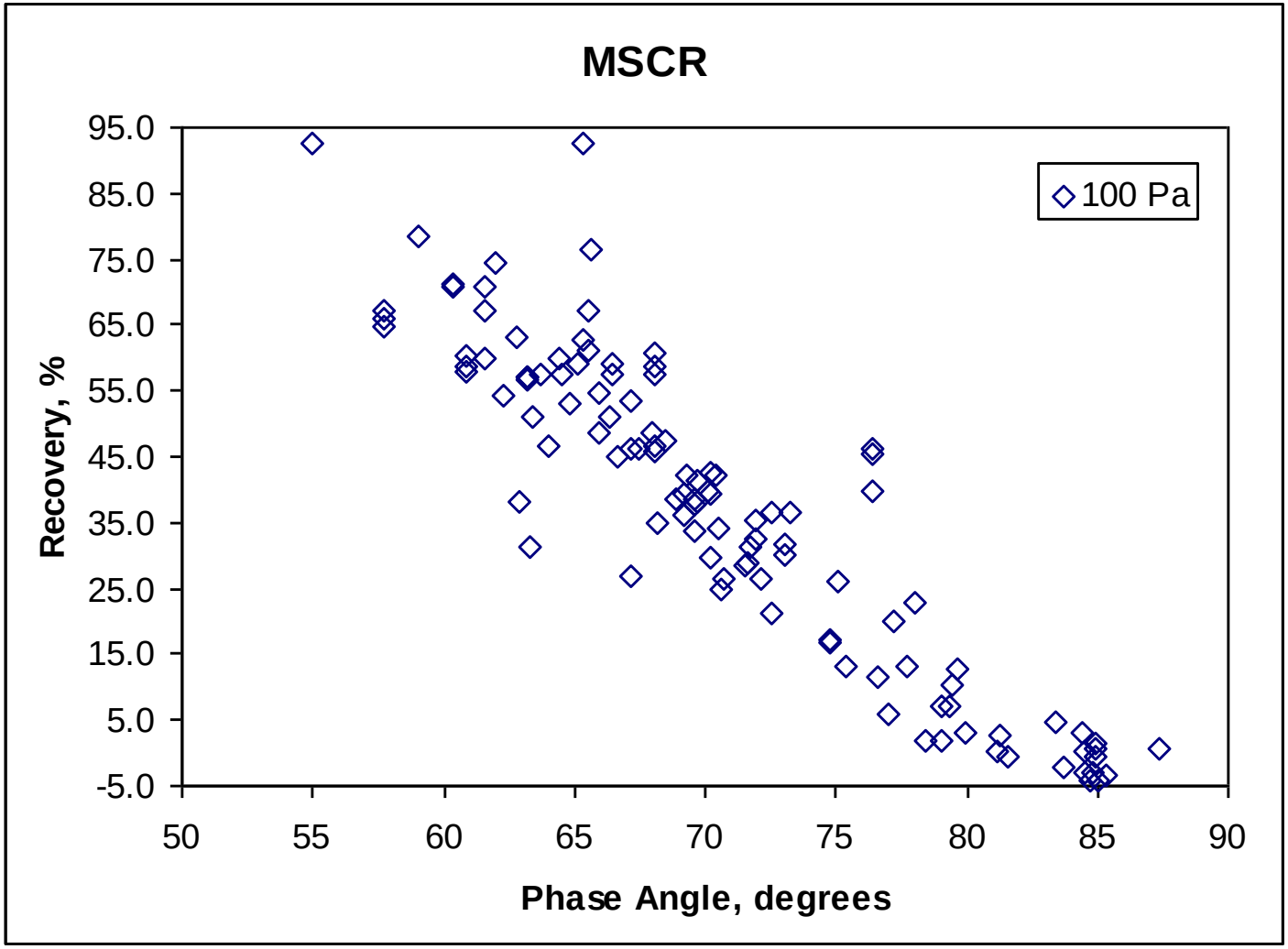
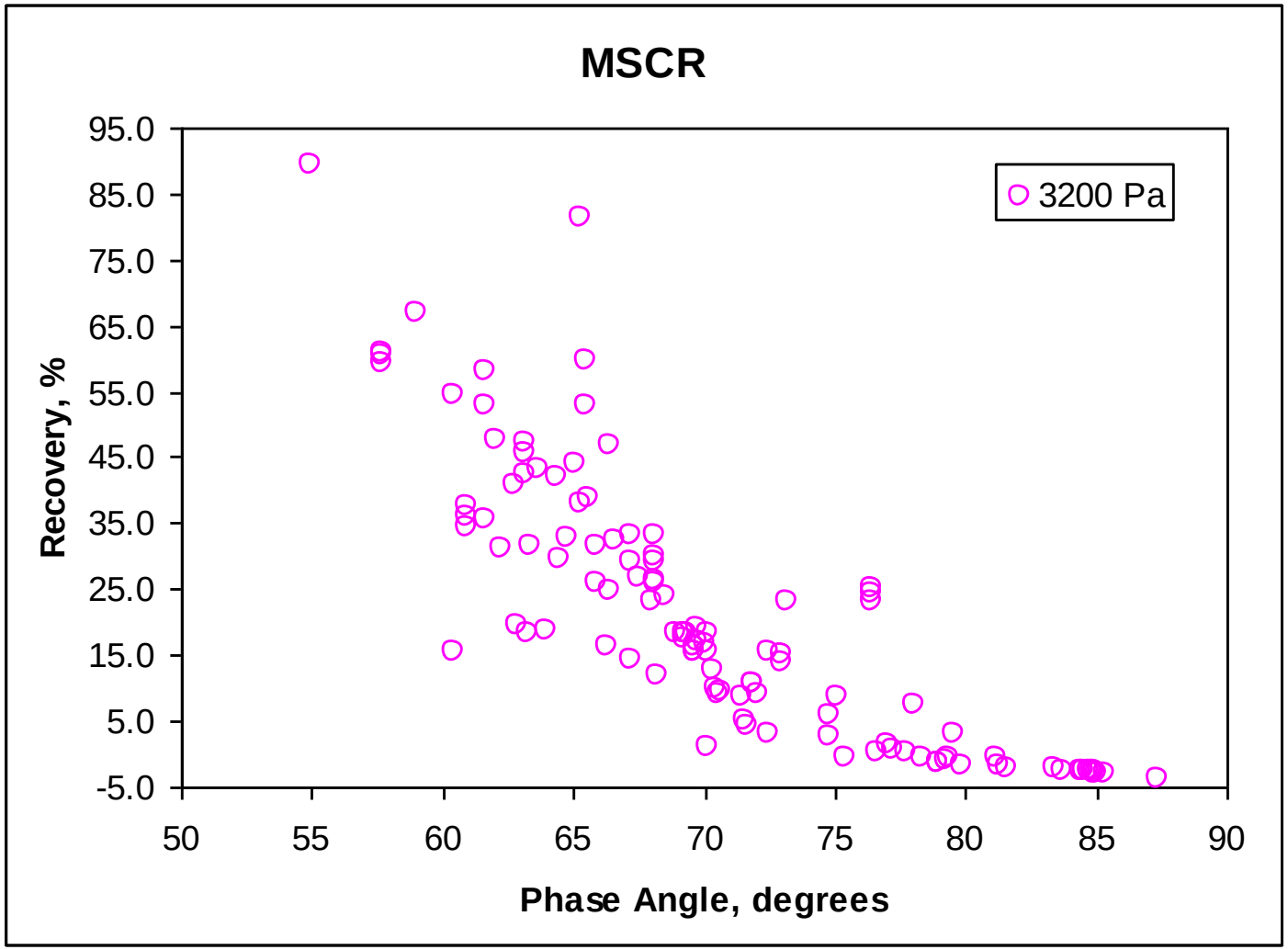


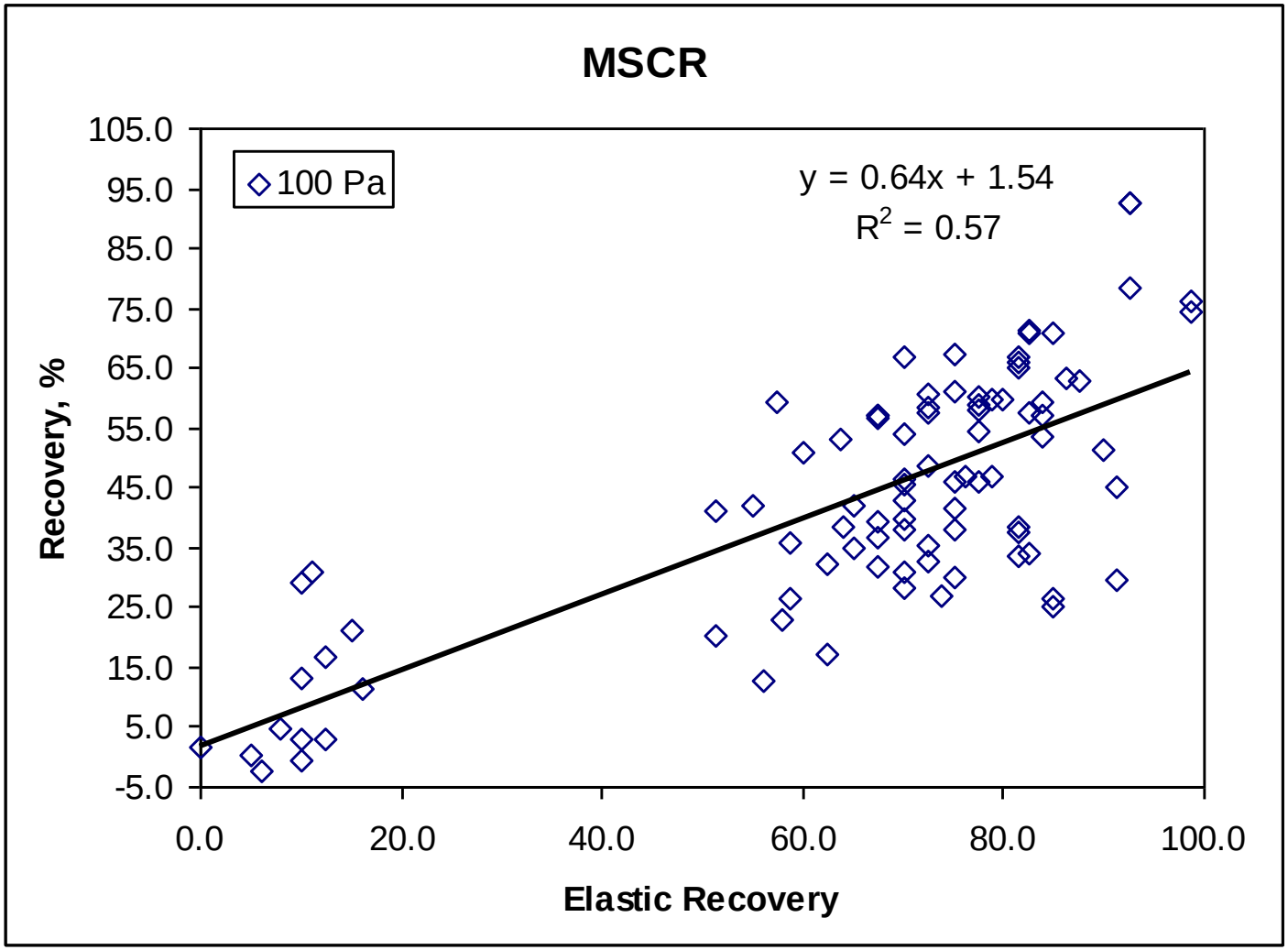
MSCR Recovery: 100 Pa



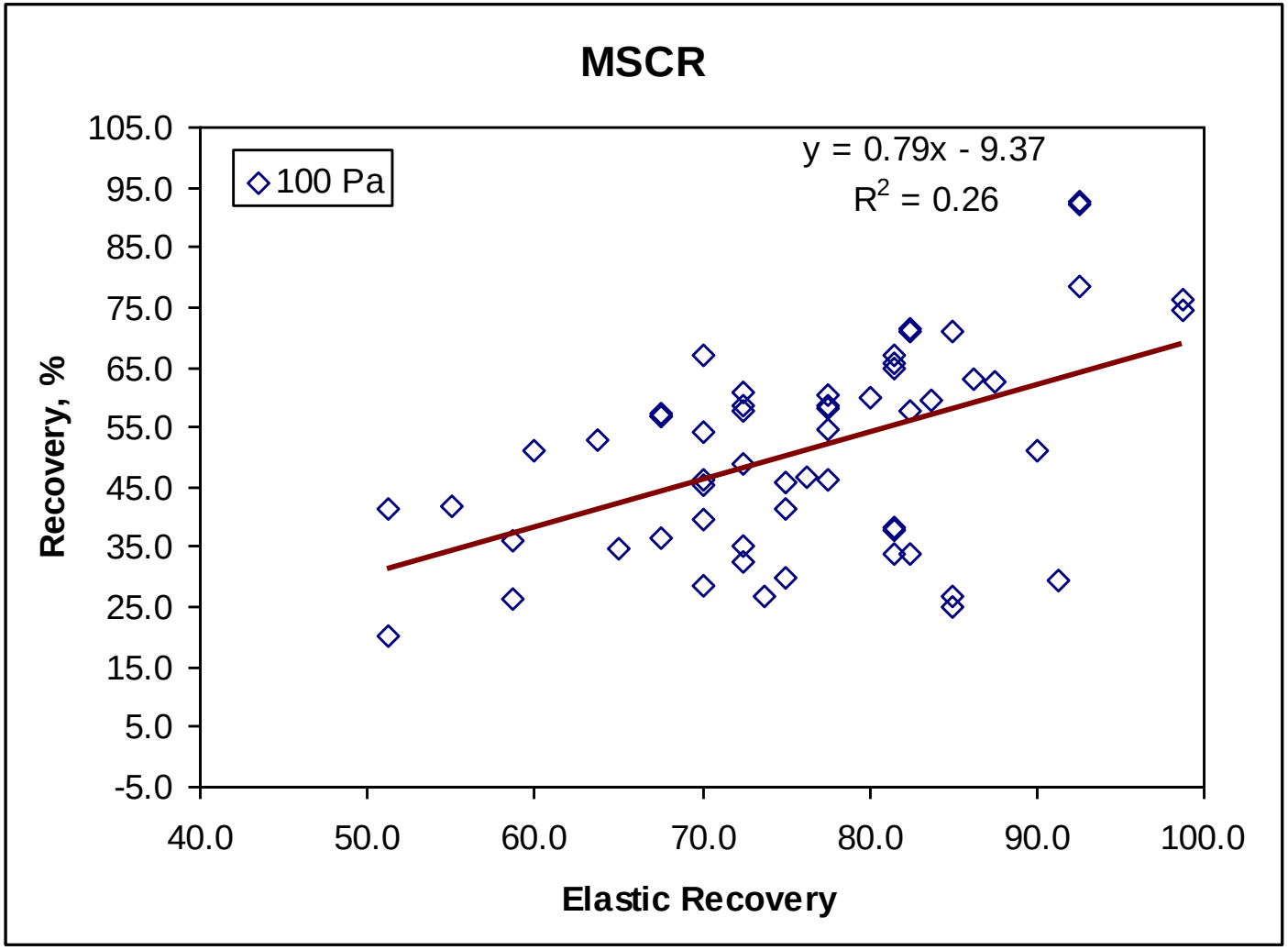
MSCR Recovery: 3200 Pa



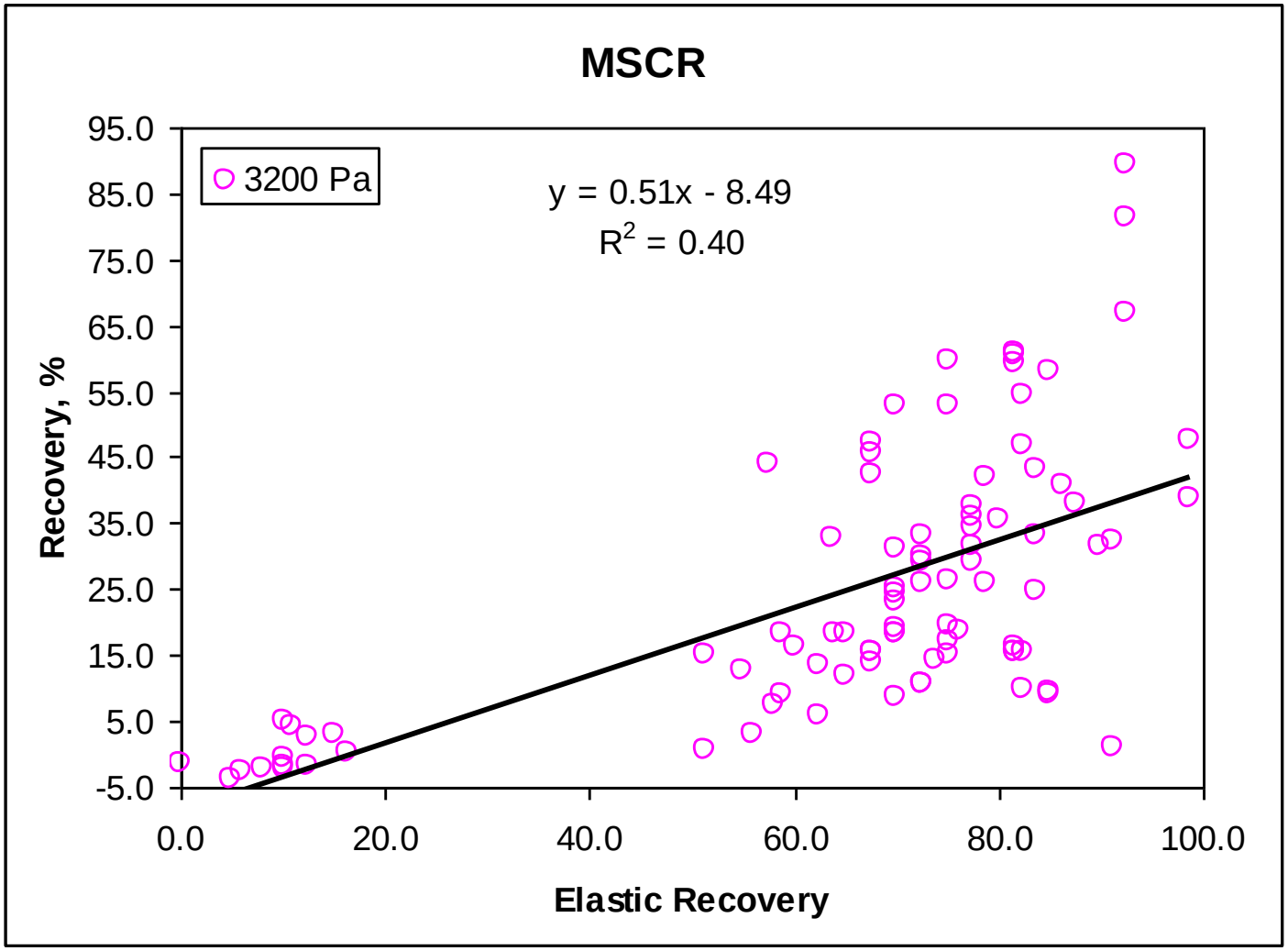
Comparison of MSCR-100 Recovery and Elastic Recovery



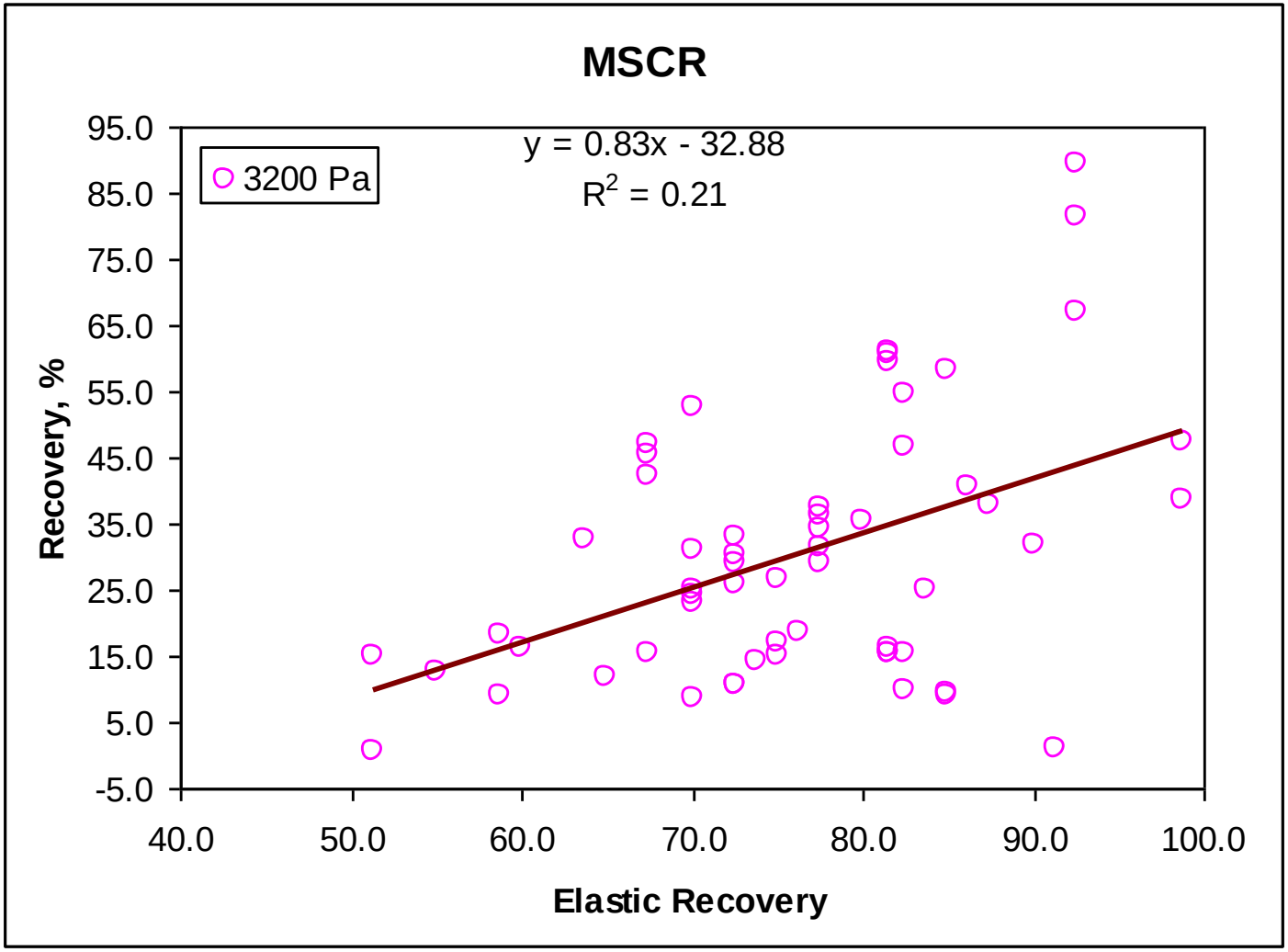
Comparison of MSCR-100 Recovery and Elastic Recovery



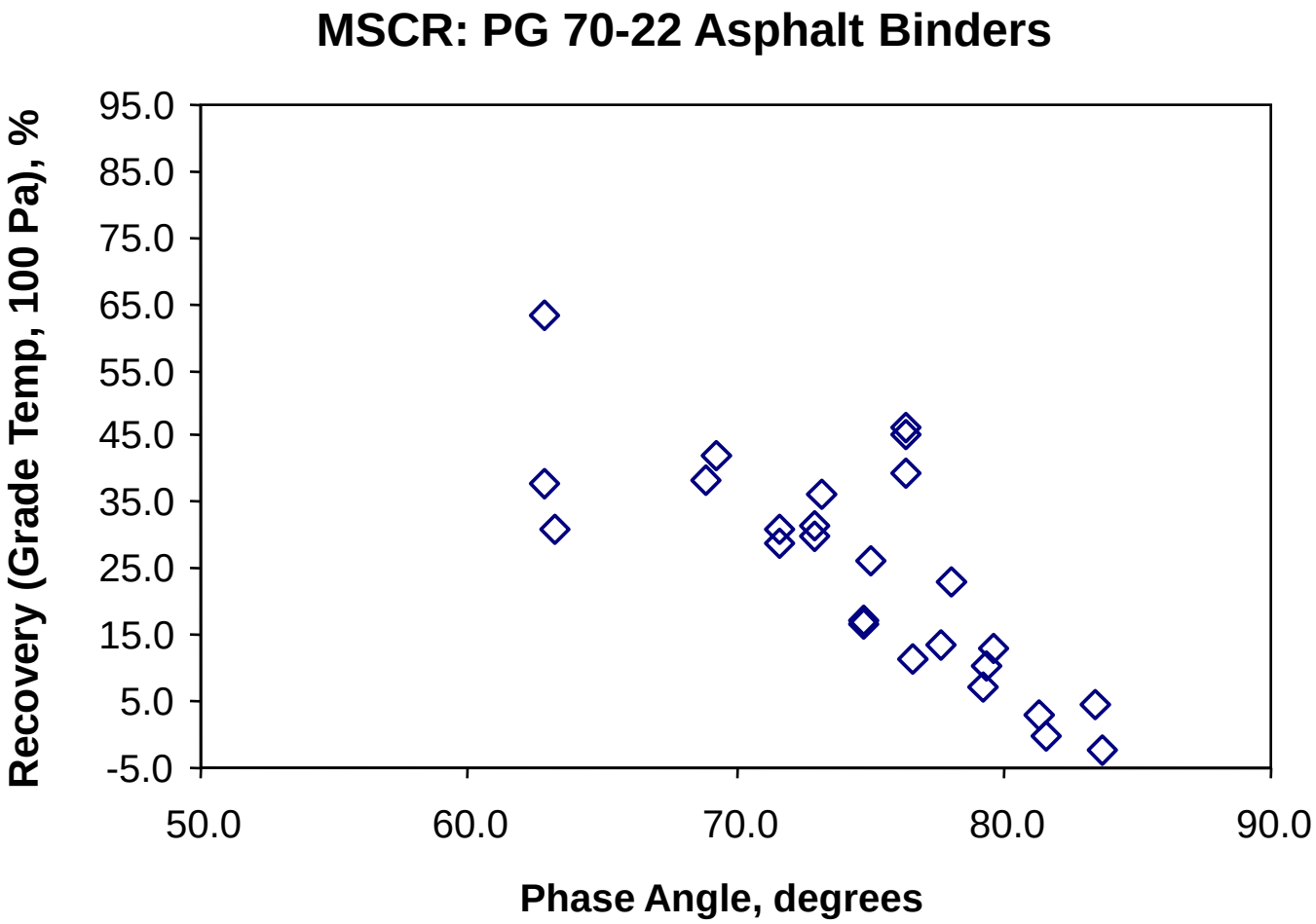
Comparison of MSCR-3200 Recovery and Elastic Recovery



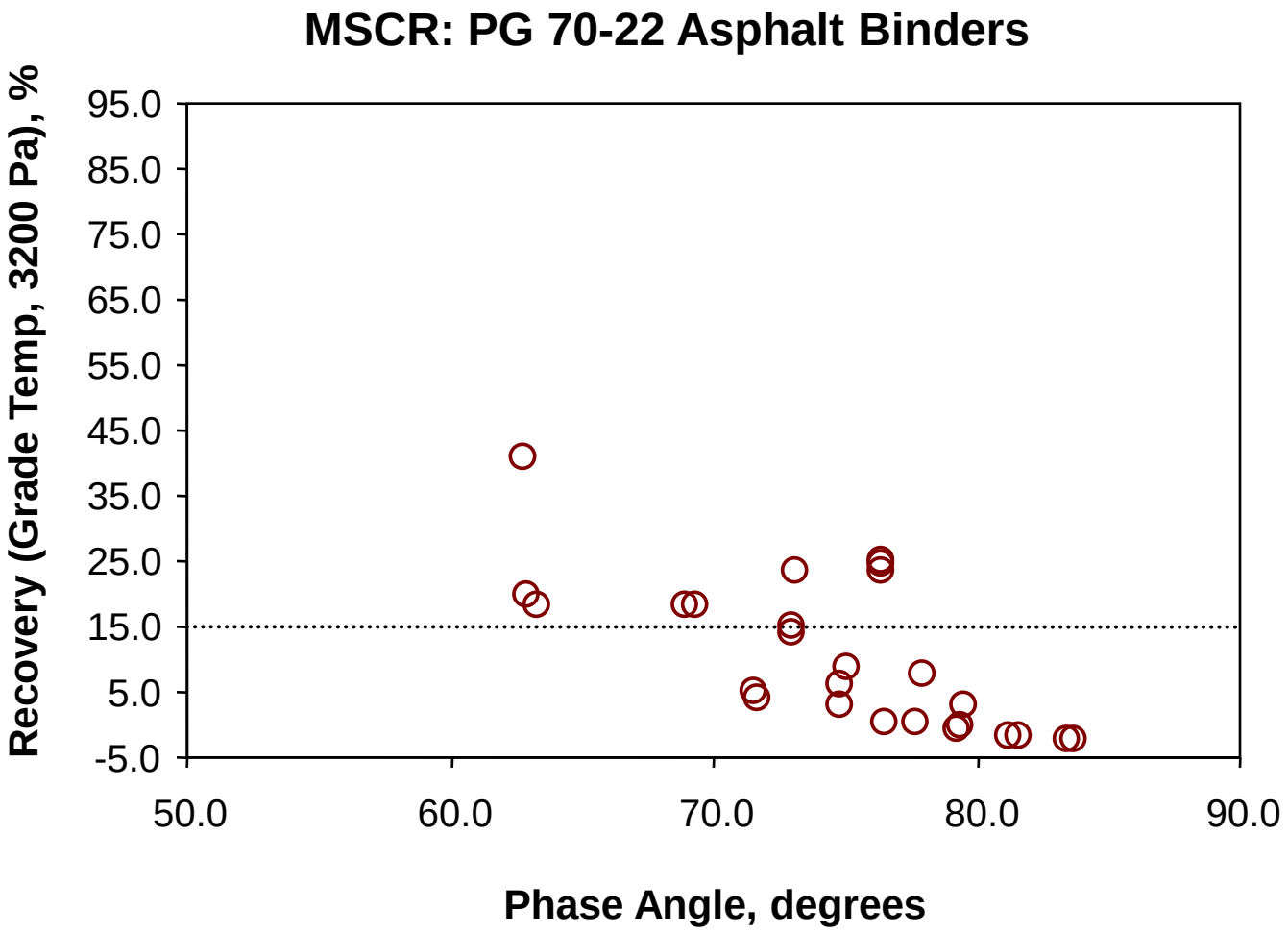
Comparison of MSCR-3200 Recovery and Elastic Recovery



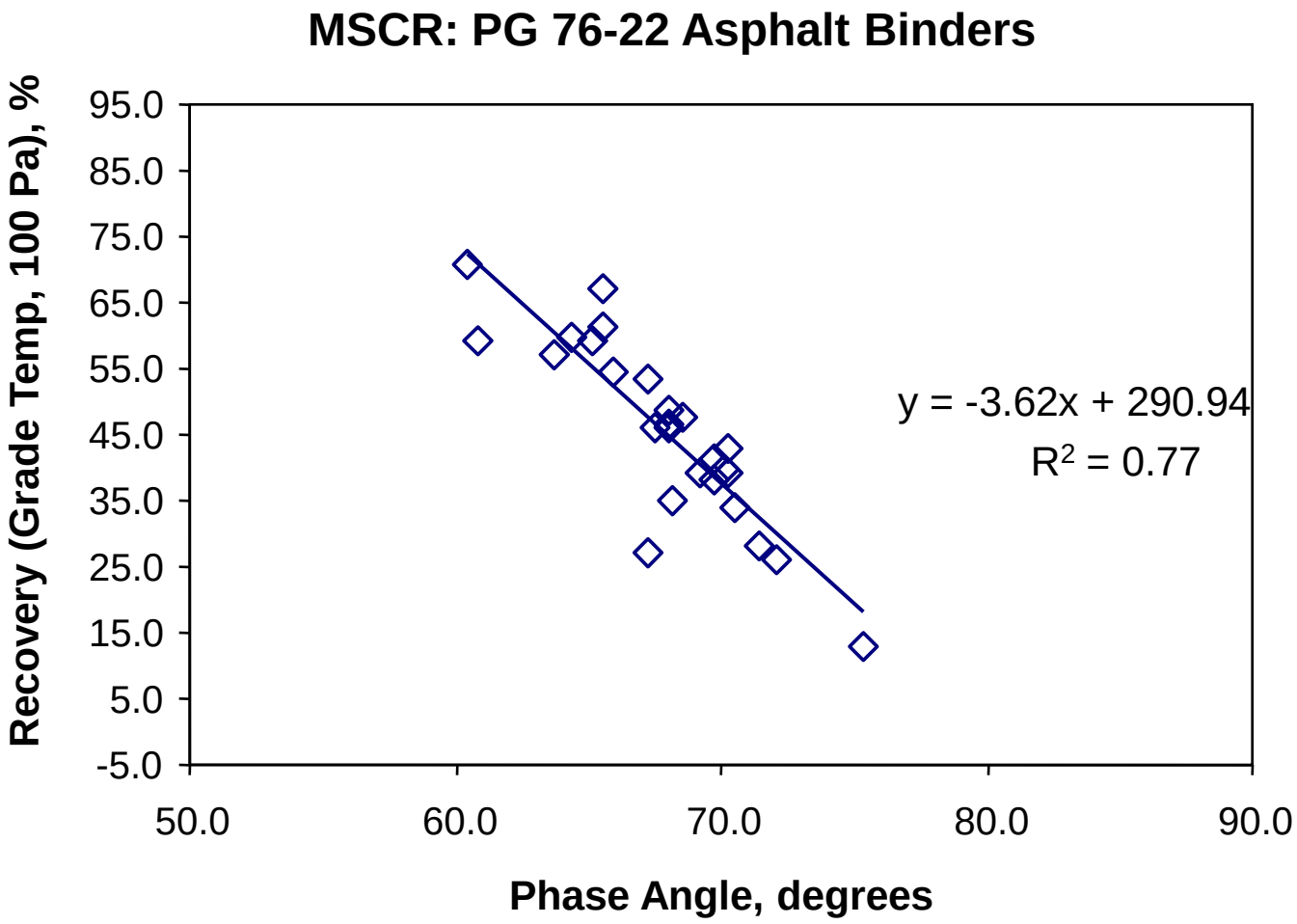
PG 70-22 Binders: MSCR-100 Recovery



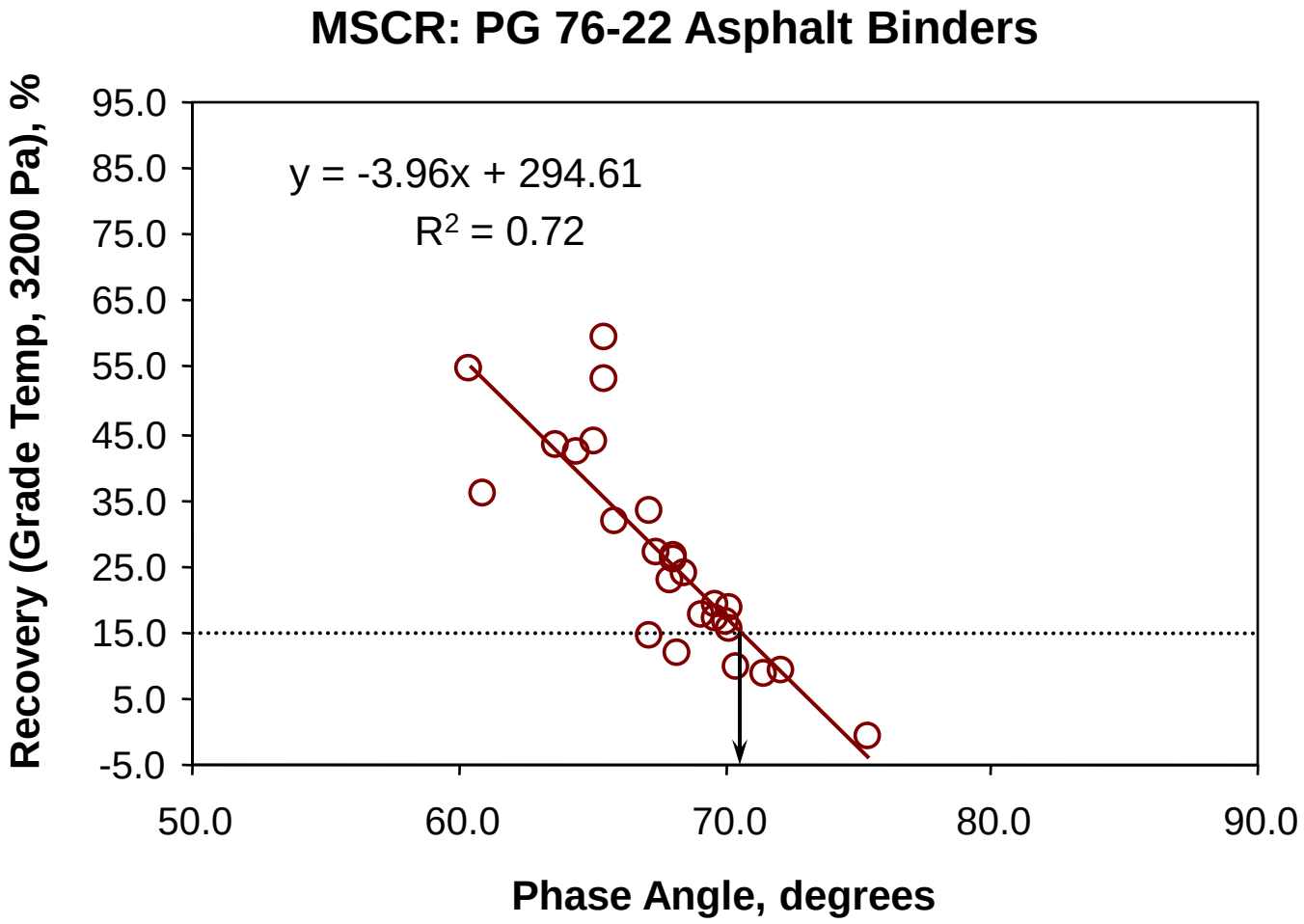
PG 70-22 Binders: MSCR-3200 Recovery



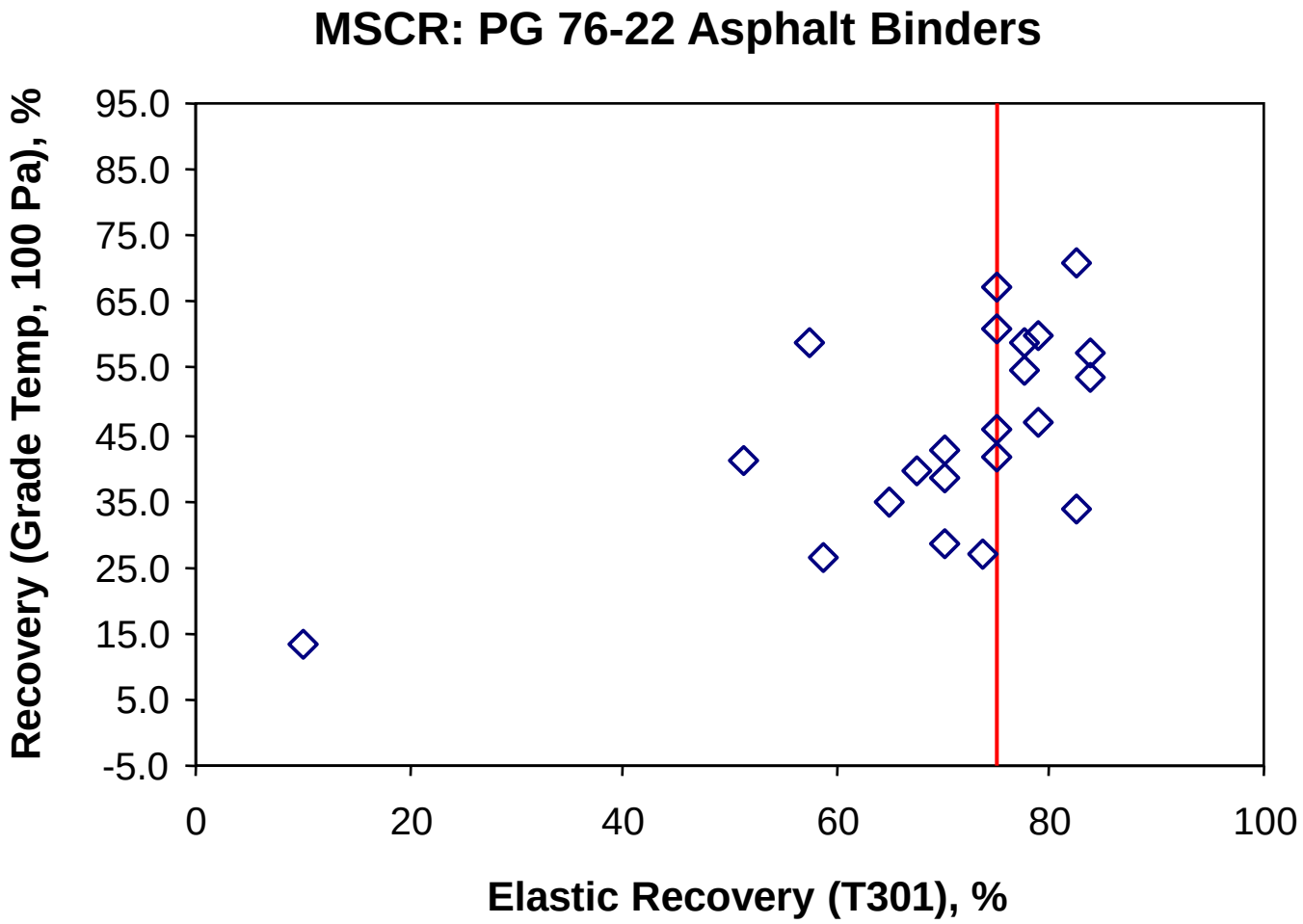
PG 76-22 Binders: MSCR-100 Recovery



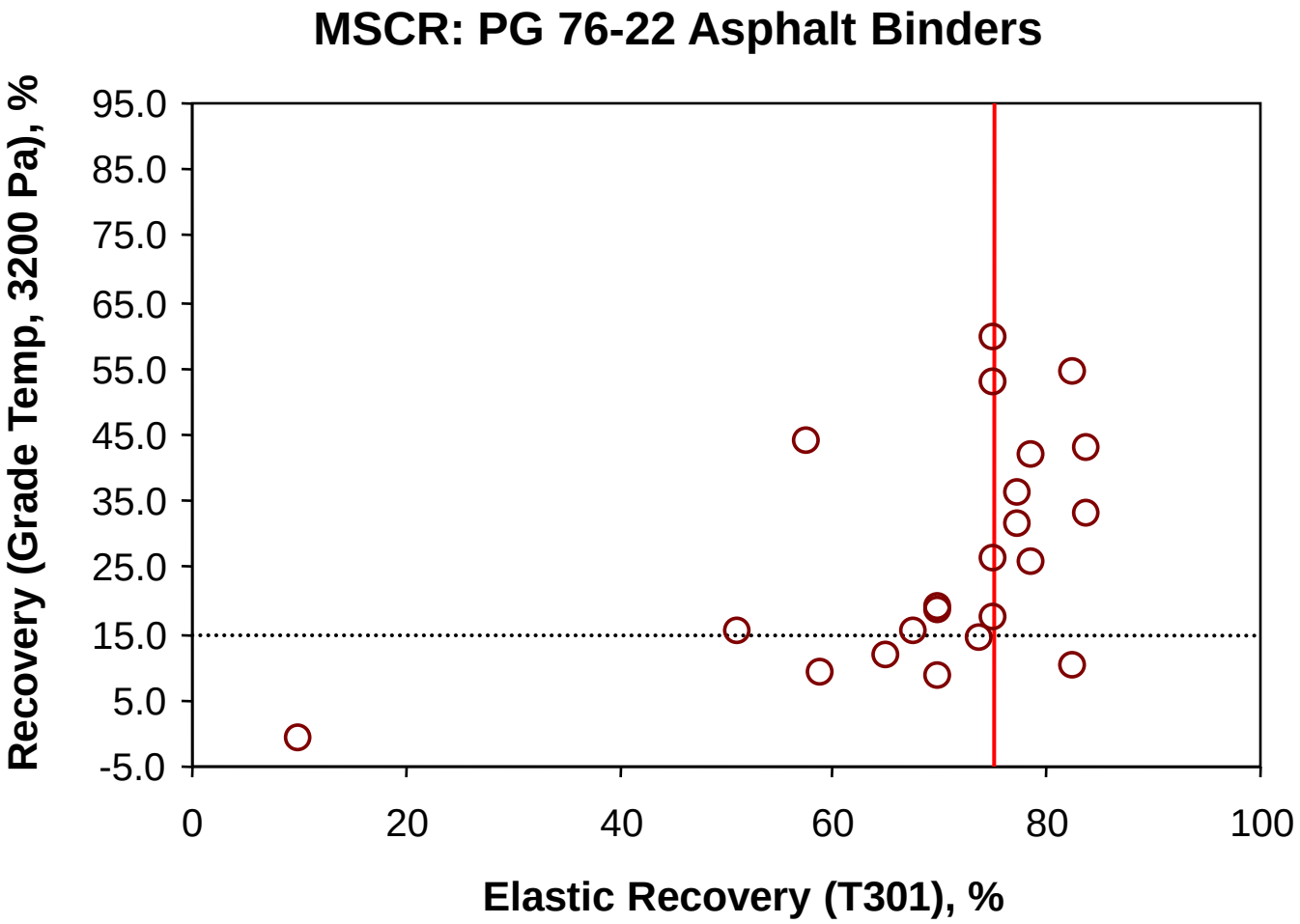
PG 76-22 Binders: 3200 Pa Recovery



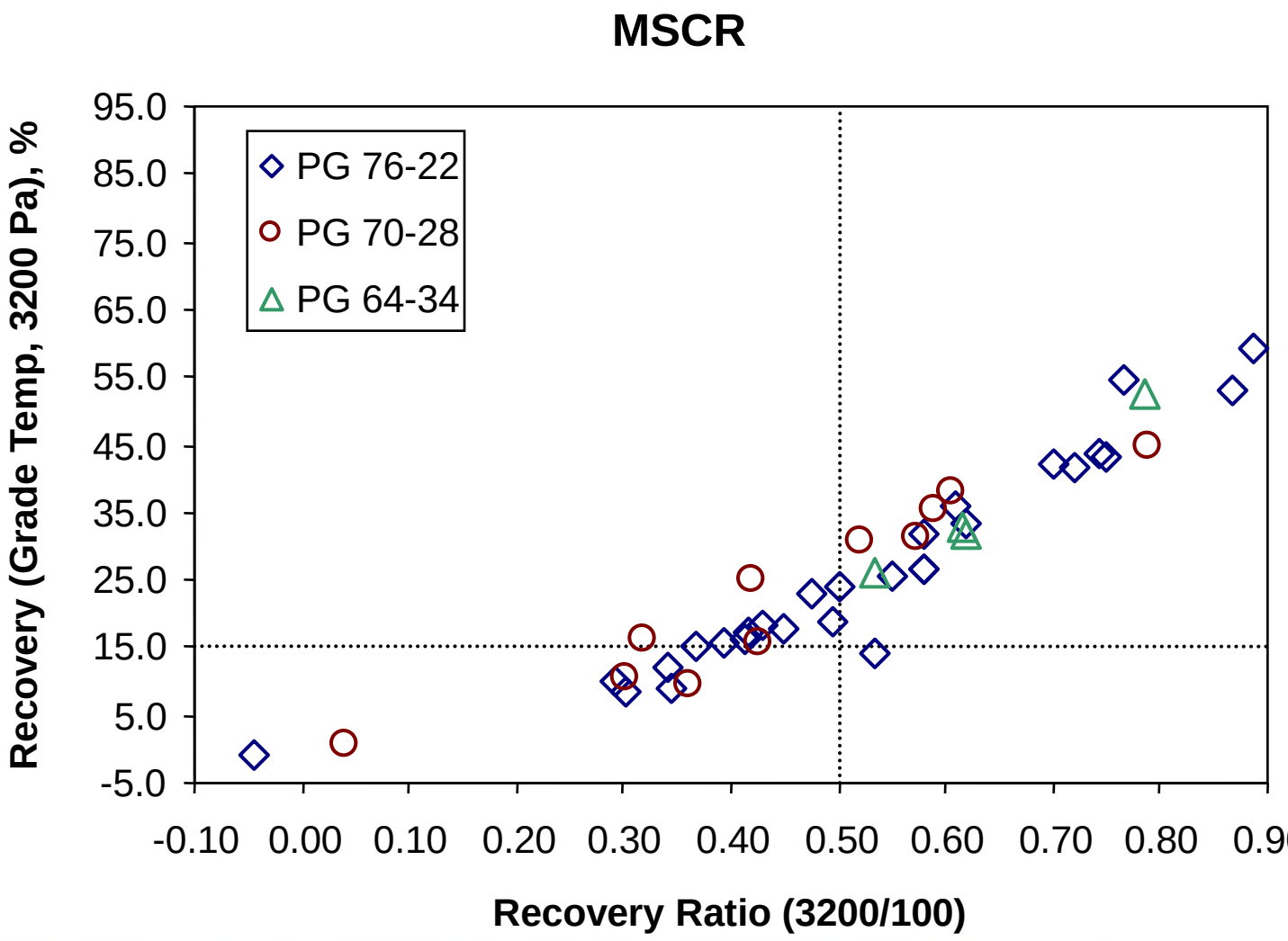
PG 76-22 Binders: MSCR-100 Recovery



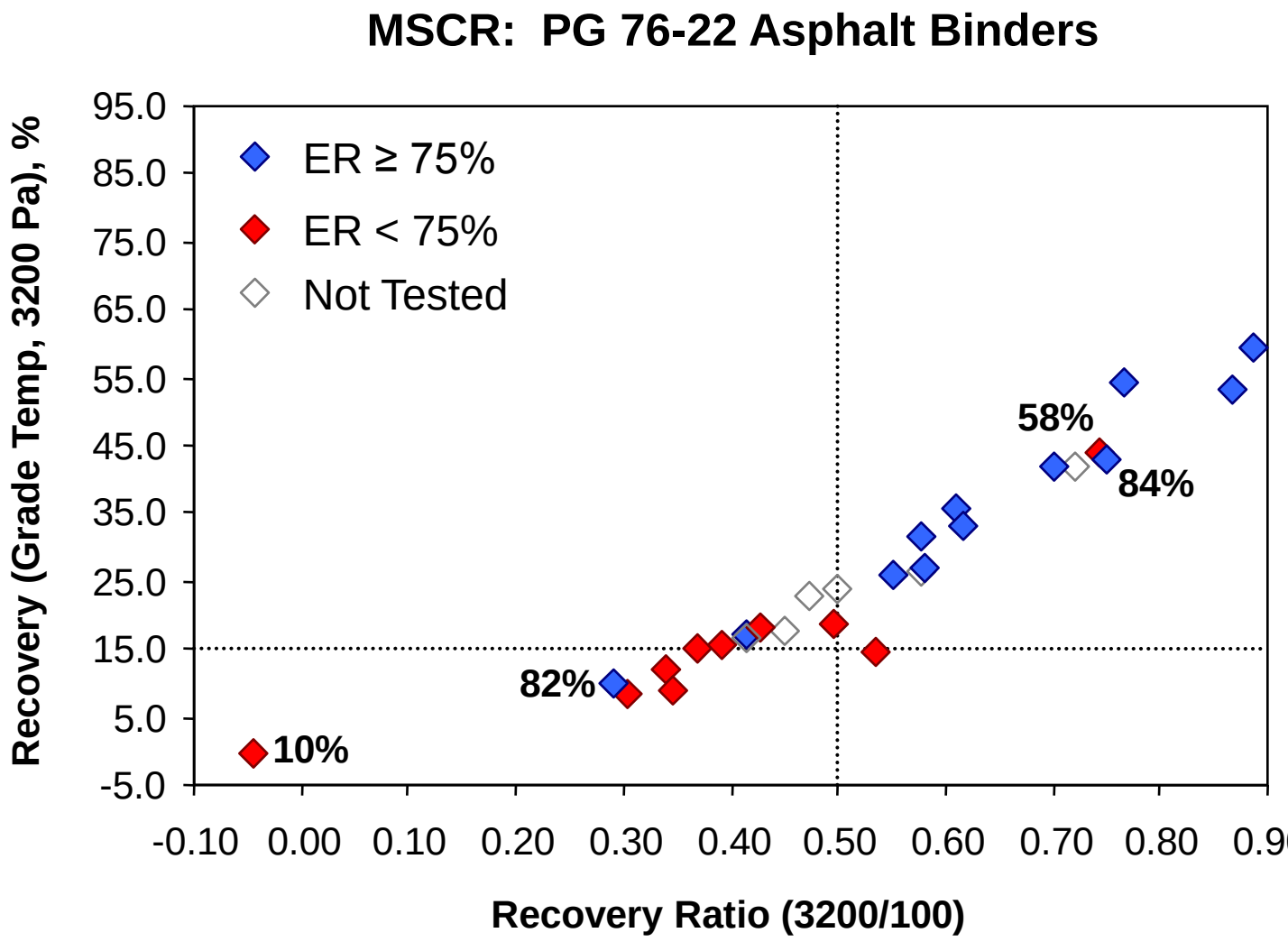
PG 76-22 Binders: 3200 Pa Recovery



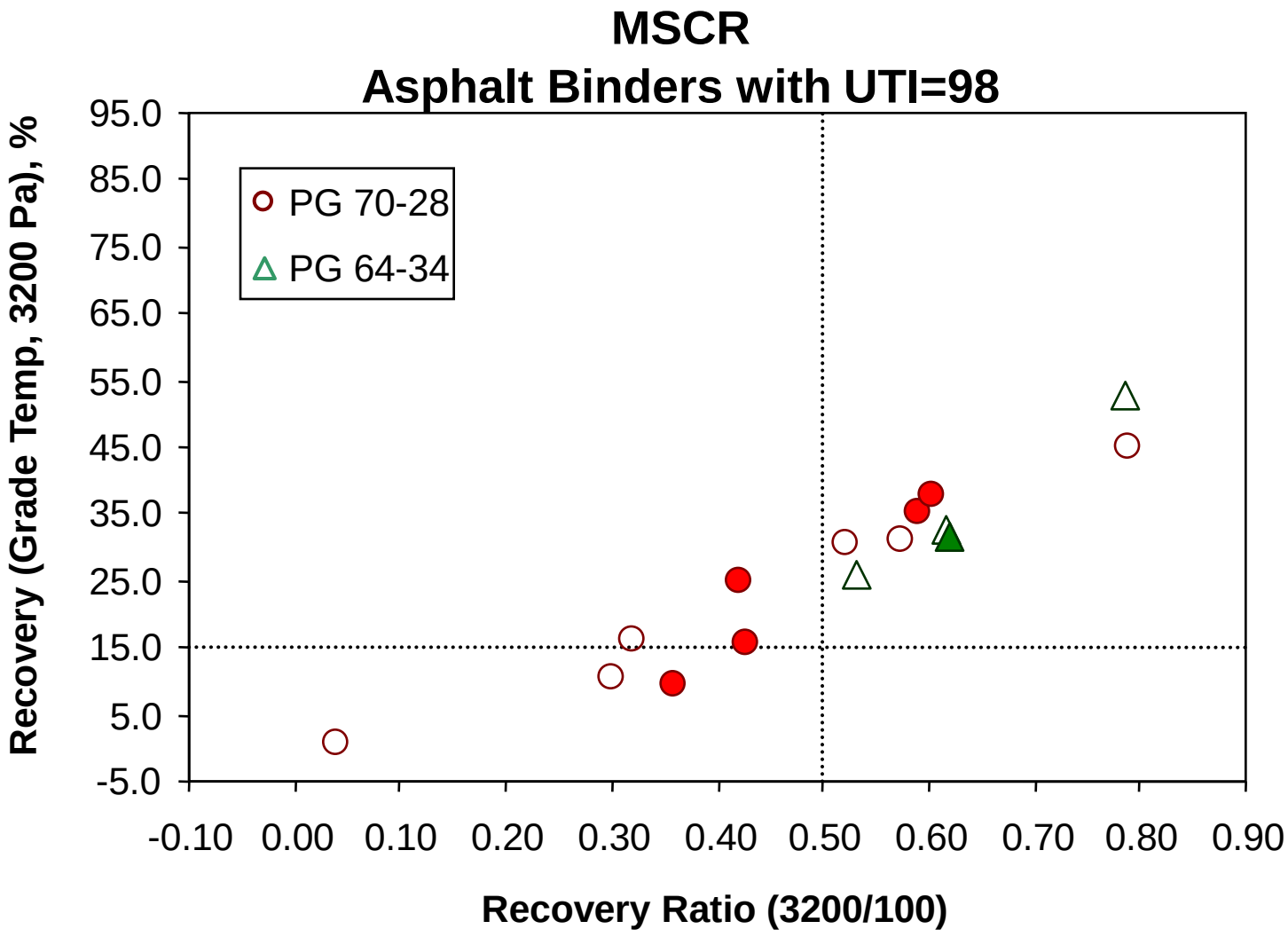
Asphalt Binders with 98 C Temperature Interval



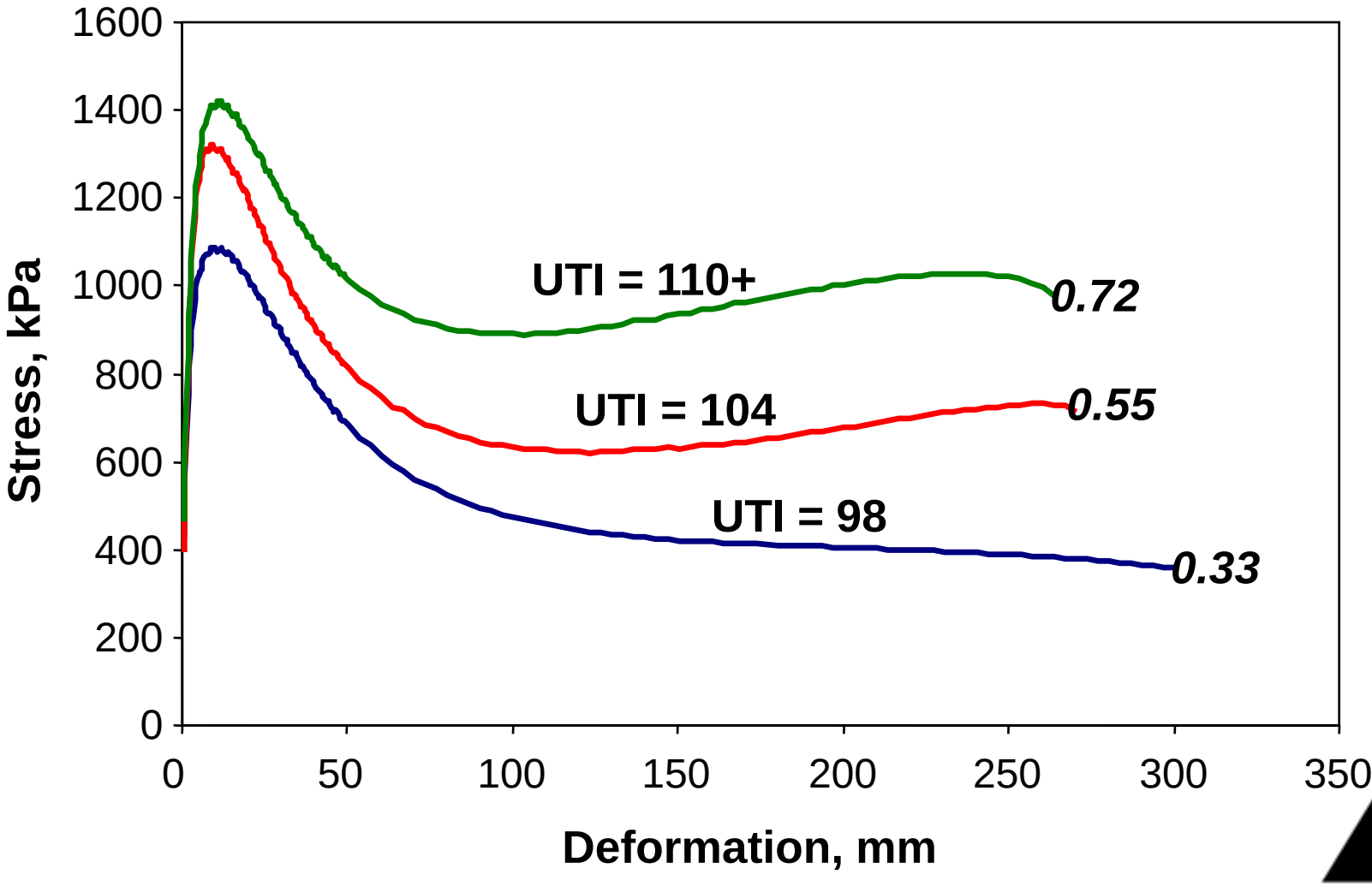
Elastic Recovery Compared to MSCR Recovery and Recovery Ratio



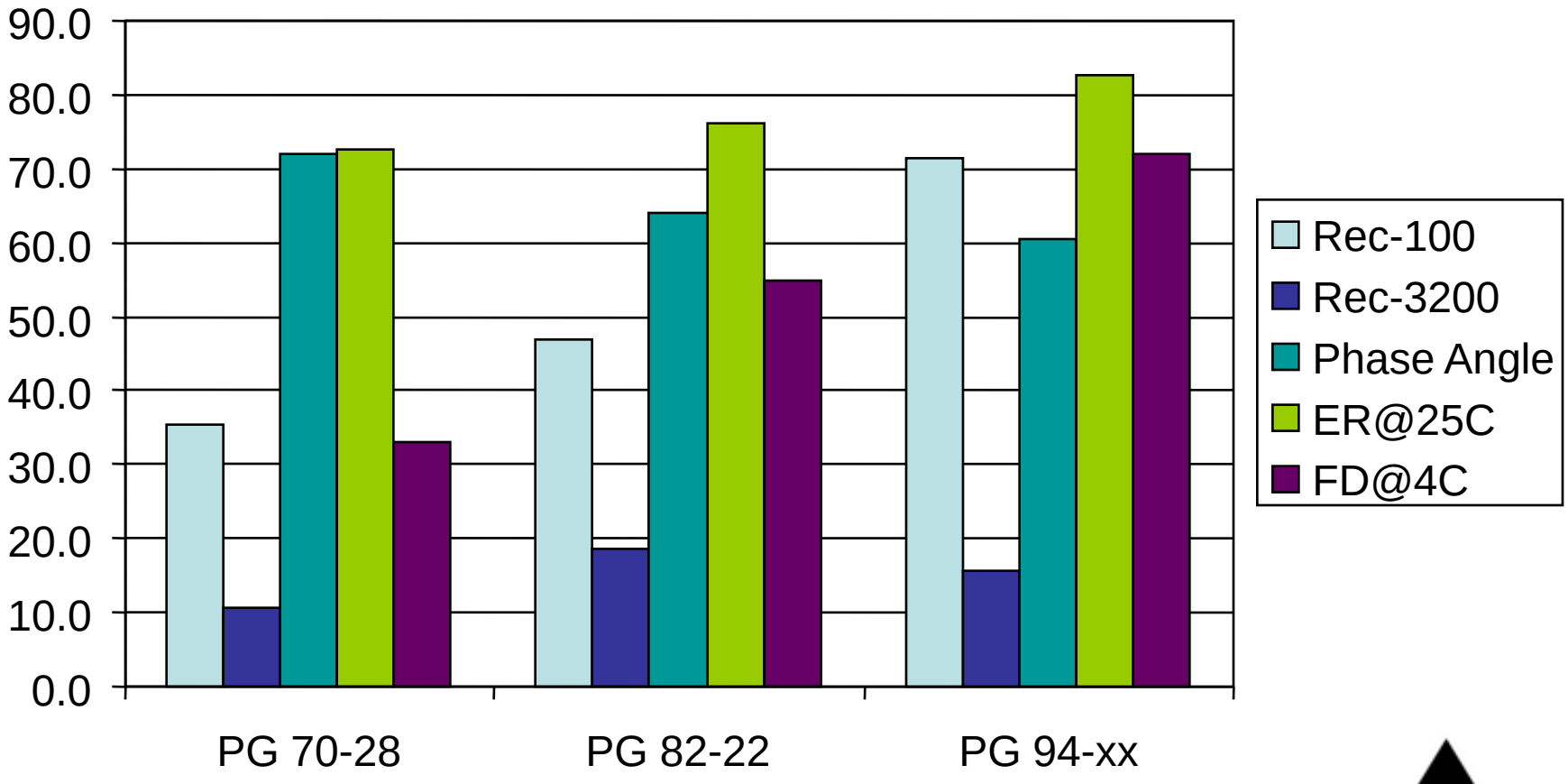
Elastic Recovery Compared to MSCR Recovery and Recovery Ratio



Force Ductility – Single Source



Single Source – PG+ Comparison



AI Repeatability – 100 Pa

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	Recovery - 100 Pa					
Grade	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

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	Recovery - 3200 Pa					
Grade	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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	Recovery - 100 Pa					
Grade	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

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	Recovery - 3200 Pa					
Grade	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

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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

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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!