IMPACT OF POLYMER MODIFIED BINDERS ON THE DSR CREEP PROPERTIES OF HMA MIXTURES

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Stacy Glidden

Mathy Technology and Engineering Services

Outline

- MOTIVATION to develop a mechanistic test for HMA
- Sample Preparation & Test Description
- Rutting Prediction Results (MN & ALF)
- Results compared to SST testing
- Impact of Binder, Modifier & Gradation

MTE

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- Work on mechanistic test not finalized at the end of SHRP research program
- SST equipment and FSCH & RSCH tests were available, test methods and analysis procedures to predict rutting not well defined
- Equipment was expensive, few units available
- Agencies & contractors were interested in answers to short term questions regarding relative performance of mixes

- **Perception among user agencies and suppliers that SHRP PG grading system did not adequately identify the performance benefits of polymers or other additives in binders**
- **Reasons for perception**
  - **SHRP binder tests seemed to correlate to mix performance for conventional binders**
  - **SHRP PG grading system did not provide tests capable of identifying superior performing binders in HMA**

- **One response was the implementation of SHRP Plus binder specifications**
  - **Forced suppliers to provide binders with a known performance history**
    - **Elastic Recovery (@ various temperatures & values)**
    - **Force Ductility (@ various temperatures & values)**
    - **Toughness & Tenacity (various results)**
  - **In effect the binder specification became a surrogate mixture performance specification**
  - **Lack of correlation to mix performance has not deterred use**
    - **Obvious need for some mechanistic solution**

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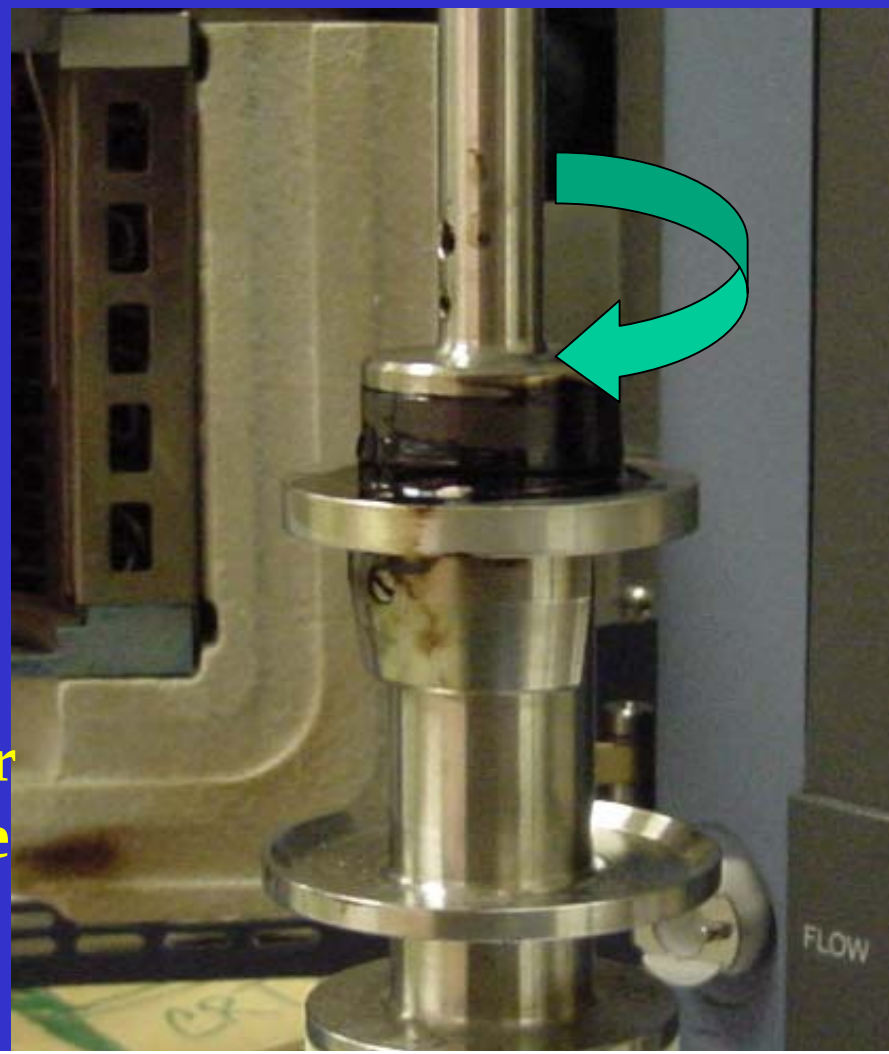
A 1 SECOND STRESS IS APPLIED FOLLOWED BY A 9 SECOND RECOVERY PERIOD



Idea for dynamic mixture test based on the procedure developed for binder cumulative strain test plus the test procedure employed in SST RSCH mix test

MTE

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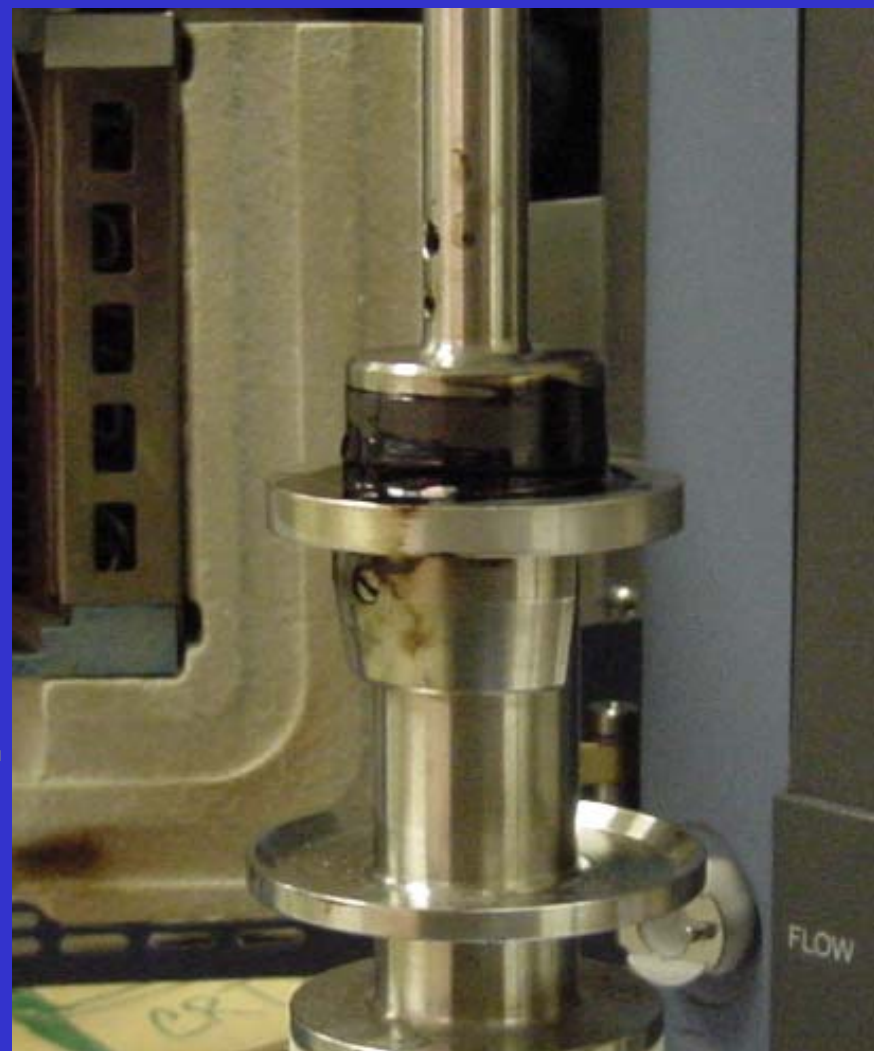
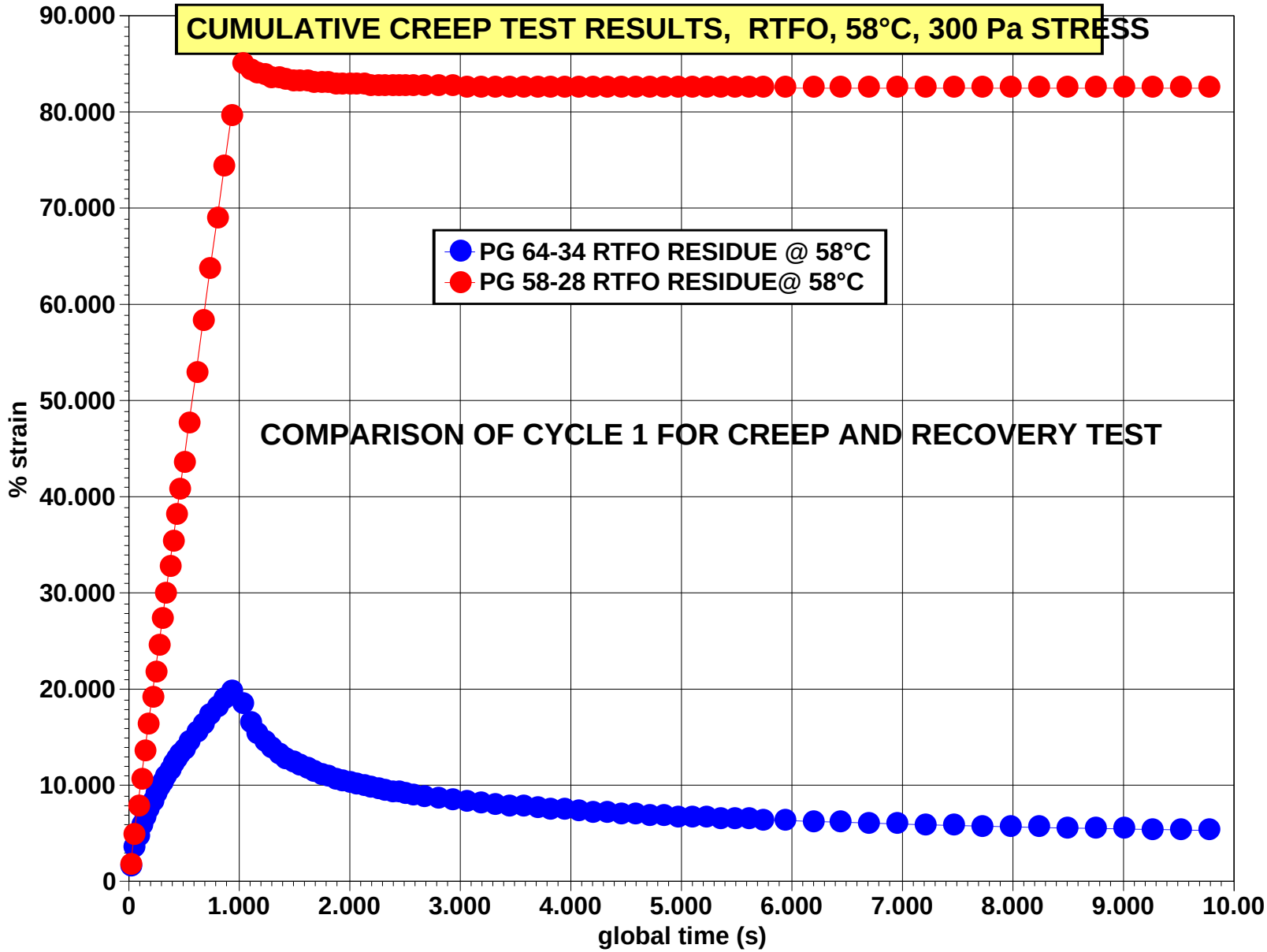
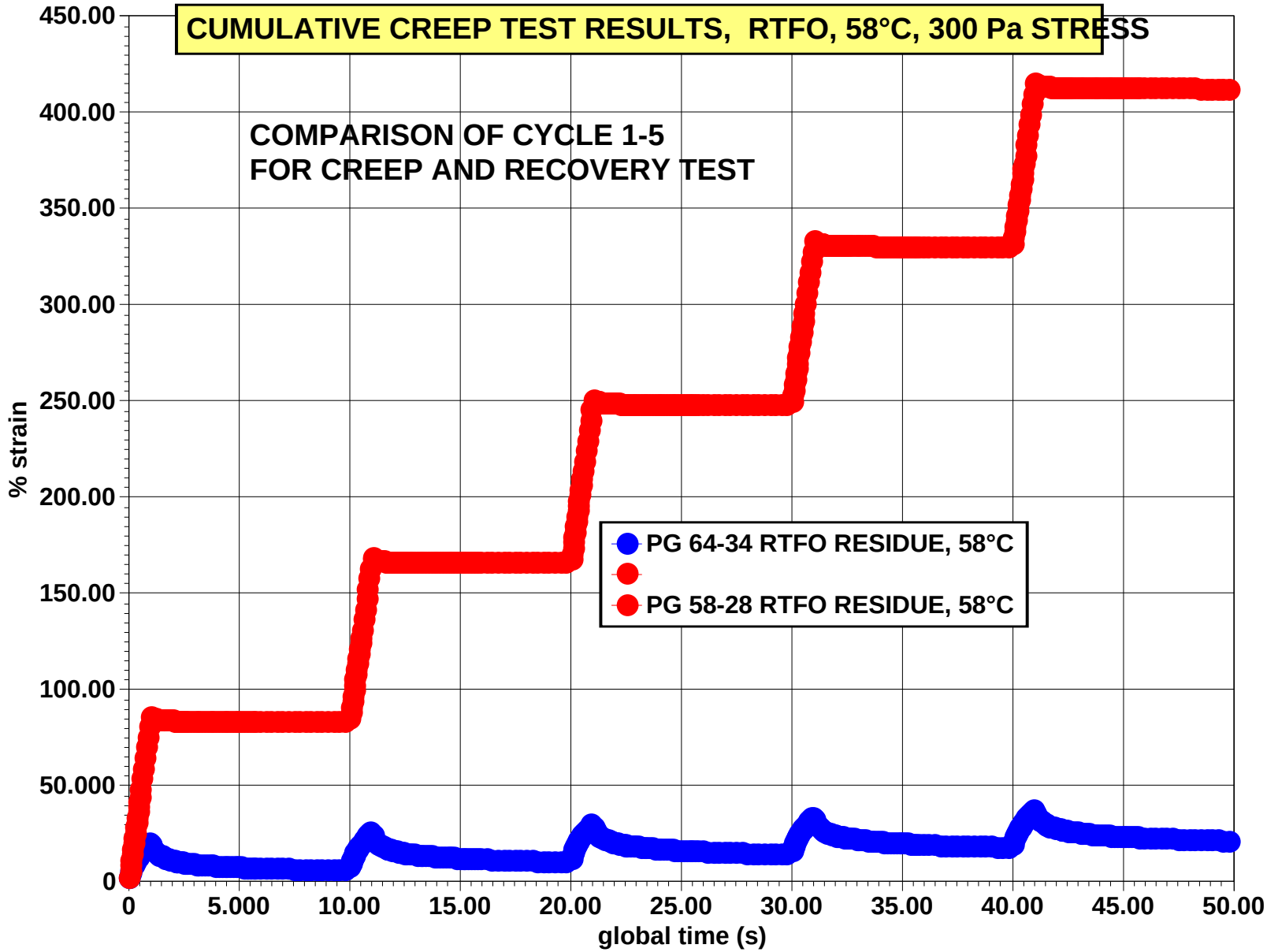
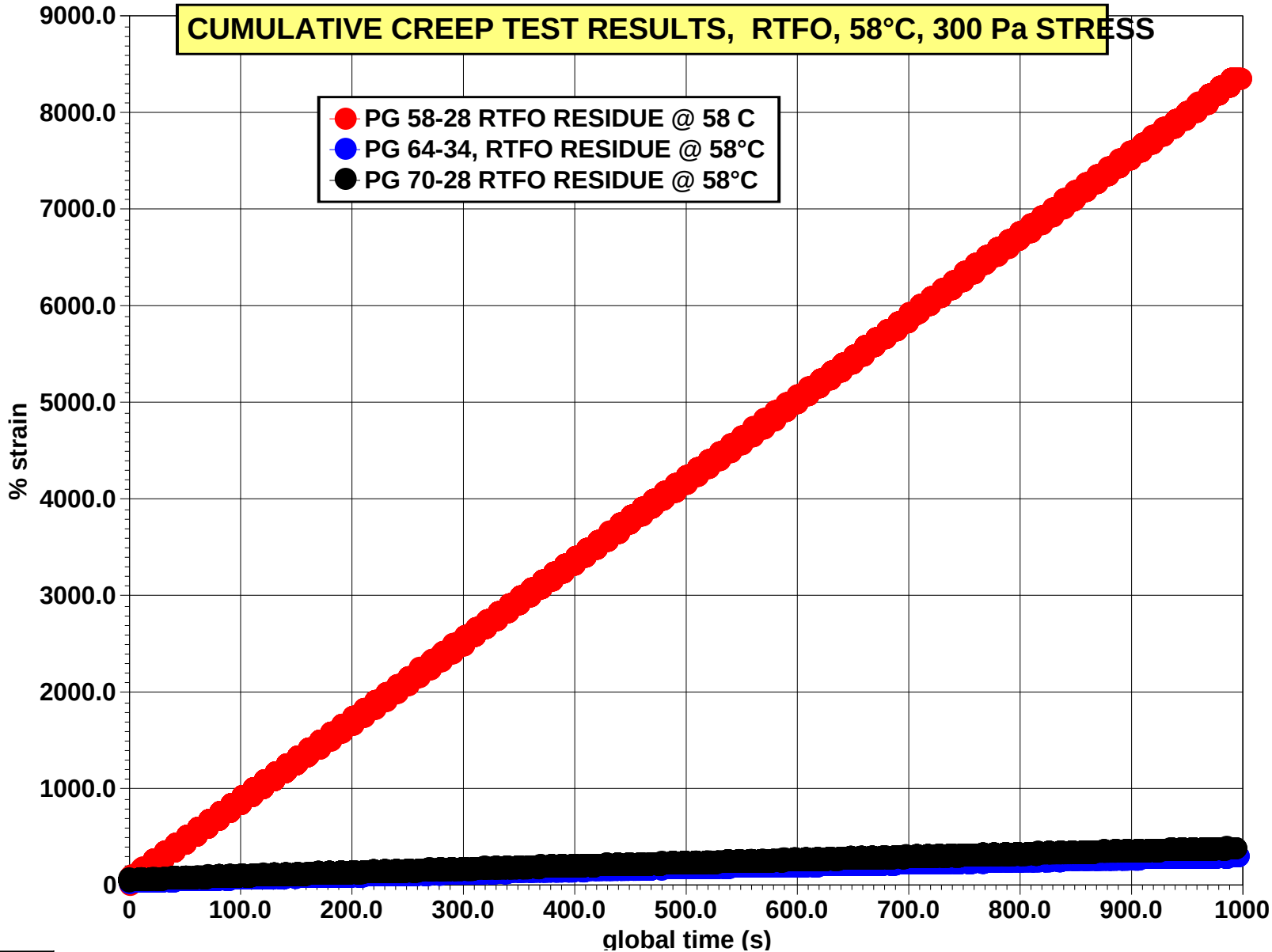


Idea for dynamic mixture test based on the procedure developed for binder cumulative strain test plus the test procedure employed in SST RSCH mix test

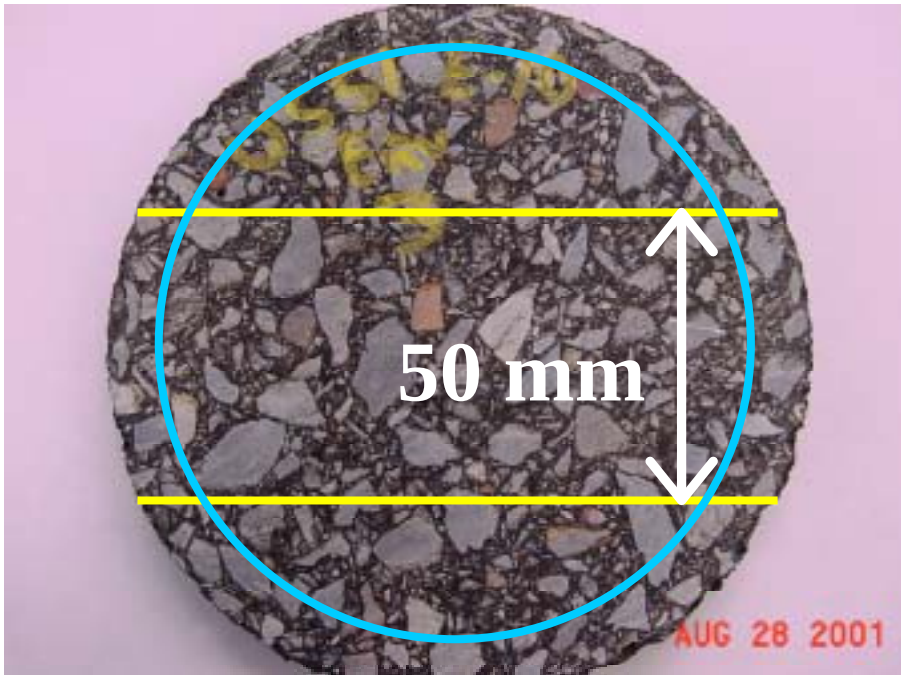
MTE


CUMULATIVE CREEP TEST RESULTS, RTFO, 58°C, 300 Pa STRESS
PG 64-34 RTFO RESIDUE @ 58°C
PG 58-28 RTFO RESIDUE@ 58°C
COMPARISON OF CYCLE 1 FOR CREEP AND RECOVERY TEST
% strain
global time (s)
90.000
80.000
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0
0
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.00


CUMULATIVE CREEP TEST RESULTS, RTFO, 58°C, 300 Pa STRESS
COMPARISON OF CYCLE 1-5
FOR CREEP AND RECOVERY TEST
% strain
global time (s)
PG 64-34 RTFO RESIDUE, 58°C
PG 58-28 RTFO RESIDUE, 58°C
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.000
0
0
5.000
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00


CUMULATIVE CREEP TEST RESULTS, RTFO, 58°C, 300 Pa STRESS
PG 58-28 RTFO RESIDUE @ 58 C
PG 64-34, RTFO RESIDUE @ 58°C
PG 70-28 RTFO RESIDUE @ 58°C
% strain
9000.0
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0
0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000
global time (s)

Sample Preparation

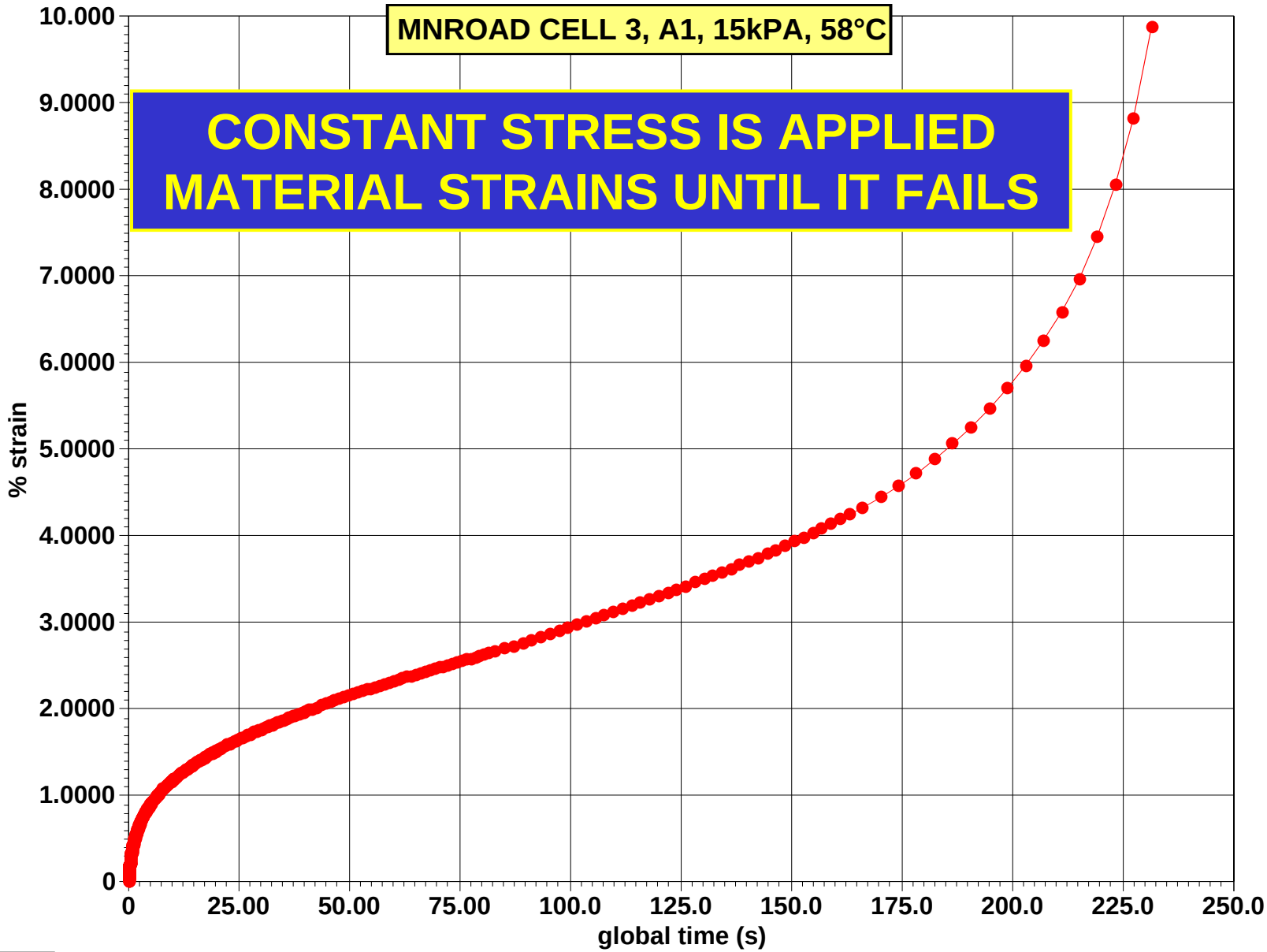


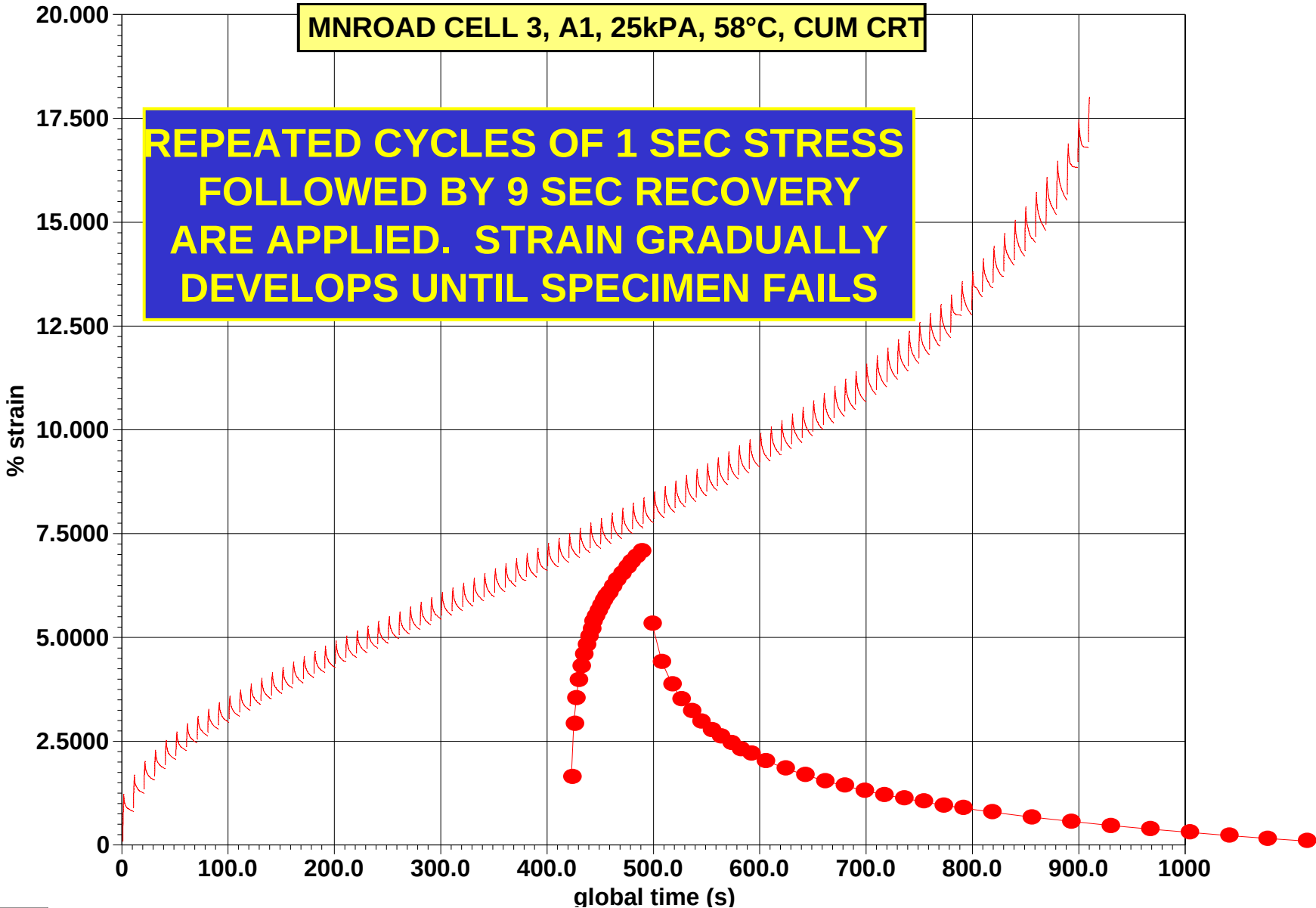
Sample Preparation & Test

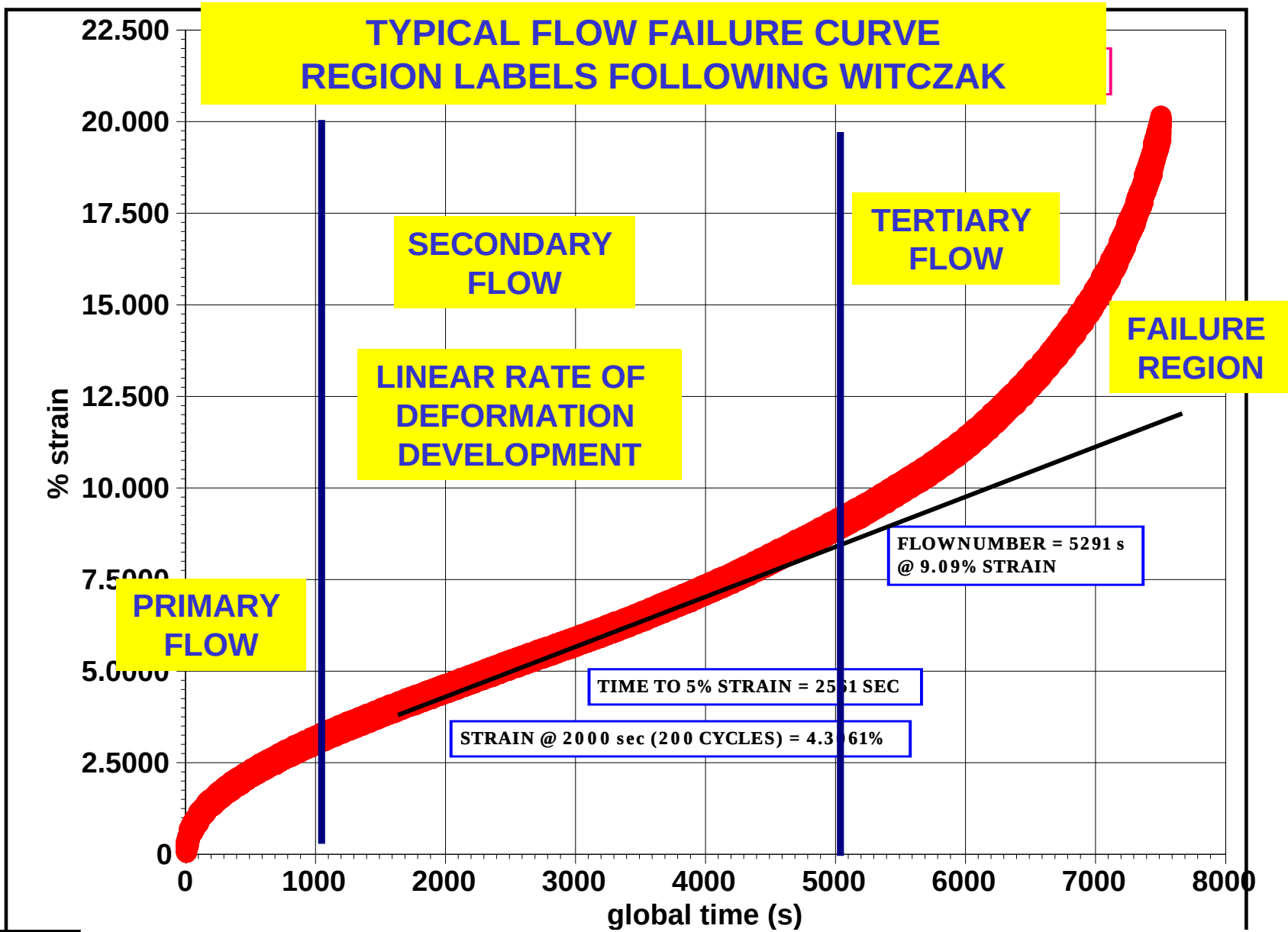
- **Sample Size**
  - **6 mm x 12 mm x 50 mm**
  - **10 mm x 12 mm x 50 mm**

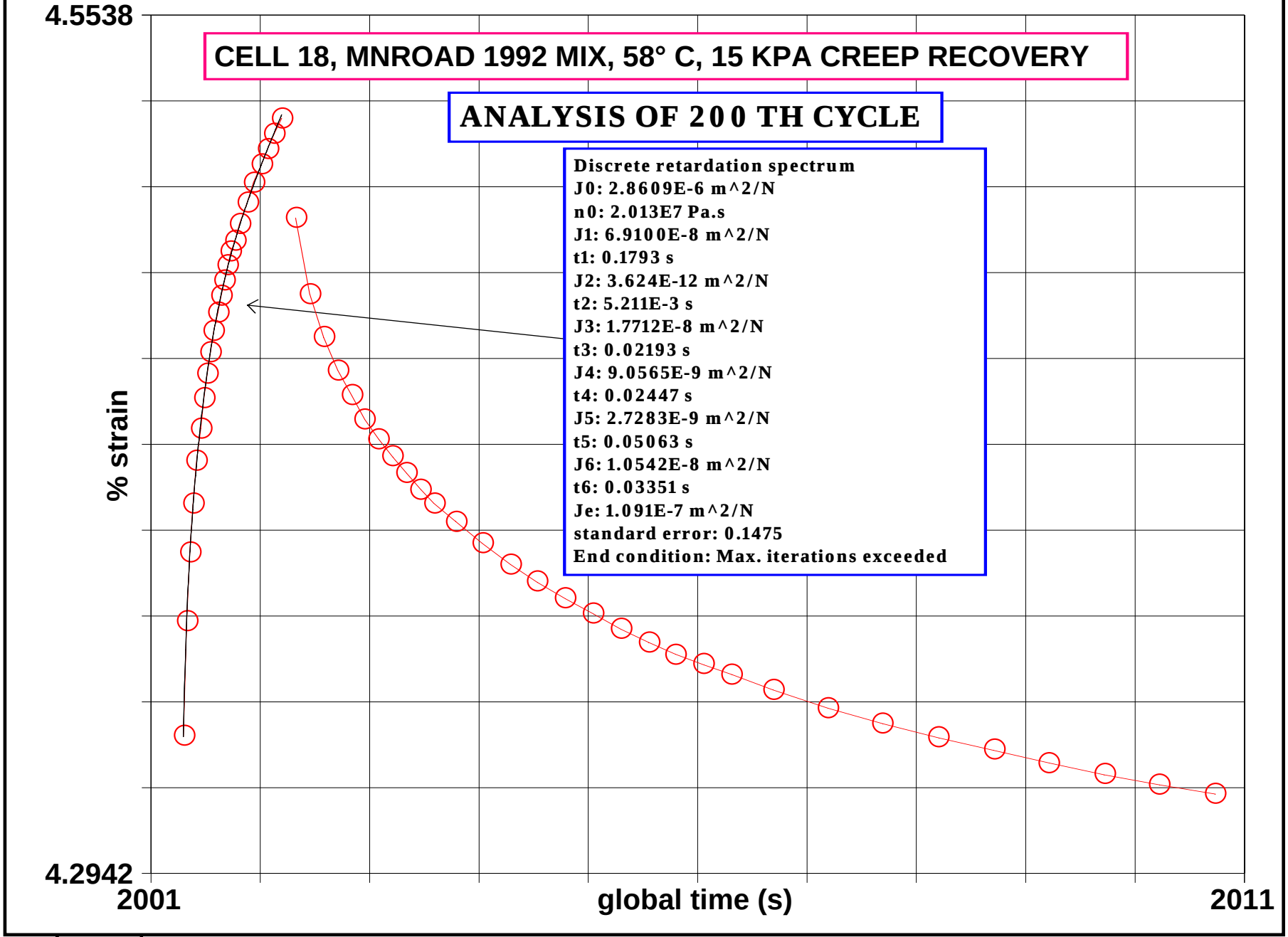
Sample Preparation & Test

- Dynamic Creep & Recovery Test
  - 10 Second Cycles
    - 1 Second Stress
    - 9 Seconds Recovery
- Static Creep Test
    - Stress Applied Until Failure


MNROAD CELL 3, A1, 15kPA, 58°C
CONSTANT STRESS IS APPLIED
MATERIAL STRAINS UNTIL IT FAILS
% strain
10.000
9.0000
8.0000
7.0000
6.0000
5.0000
4.0000
3.0000
2.0000
1.0000
0
0
25.00
50.00
75.00
100.0
125.0
150.0
175.0
200.0
225.0
250.0
global time (s)


MNROAD CELL 3, A1, 25kPA, 58°C, CUM CRT
REPEATED CYCLES OF 1 SEC STRESS FOLLOWED BY 9 SEC RECOVERY ARE APPLIED. STRAIN GRADUALLY DEVELOPS UNTIL SPECIMEN FAILS
% strain
20.000
17.500
15.000
12.500
10.000
7.5000
5.0000
2.5000
0
0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000
global time (s)


TYPICAL FLOW FAILURE CURVE
REGION LABELS FOLLOWING WITCZAK
PRIMARY FLOW
SECONDARY FLOW
LINEAR RATE OF DEFORMATION DEVELOPMENT
TERTIARY FLOW
FAILURE REGION
FLOWNUMBER = 5291 s
@ 9.09% STRAIN
TIME TO 5% STRAIN = 25 1 SEC
STRAIN @ 2000 sec (200 CYCLES) = 4.3 61%
% strain
global time (s)
22.500
20.000
17.500
15.000
12.500
10.000
7.5000
5.0000
2.5000
0
0
1000
2000
3000
4000
5000
6000
7000
8000


CELL 18, MNROAD 1992 MIX, 58° C, 15 KPA CREEP RECOVERY
ANALYSIS OF 200 TH CYCLE
Discrete retardation spectrum
J0: 2.8609E-6 m^2/N
n0: 2.013E7 Pa.s
J1: 6.9100E-8 m^2/N
t1: 0.1793 s
J2: 3.624E-12 m^2/N
t2: 5.211E-3 s
J3: 1.7712E-8 m^2/N
t3: 0.02193 s
J4: 9.0565E-9 m^2/N
t4: 0.02447 s
J5: 2.7283E-9 m^2/N
t5: 0.05063 s
J6: 1.0542E-8 m^2/N
t6: 0.03351 s
Je: 1.091E-7 m^2/N
standard error: 0.1475
End condition: Max. iterations exceeded
4.5538
4.2942
% strain
2001
global time (s)
2011

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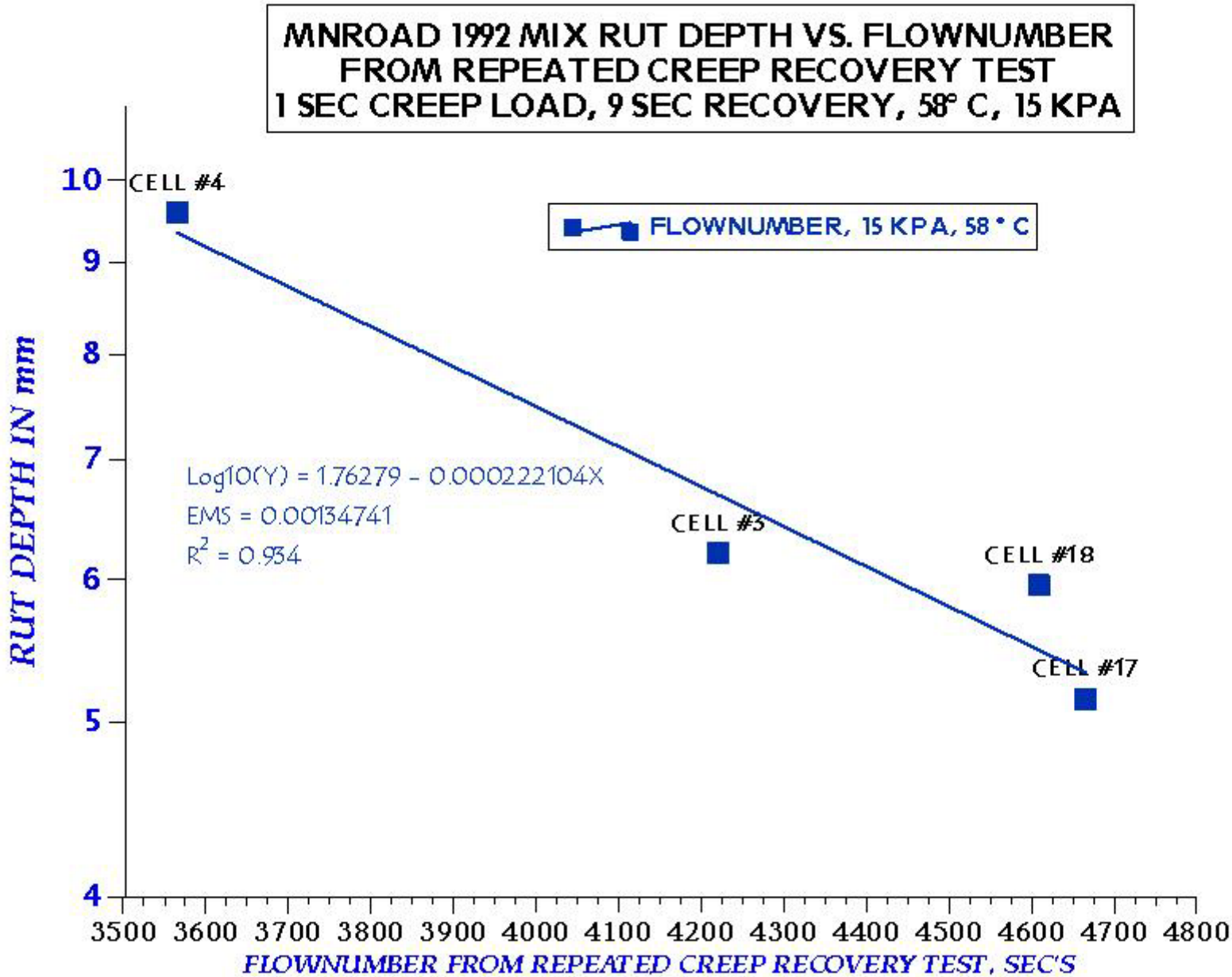
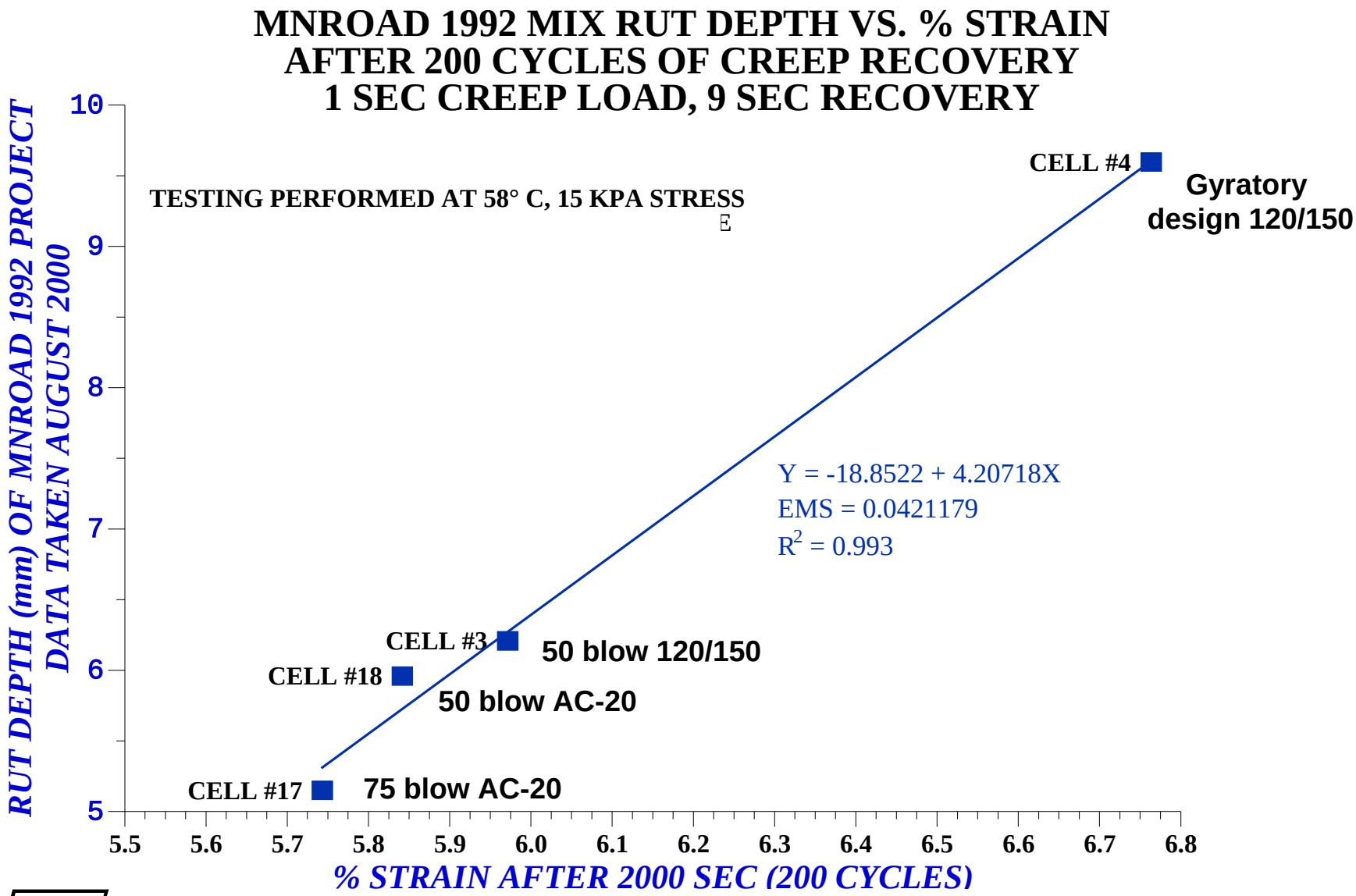
MNROAD 1992 MIX INFORMATION

CELL #	MIX TYPE & BINDER	AVE RUT DEPTH AUG 2000, mm
CELL 3	50 BLOW MARSHALL, 120/150	6.21
CELL 4	GYRATORY DESIGN, 120/150	9.60
CELL 17	75 BLOW MARSHALL, AC-20	5.15
CELL 18	50 BLOW MARSHALL, AC-20	5.96

MTE


MNROAD 1992 MIX RUT DEPTH VS. FLOWNUMBER
FROM REPEATED CREEP RECOVERY TEST
1 SEC CREEP LOAD, 9 SEC RECOVERY, 58° C, 15 KPA
FLOWNUMBER, 15 KPA, 58 ° C
CELL #4
CELL #3
CELL #18
CELL #17
Log10(Y) = 1.76279 - 0.000222104X
EMS = 0.00134741
R2 = 0.934
RUT DEPTH IN mm
10
9
8
7
6
5
4
3500 3600 3700 3800 3900 4000 4100 4200 4300 4400 4500 4600 4700 4800
FLOWNUMBER FROM REPEATED CREEP RECOVERY TEST, SEC'S

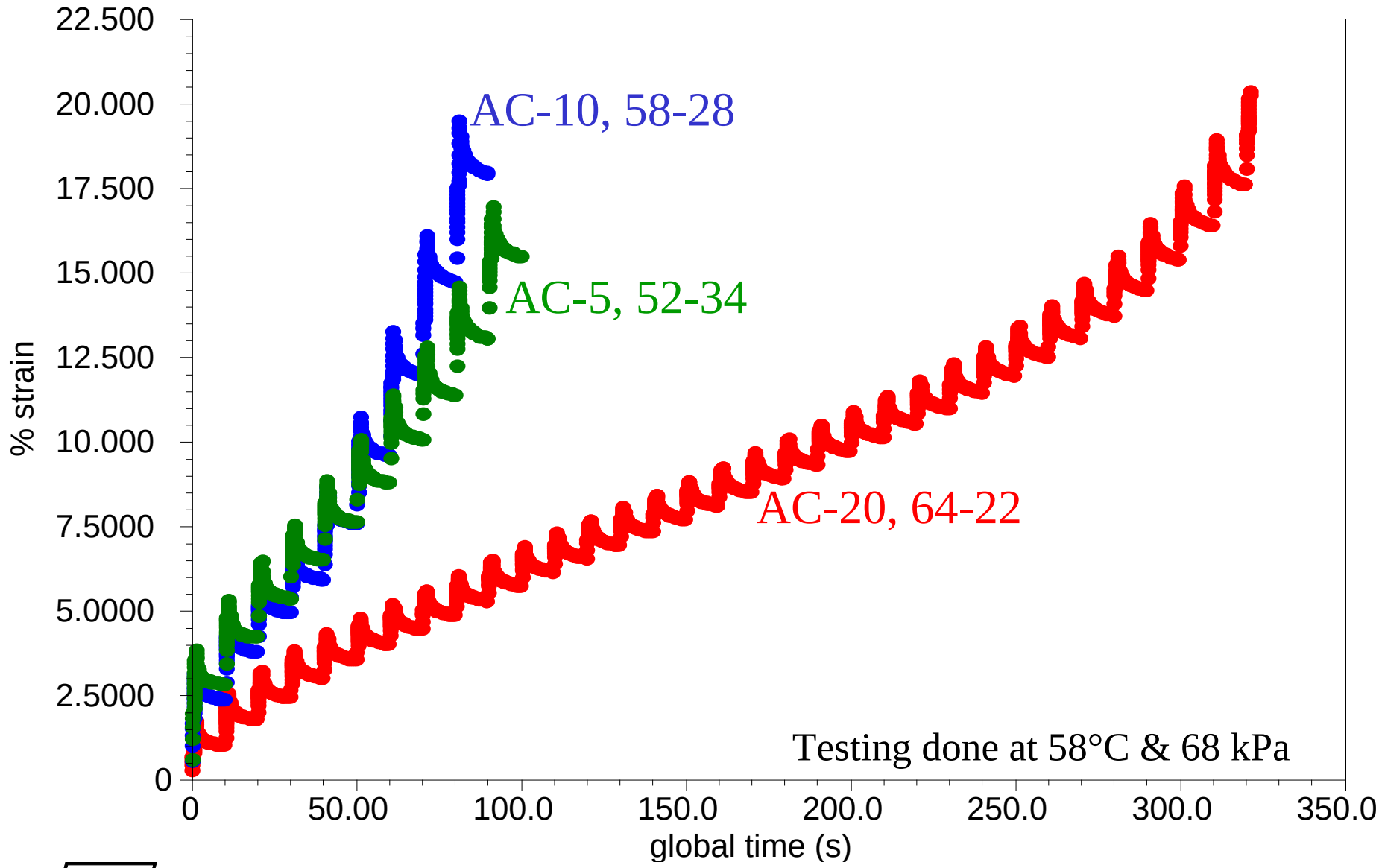
MN Road Testing

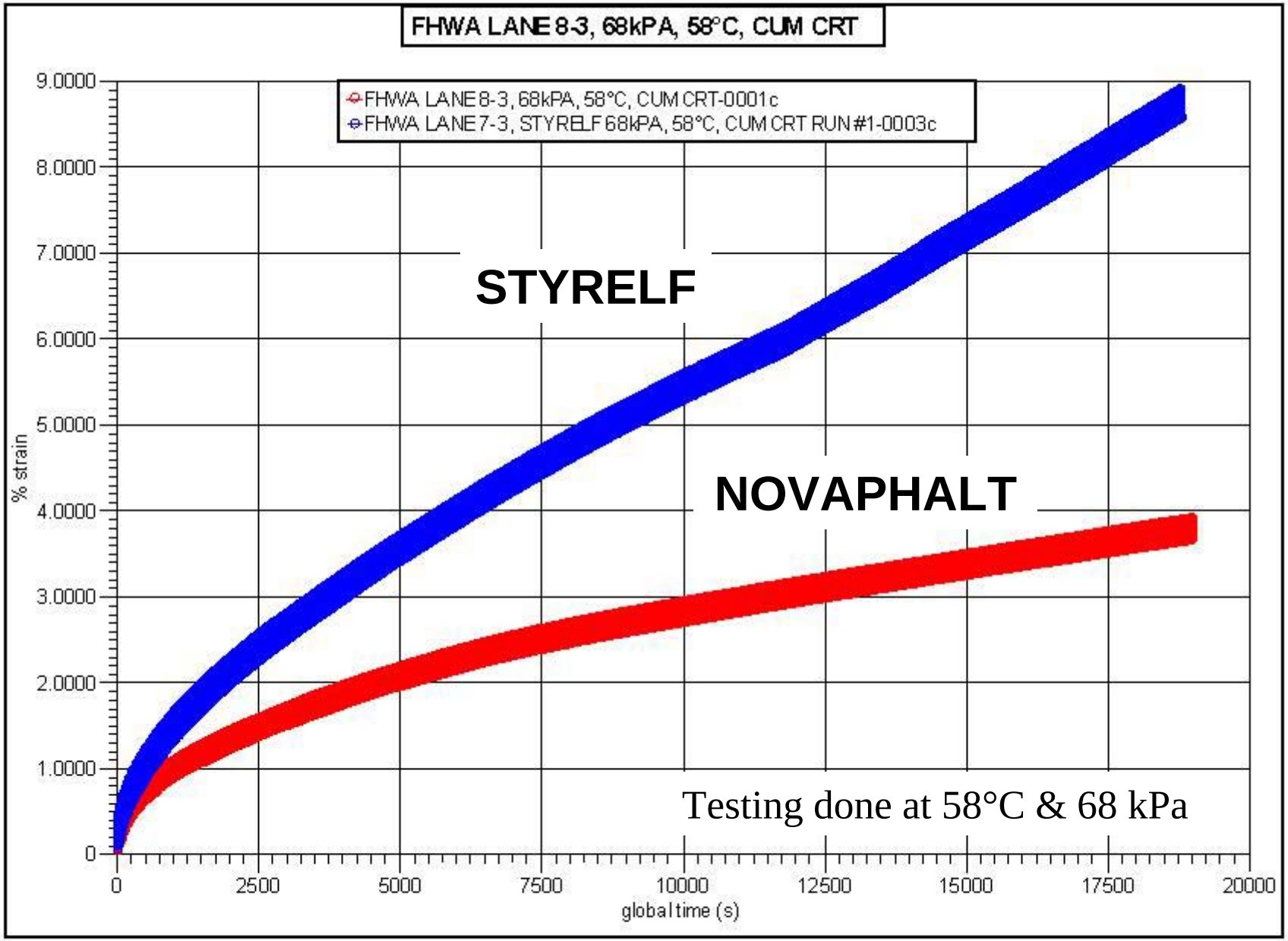


RUT DATA FROM ALF REPORT TESTING PERFORMED @ 58° C

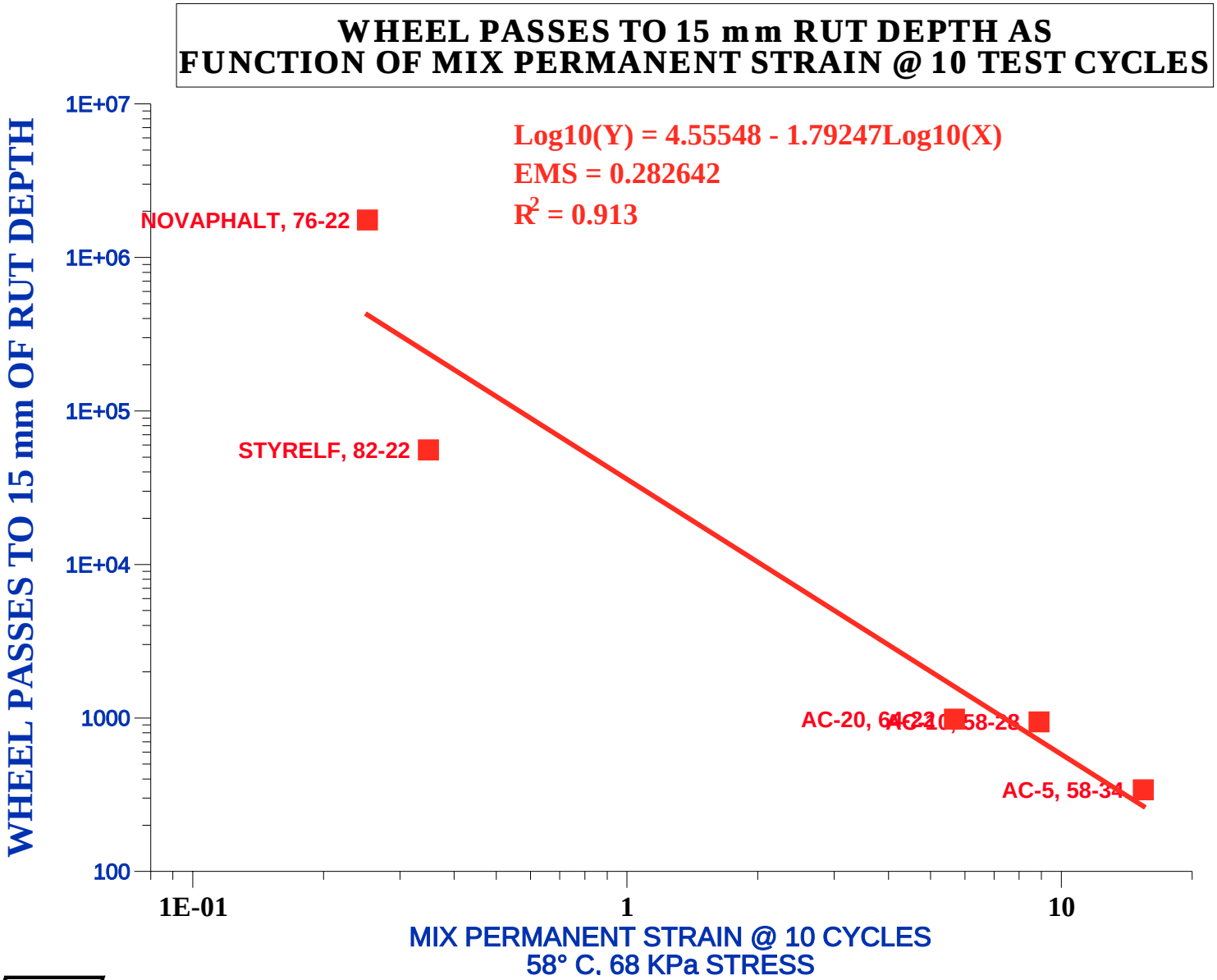
LANE #	BINDER	1994 Rut, mm	Rutting @ 2730 wheel passes	Wheel passes to 15 mm rut depth	Rutting @ 10,000 wheel passes
5	AC-10, 58-28	27	23.2	946	39.3
7	STYRELF 82-22	18	8	5.55 E4	12
8	NOVAPHALT, 76-22	9	3.5	1.75 E6	4.4
9	AC-5, 52-34	22	37.4	340	48.1
10	AC-20, 64-22	36	20.1	980	36.3

FHWA ALF Testing

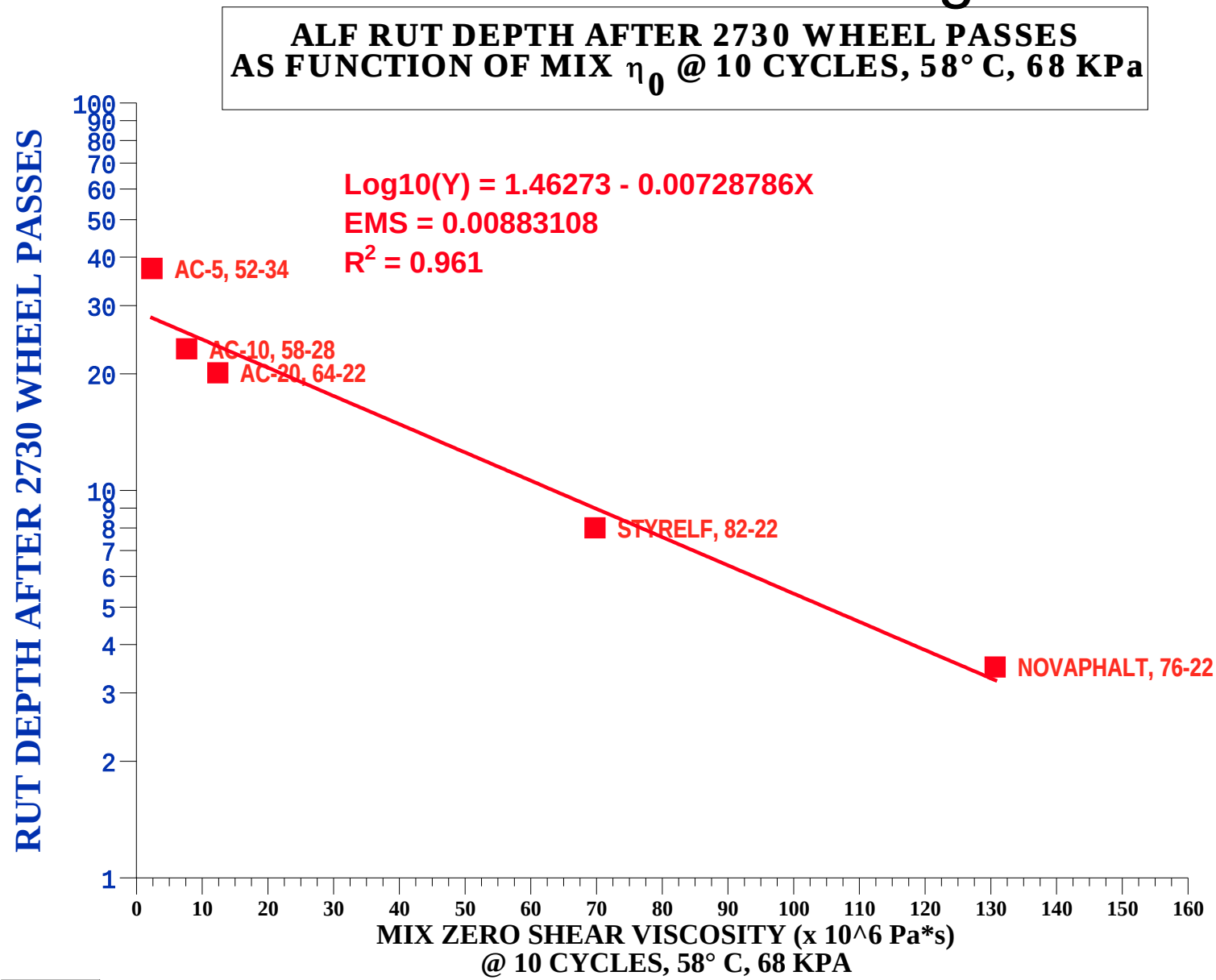



FHWA LANE 8-3, 68kPA, 58°C, CUM CRT
FHWA LANE 8-3, 68kPA, 58°C, CUM CRT-0001c
FHWA LANE 7-3, STYRELF 68kPA, 58°C, CUM CRT RUN #1-0003c
STYRELF
NOVAPHALT
Testing done at 58°C & 68 kPa
% strain
global time (s)
0
1.0000
2.0000
3.0000
4.0000
5.0000
6.0000
7.0000
8.0000
9.0000
0
2500
5000
7500
10000
12500
15000
17500
20000

FHWA ALF Testing

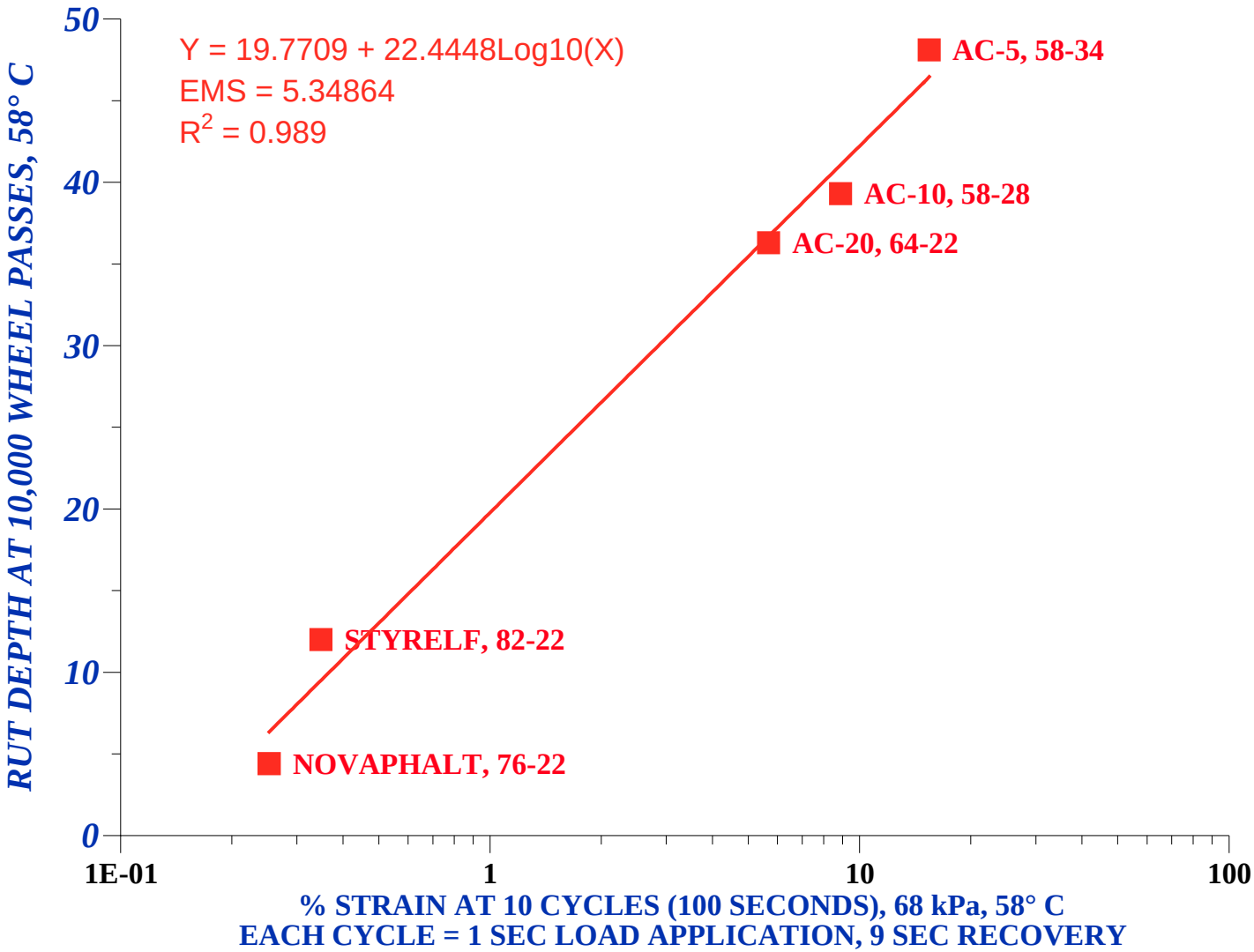


FHWA ALF Testing



FHWA ALF Testing

RUT DEPTH AT 10,000 WHEEL PASSES AS FUNCTION OF % STRAIN AT 10 CYCLES



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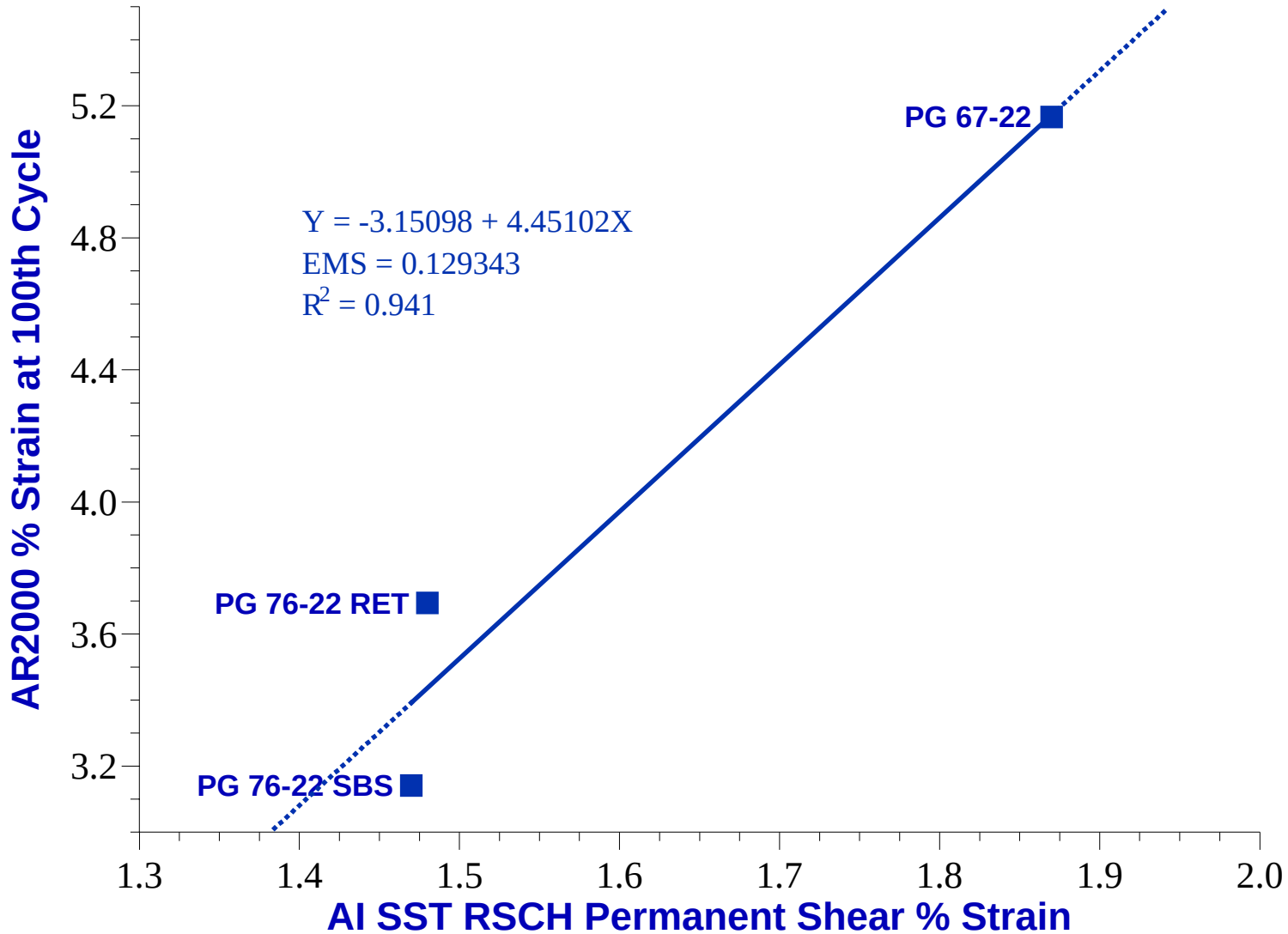
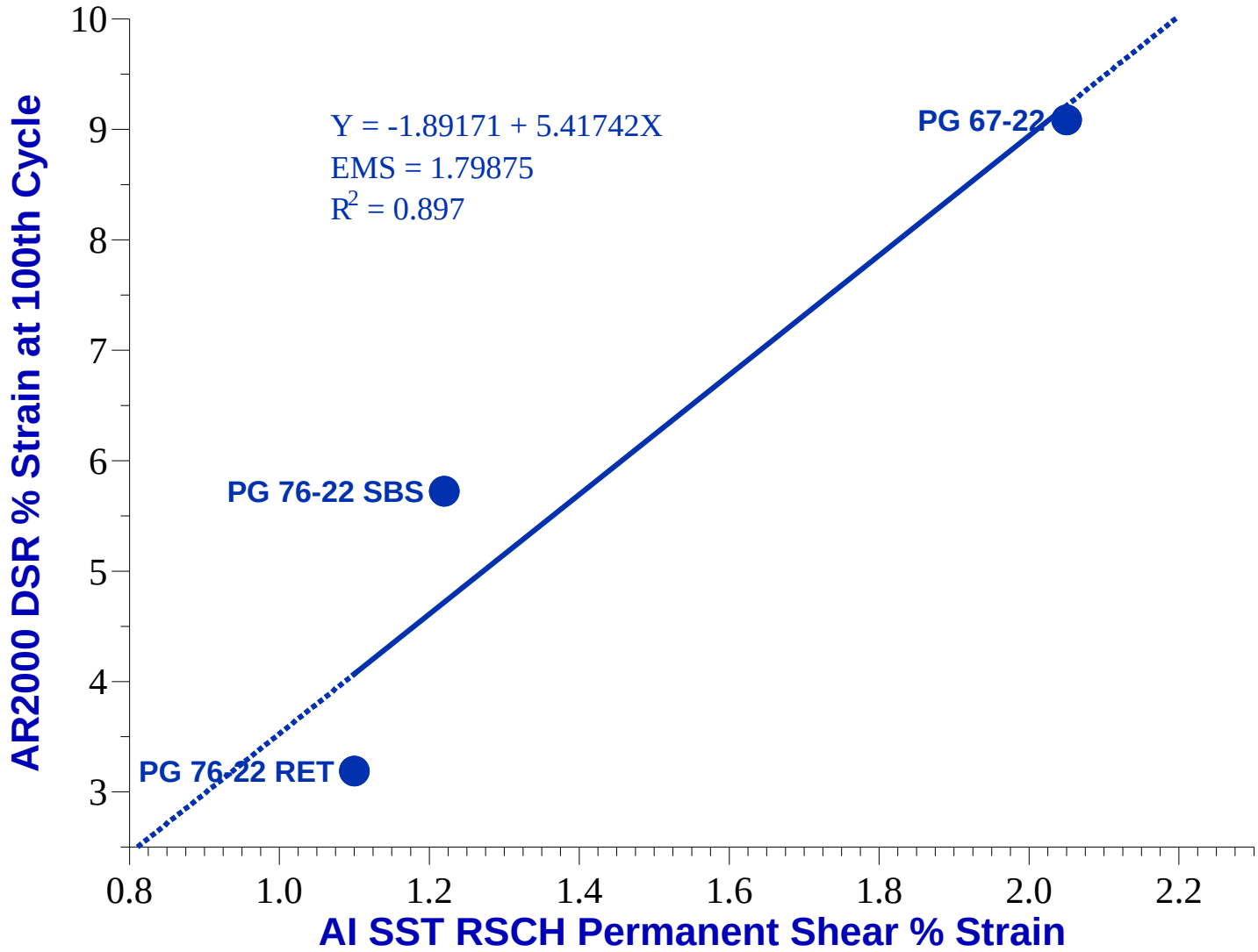
MTE

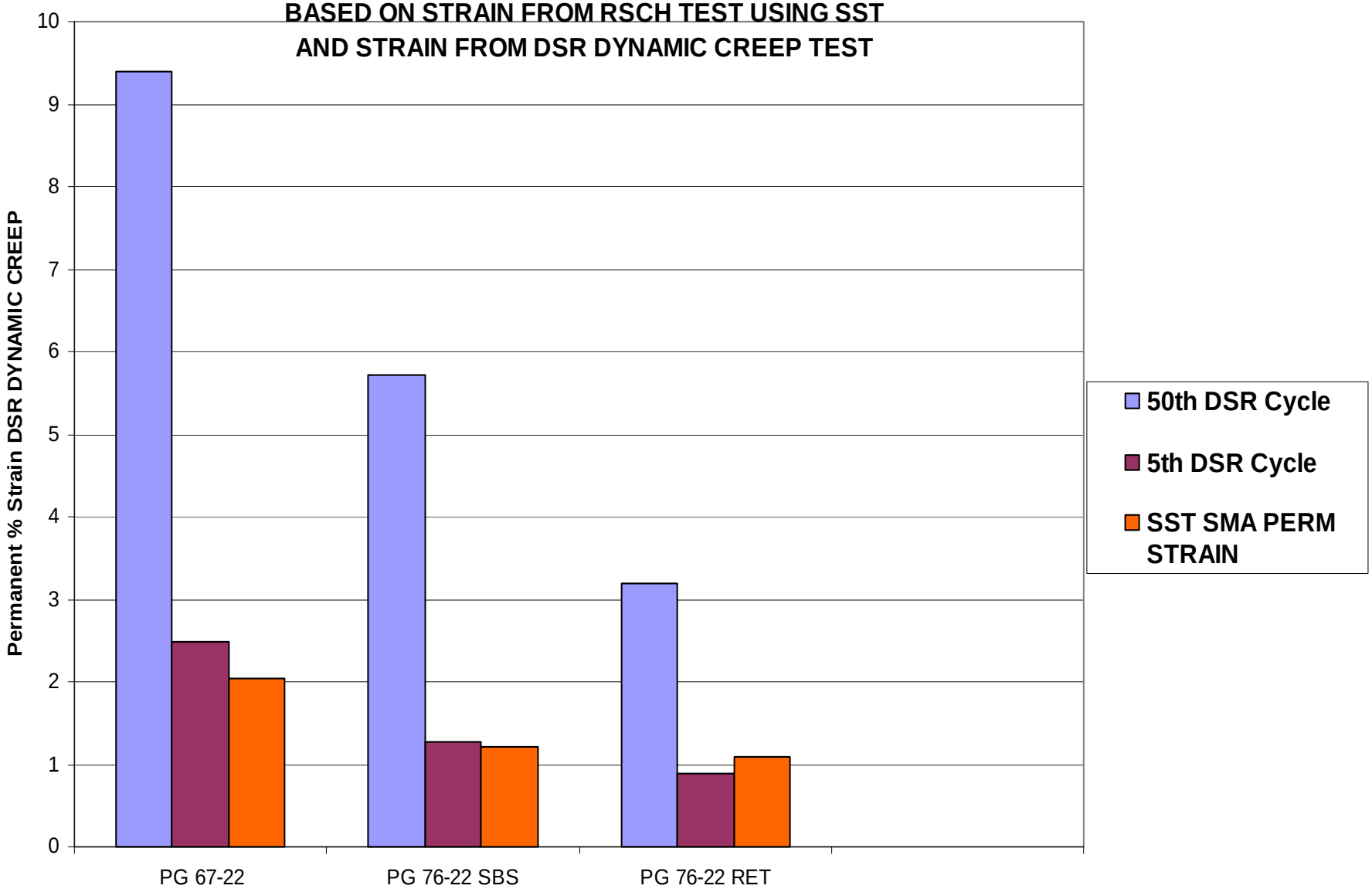
SUPERPAVE MIX - COMPARE SST TO DSR DYNAMIC CREEP RESULTS

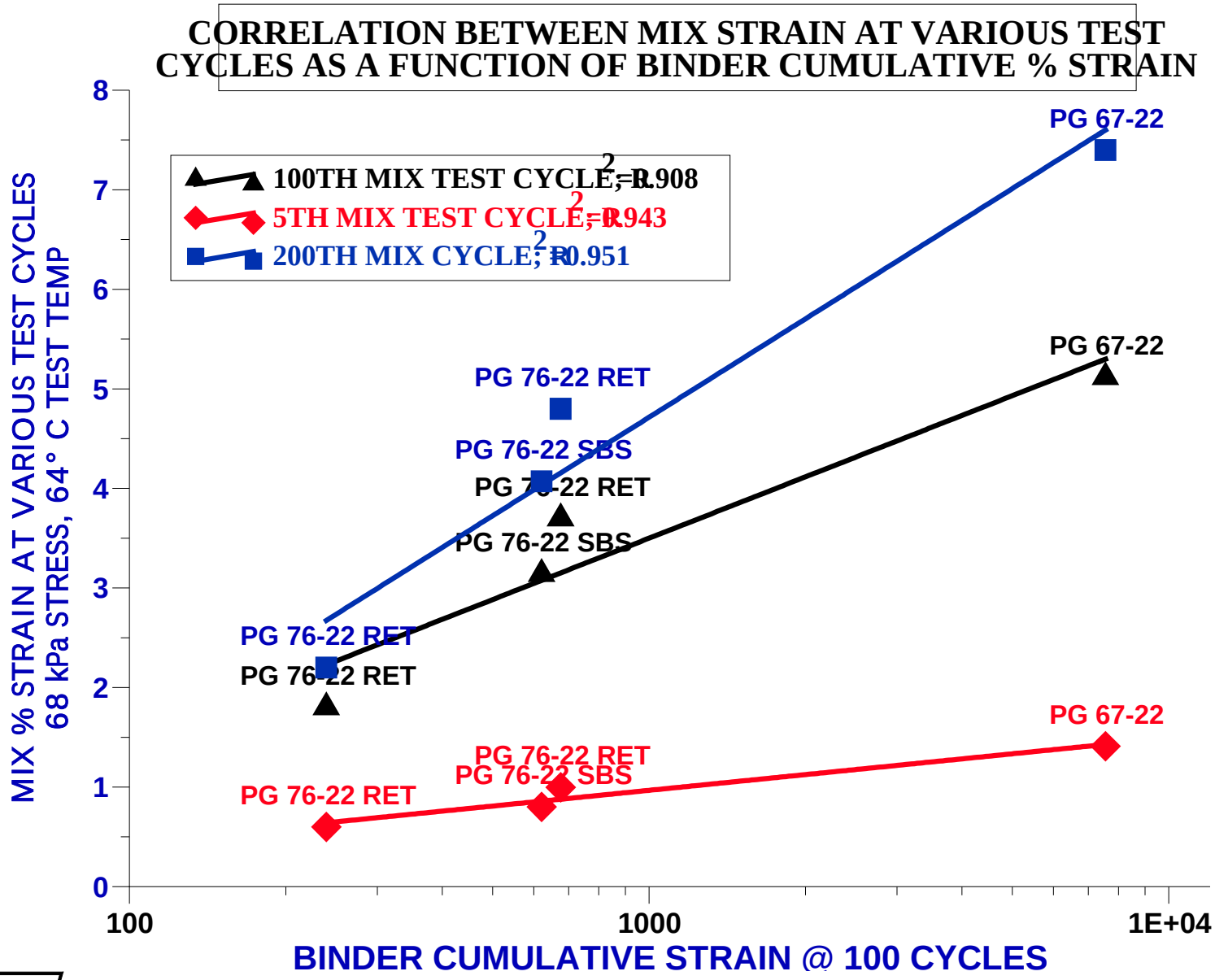


SMA MIX - COMPARE SST TO DSR DYNAMIC CREEP RESULTS

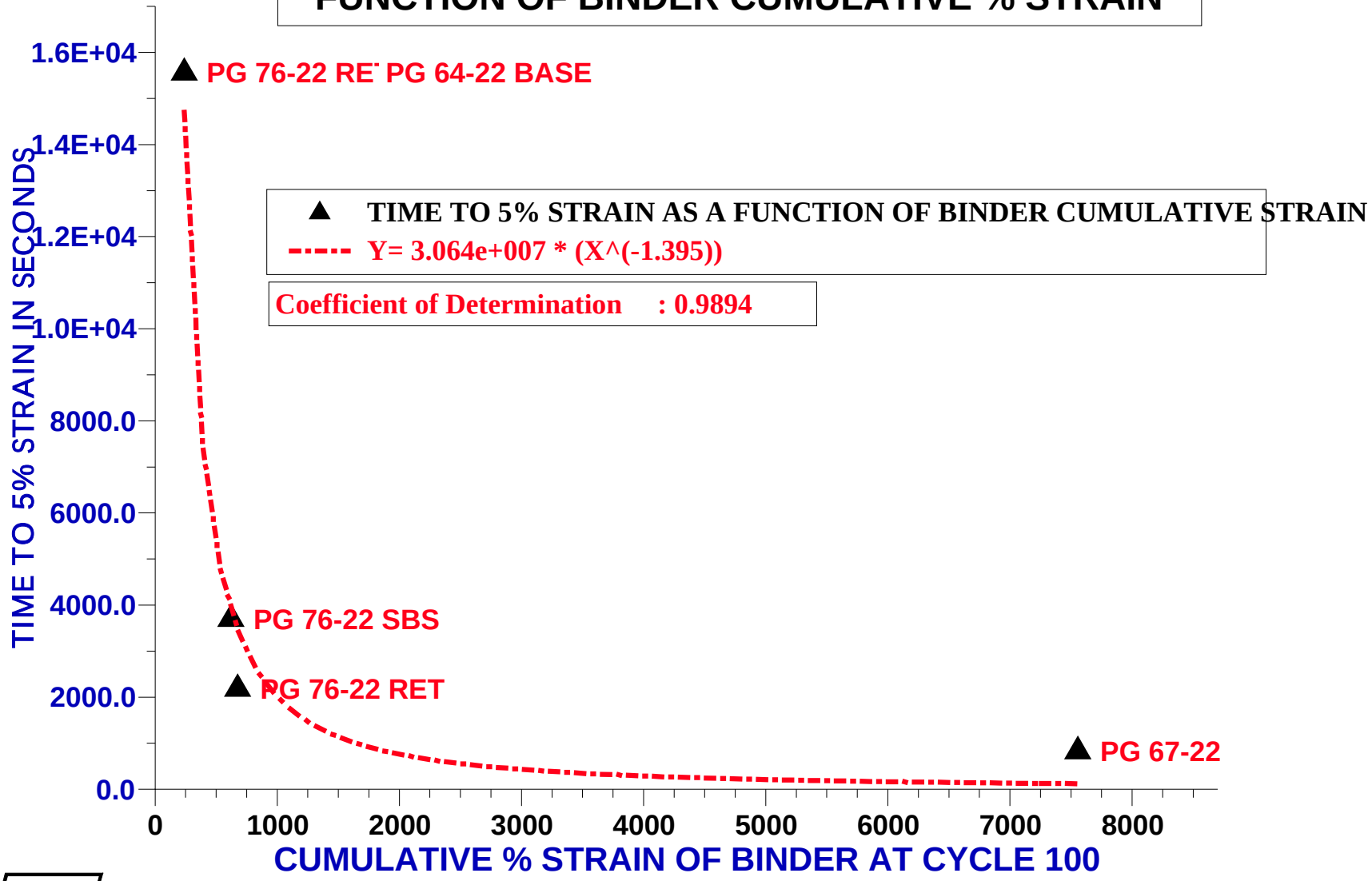


COMPAIRSON OF SMA MIXES USING MODIFIED BINDERS
PG 67-22, PG 76-22 USING REATIVE ETHYLENE TERPOLYMER & PG 76-22 USING SBS
BASED ON STRAIN FROM RSCH TEST USING SST
AND STRAIN FROM DSR DYNAMIC CREEP TEST




CORRELATION BETWEEN MIX STRAIN AT VARIOUS TEST CYCLES AS A FUNCTION OF BINDER CUMULATIVE % STRAIN
100TH MIX TEST CYCLE; R2=0.908
5TH MIX TEST CYCLE; R2=0.943
200TH MIX CYCLE; R2=0.951
MIX % STRAIN AT VARIOUS TEST CYCLES
68 kPa STRESS, 64° C TEST TEMP
BINDER CUMULATIVE STRAIN @ 100 CYCLES
0
1
2
3
4
5
6
7
8
100
1000
1E+04
PG 67-22
PG 67-22
PG 67-22
PG 76-22 RET
PG 76-22 SBS
PG 76-22 RET
PG 76-22 SBS
PG 76-22 RET
PG 76-22 RET
PG 76-22 RET
PG 76-22 SBS
PG 76-22 RET

RELATIONSHIP BETWEEN TIME TO 5% STRAIN FOR MIX USING DSR DYNAMIC CREEP TEST AS A FUNCTION OF BINDER CUMULATIVE % STRAIN



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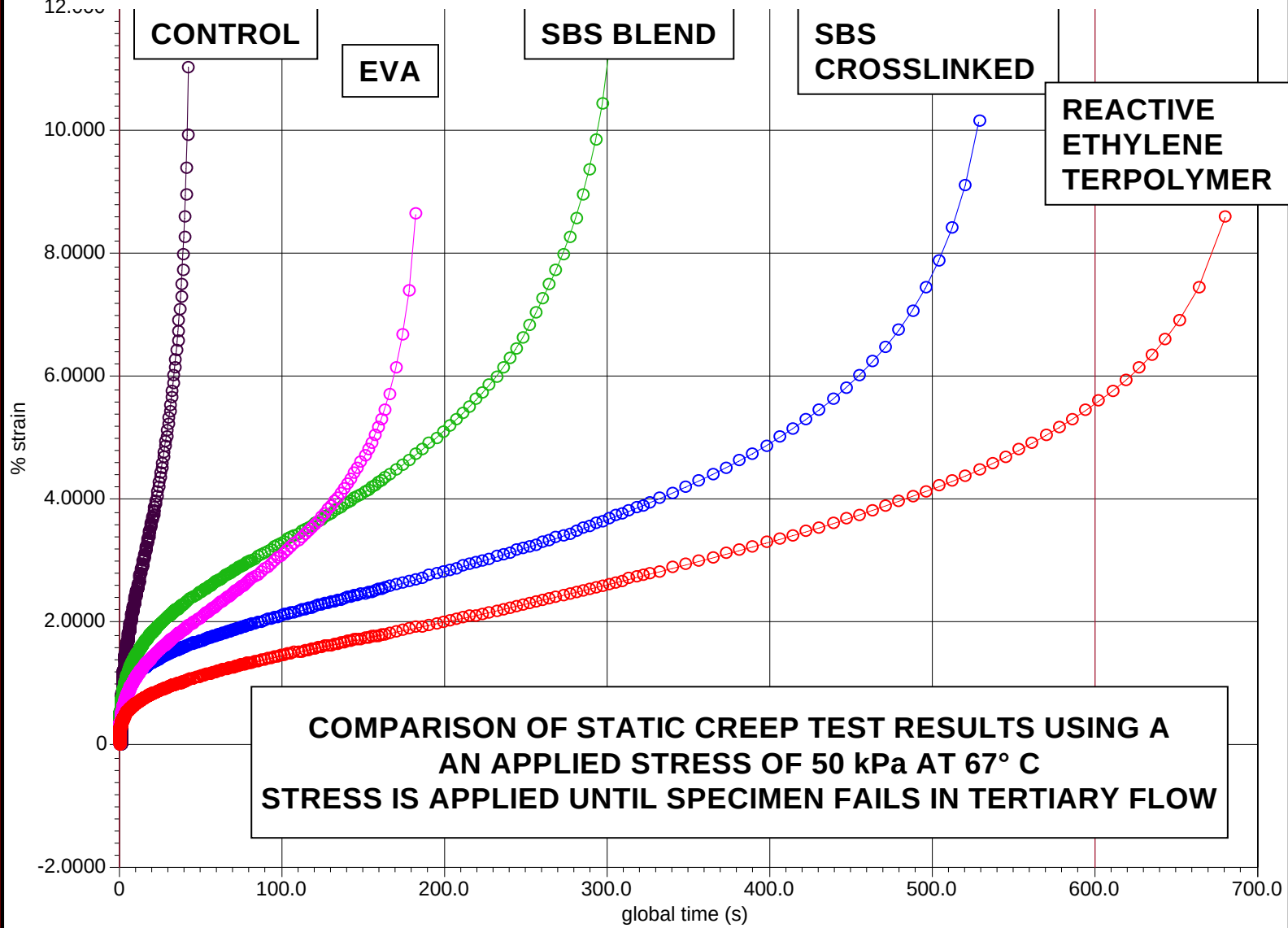
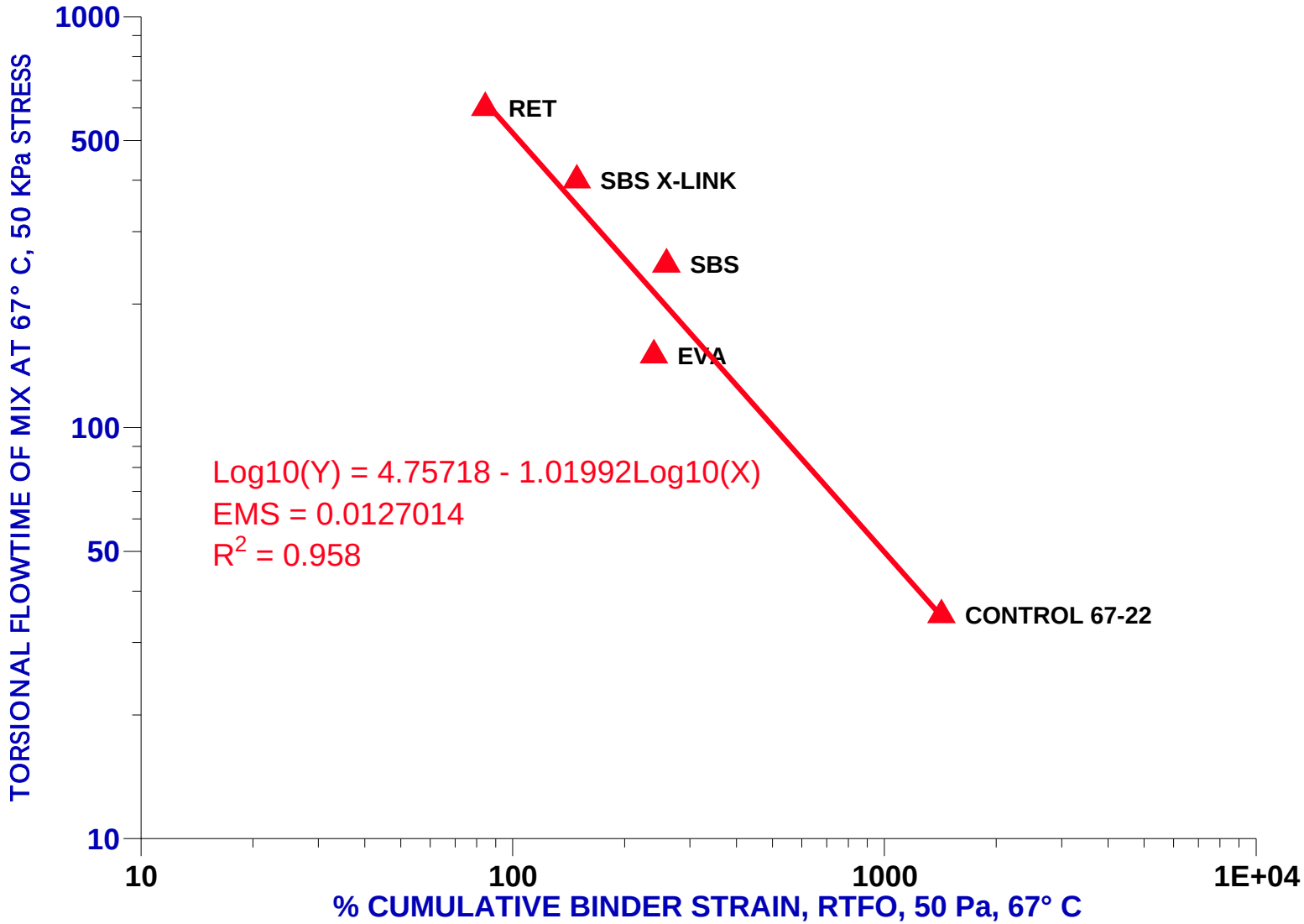
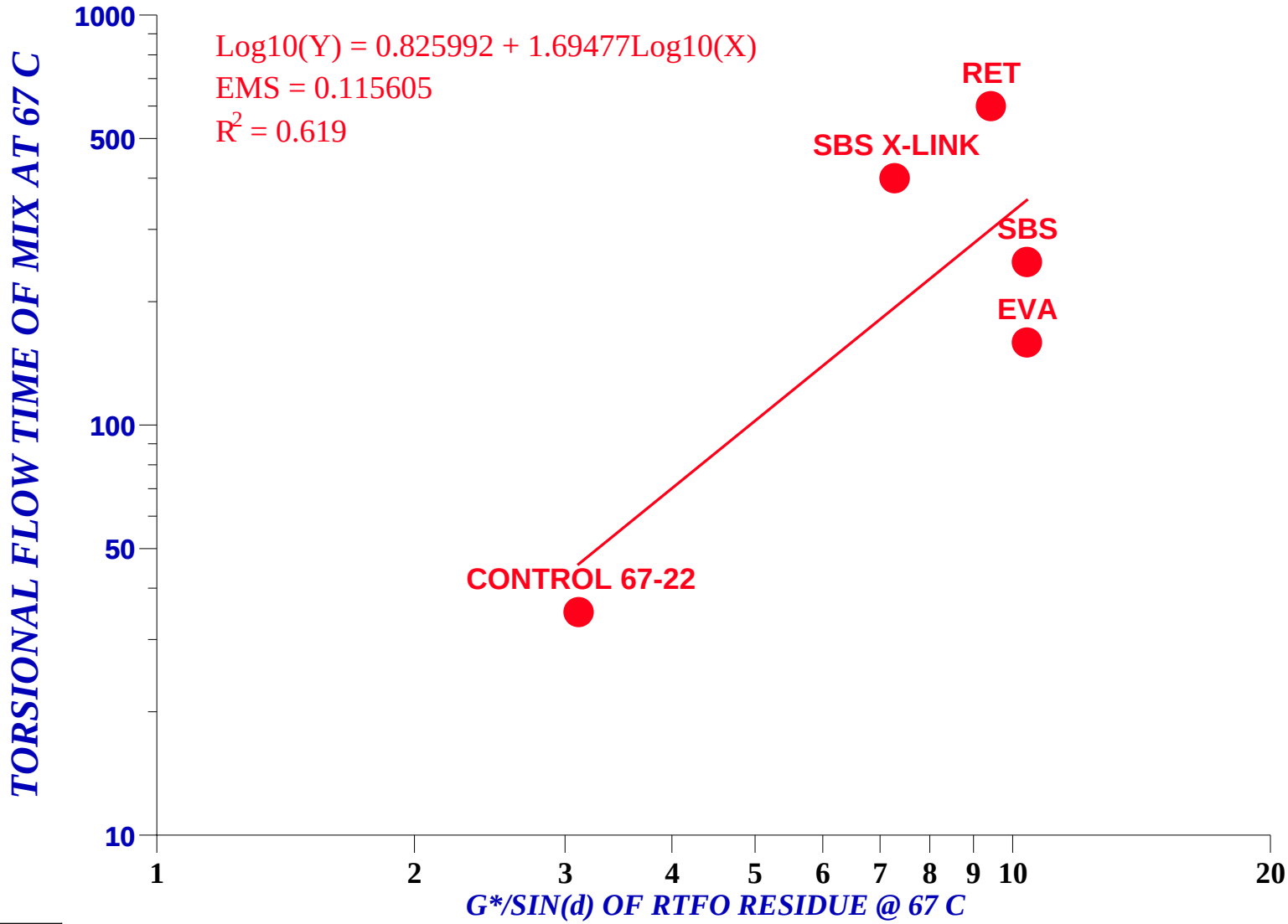
MIXTURE STATIC CREEP TEST COMPARISON
ALL MIXES USED THE SAME AGGREGATE



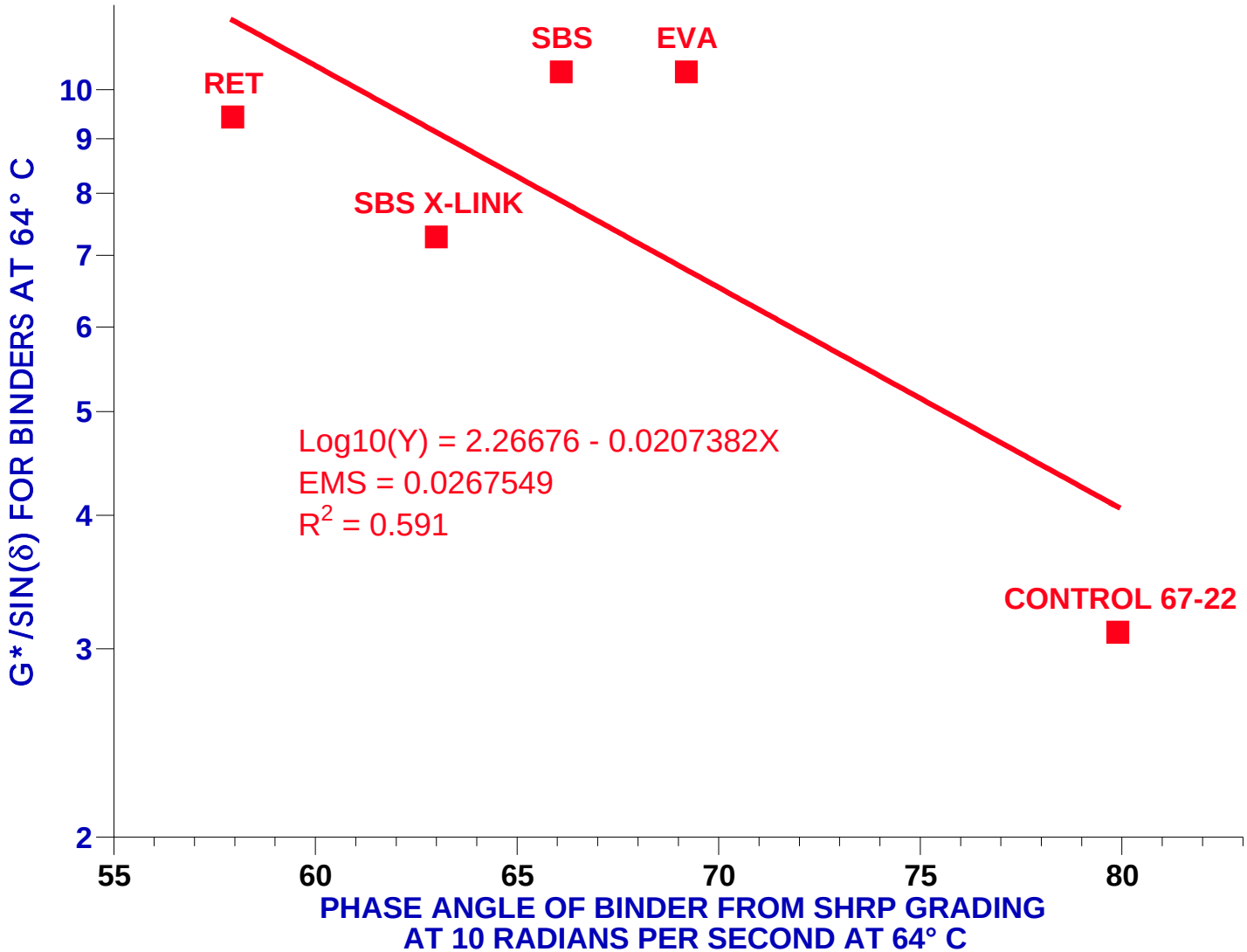
TORSIONAL FLOWTIME TO FAILURE OF MIX, 67° C, 50 KPa CORRELATED TO CUMULATIVE STRAIN OF RTFO RESIDUE DETERMINED AT 67° C & 50 Pa STRESS



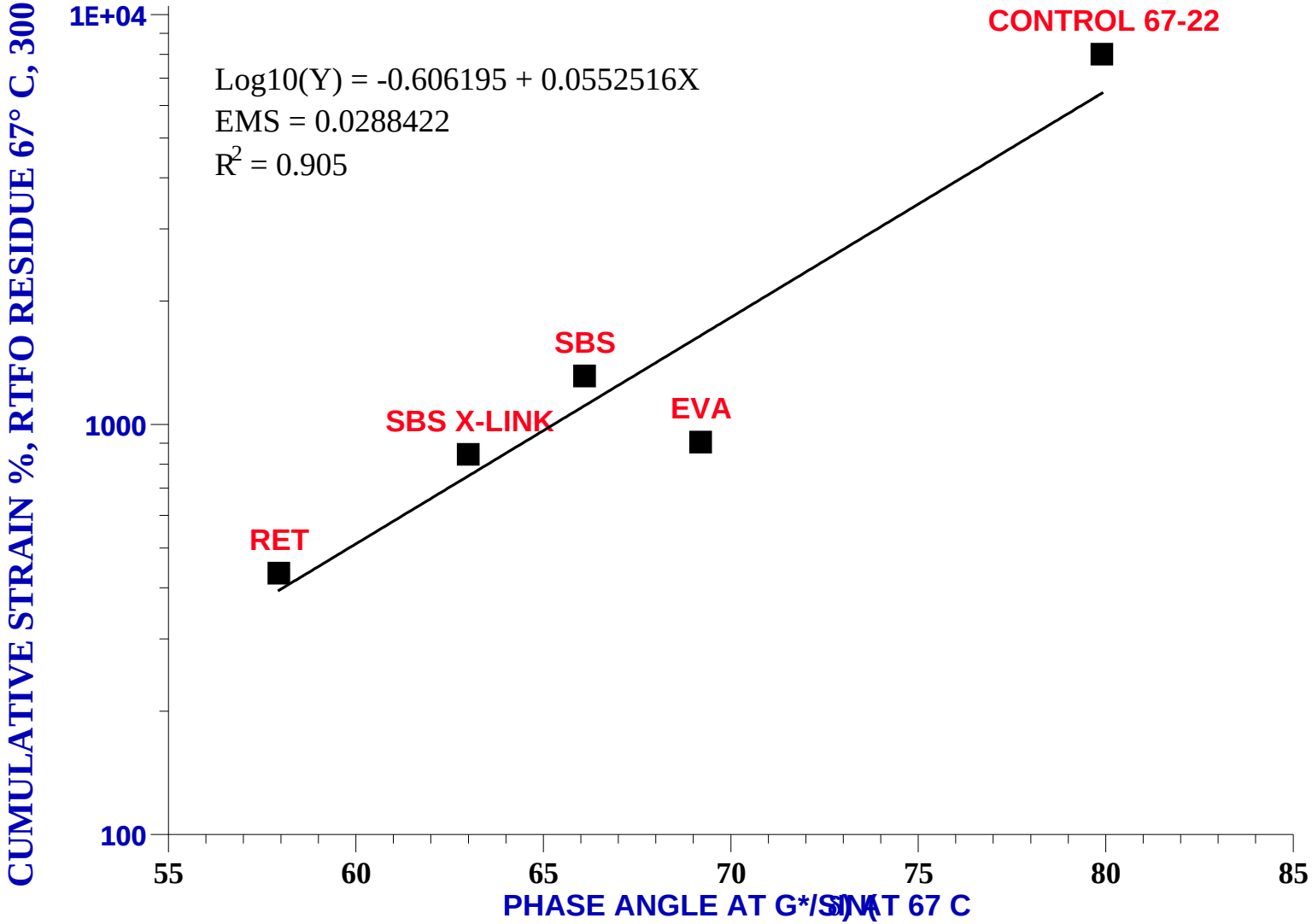
FLOW TIME TO FAILURE CORRELATED TO SHRP STIFFNESS



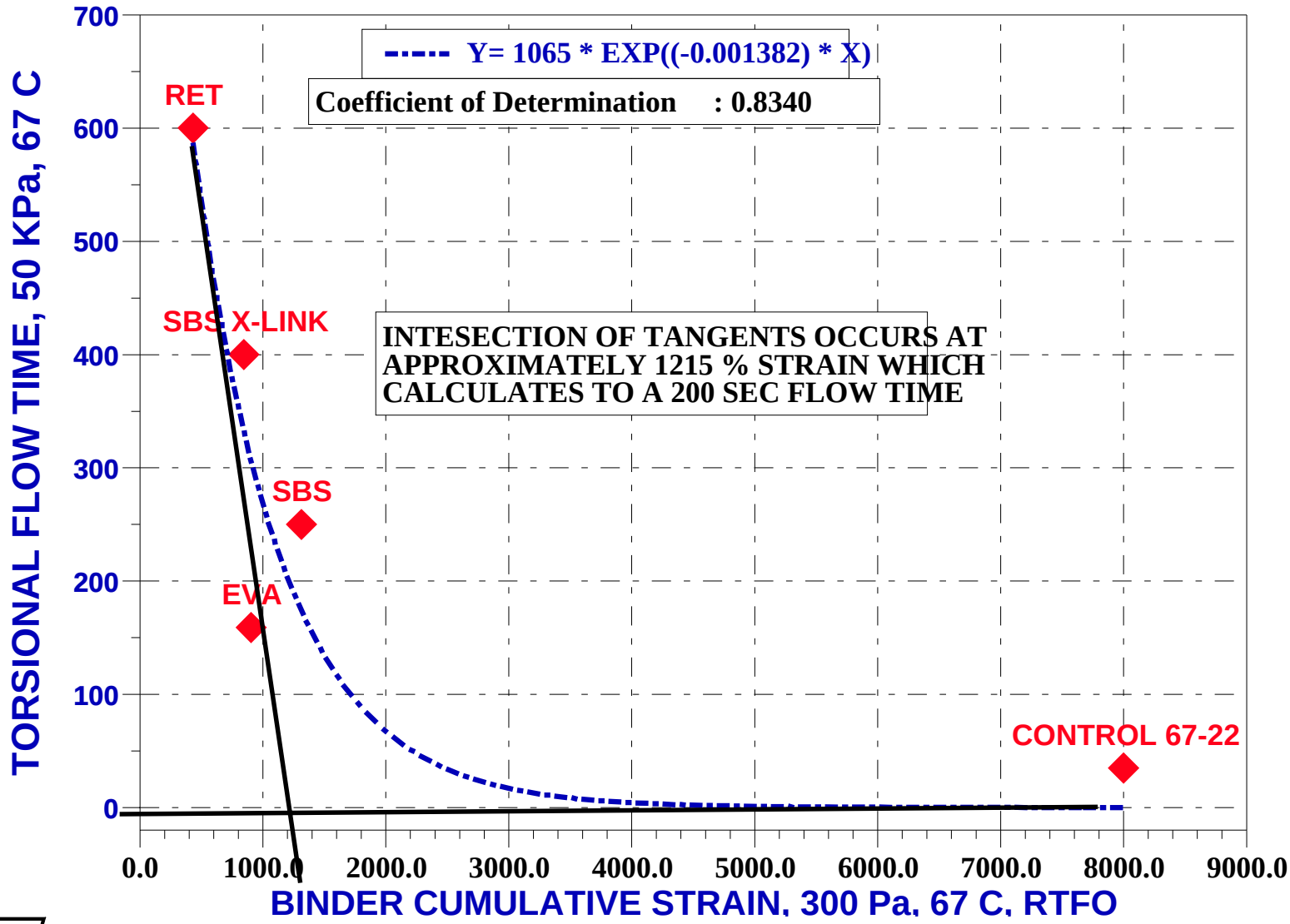
RELATIONSHIP OF G*/SIN(δ) TO THE PHASE ANGLE OF THE BINDER DETERMINED AT 64° C & 10 RAD/SEC



RELATIONSHIP BETWEEN CUMULATIVE STRAIN RESULTS AND BINDER PHASE ANGLE DETERMINED FROM SHRP TEST AT 64° C AND 10 RAD/SEC

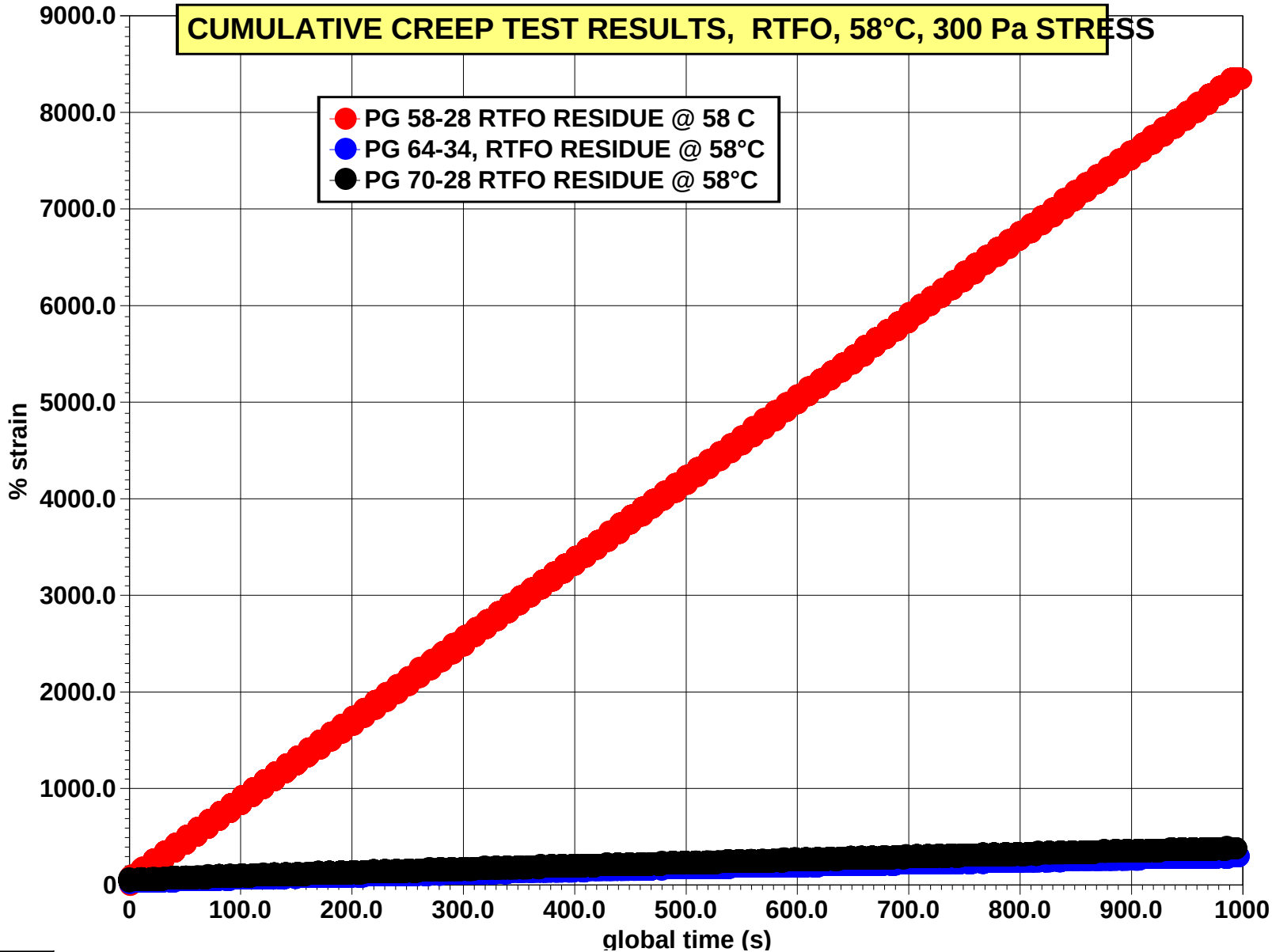


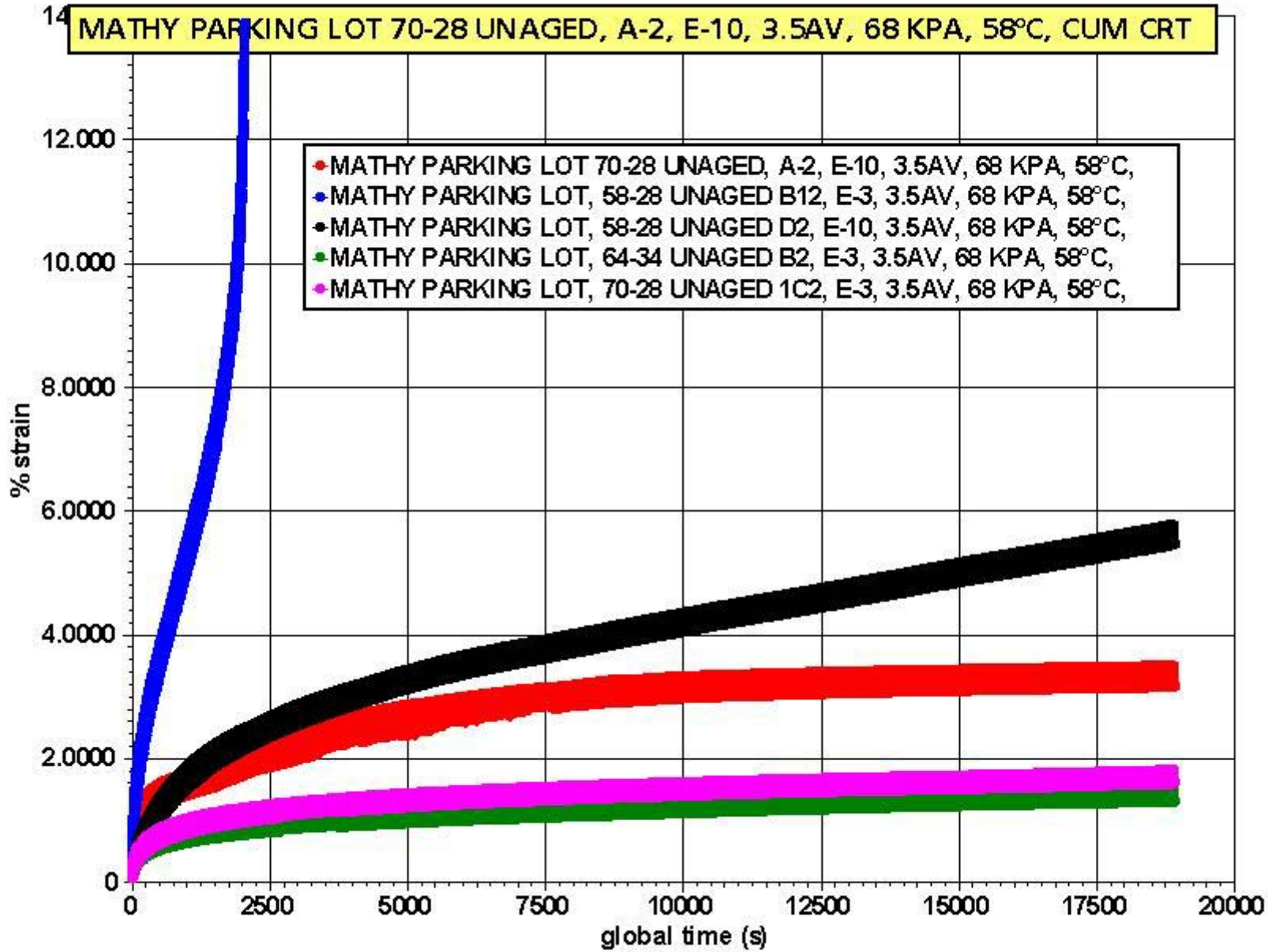
CORRELATION BETWEEN MIX FLOW TIME TO FAILURE AND THE CUMULATIVE % STRAIN OF THE BINDER



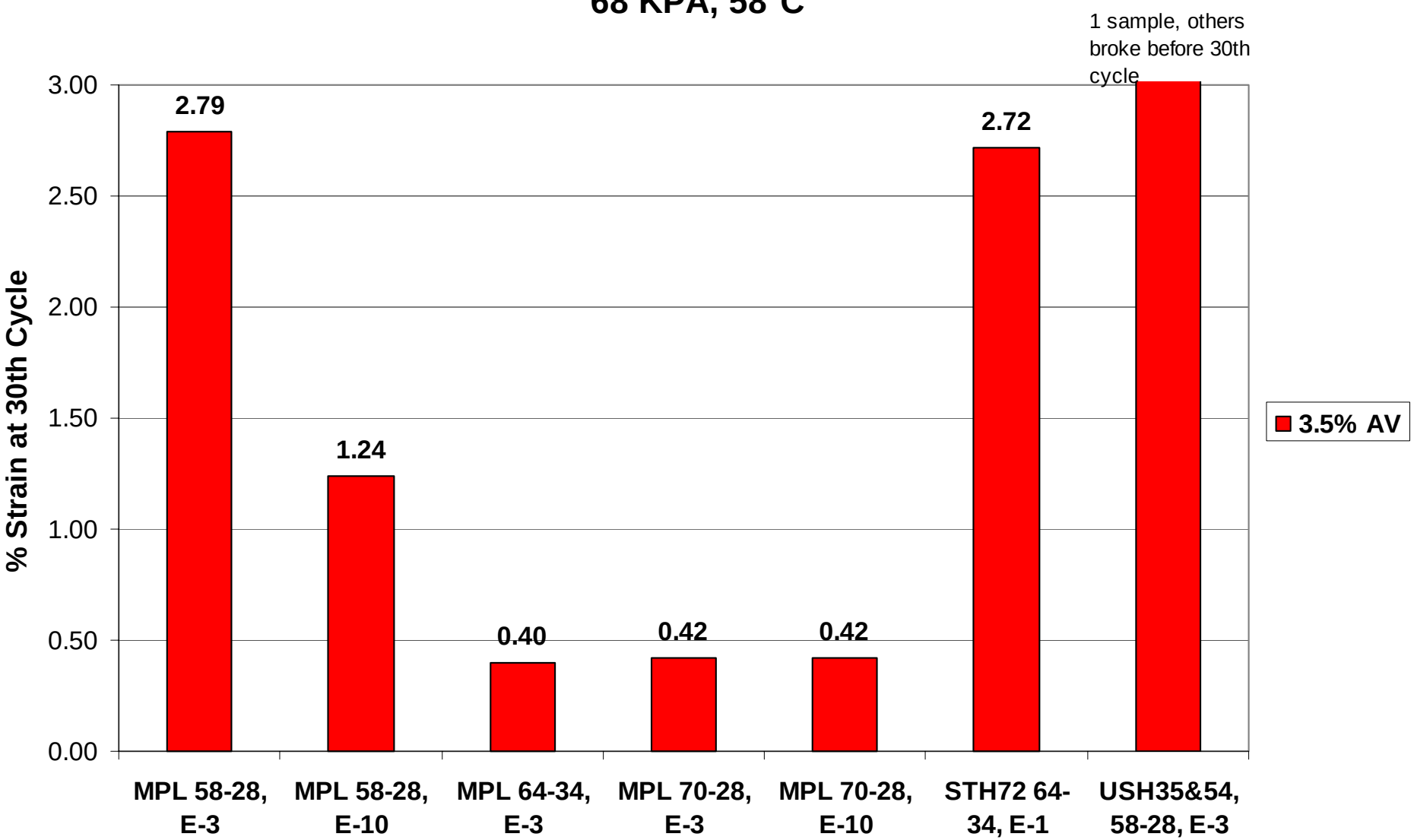
Comparison of 2 aggregate structures with 3 binders

- Mix types
  - e-3
    - 75 gyration @ N_{design}
    - 1 to < 3 million ESAL's
    - PG 58-28, PG 64-34, PG 70-28; 6.0% binder
  - E-10
    - 100 Gyrations @ N_{design}
    - 3 to < 10 million ESAL's
    - PG 58-28, PG 70-28; 5.4% binder content

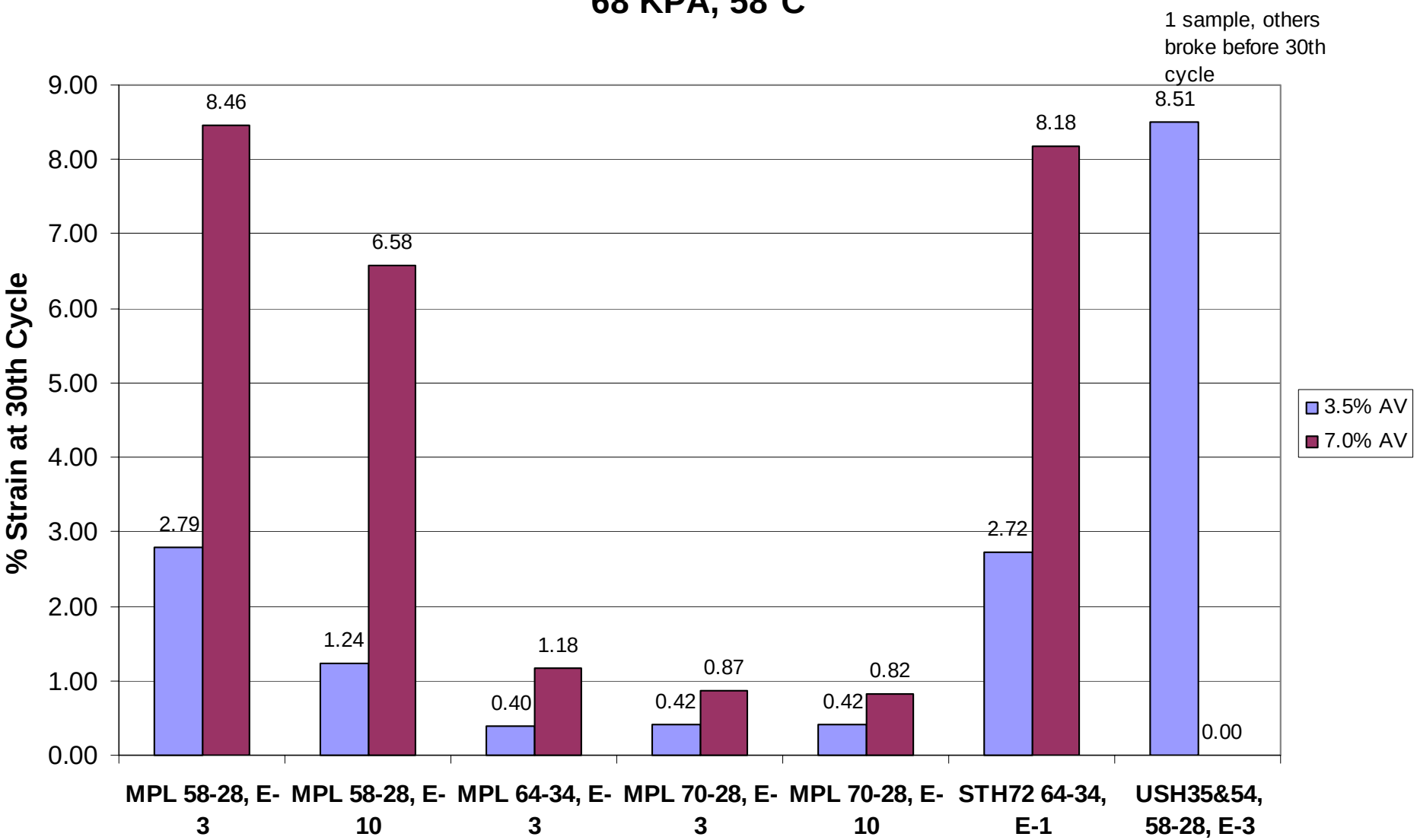

CUMULATIVE CREEP TEST RESULTS, RTFO, 58°C, 300 Pa STRESS
PG 58-28 RTFO RESIDUE @ 58 C
PG 64-34, RTFO RESIDUE @ 58°C
PG 70-28 RTFO RESIDUE @ 58°C
% strain
9000.0
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0
0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000
global time (s)


MATHY PARKING LOT 70-28 UNAGED, A-2, E-10, 3.5AV, 68 KPA, 58°C, CUM CRT
MATHY PARKING LOT 70-28 UNAGED, A-2, E-10, 3.5AV, 68 KPA, 58°C,
MATHY PARKING LOT, 58-28 UNAGED B12, E-3, 3.5AV, 68 KPA, 58°C,
MATHY PARKING LOT, 58-28 UNAGED D2, E-10, 3.5AV, 68 KPA, 58°C,
MATHY PARKING LOT, 64-34 UNAGED B2, E-3, 3.5AV, 68 KPA, 58°C,
MATHY PARKING LOT, 70-28 UNAGED 1C2, E-3, 3.5AV, 68 KPA, 58°C,
% strain
14
12.000
10.000
8.0000
6.0000
4.0000
2.0000
0
0
2500
5000
7500
10000
12500
15000
17500
20000
global time (s)

DSR Repeated Creep-Recovery Test
68 KPA, 58°C



DSR Repeated Creep-Recovery Test
68 KPA, 58°C



Recommendations

- Use 10 mm thick slices to minimize testing variabilty
- Test should be conducted at the appropriate climatic temperature, not the PG Grade temperature
- Use 68 kPa stress level whenever possible, lower stress levels can be used but relationship to 68 kPa results is not known
- Dynamic creep testing should be used, especially for polymer modified mixes

Conclusions

- The DSR dynamic creep test can identify performance differences between
  - Aggregate structure
  - Mix type
  - Binder grades
  - Impact of polymer or other additives (fillers/fibers)
  - Service temperature variations
- The DSR dynamic creep test correlates well to the rutting behavior in the field for the two test road projects investigated (MNROAD & ALF)

CONCLUSION

- The DSR dynamic creep test results correlate well to SST RSCH results for the project investigated
- Testing of field cores yields lower response values than testing lab specimens
  - Due in part to differences in air voids
- DSR creep testing of SMA mixes not yet as robust as testing of Superpave mixes
  - Due to aggregate skeleton
  - Inability to apply confining pressure

CONCLUSION

- **THE BINDER CUMULATIVE STRAIN RESULTS WERE PREDICTIVE OF DSR CREEP RESULTS FOR MIXTURES**
  - **BINDER CUMULATIVE STRAINS BELOW 1500% MEASURED AT THE CLIMATE TEMPERATURE USING 300 Pa OF STRESS RESULTED IN MIXES WITH IMPROVED DYNAMIC CREEP TEST RESULTS COMPARED TO CONTROL BINDERS**
    - **IT IS SUGGESTED TO USE A BINDER STRAIN OF $\leq$ 2000% AS A STARTING POINT TO BEGIN EVALUATING THE IMPACT OF BINDER STRAIN ON MIX PERFORMANCE**

MTE

TO BE CONSIDERED

- **The DSR dynamic creep test is suitable as a mix design tool, however more study needs to be conducted to determine appropriate response levels for field performance**
  - **Select a test response and monitor the field rutting behavior of mix**
    - **Time to 5% strain**
    - **Compliance or % strain at 100 or 200 seconds**
    - **Zero shear viscosity of mix at 100 or 200 cycles**
    - **Flownumber to tertiary failure**

MTE

TO BE CONSIDERED

- **The DSR dynamic creep test is suitable as a HMA QC tool. Volumetric QC specimens could be prepared for creep testing within a 6 hr time period**
  - **Creep response data available on the same day as mix laydown. Match with mix design values**
  - **Field lab installation is feasible, although most logically used on major projects**
  - **Equipment cost, including saws, is approximately $75,000**

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Kevin Stuart, FHWA
ALF Samples

END

If you were unable to obtain a CD copy and would like one I can be reached at: greinke@mathy.com