Warm mix study with the use of wax modified asphalt binders

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Binder ETG Meeting
Irvine, CA
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Objectives

- To investigate the effect on rheology and performance of various warm mix additives with various was additives

Materials tested

0 Lion Oil PG 64-22

9 - Waxes:

1 Romanta Normal Montan
2 Romanta Asphaltan A
3 Romanta Asphaltan B
4 Licomont BS 100
5 Sasobit
6 Luxco Pitch # 2
7 Alphamin GHP
8 Strohmeyer and Arpe Montan LGE
9 Astra Wax 3816D Microcrystalline

Test program

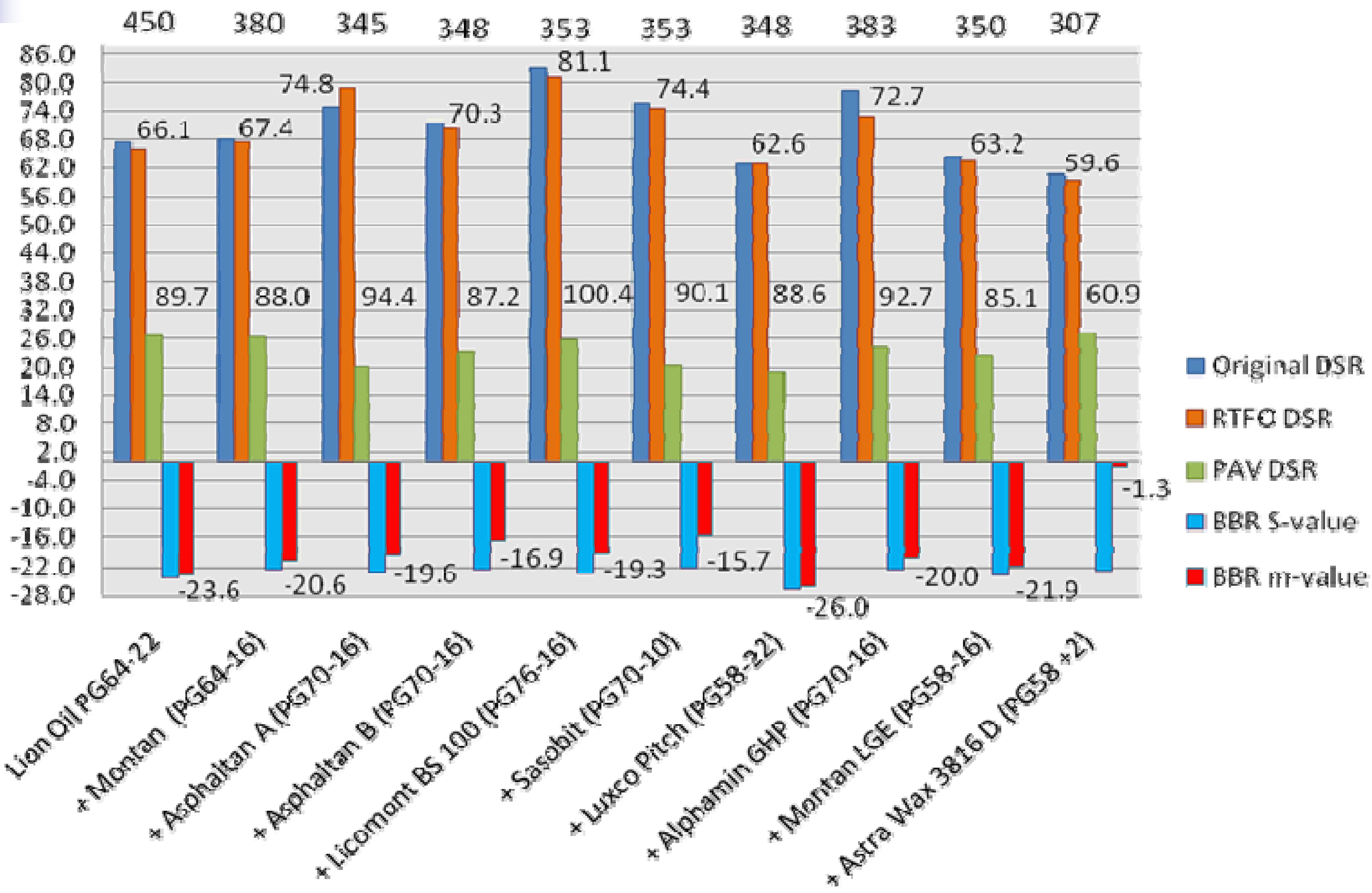
- Binder
  - M320 – Table 1 and 2
  - Binder master curves – BBR and DSR
  - BBR tests at different aging conditions (0, 2, 4, 8, 16 and 32 days)
  - MSCR
- Mixture
  - Mix BBR tests – 2 temperatures for limited mastercurves
  - Repeated creep tests
  - Fatigue – monotonic tests and repeated load
  - Master curves

Mix stiffness in BBR

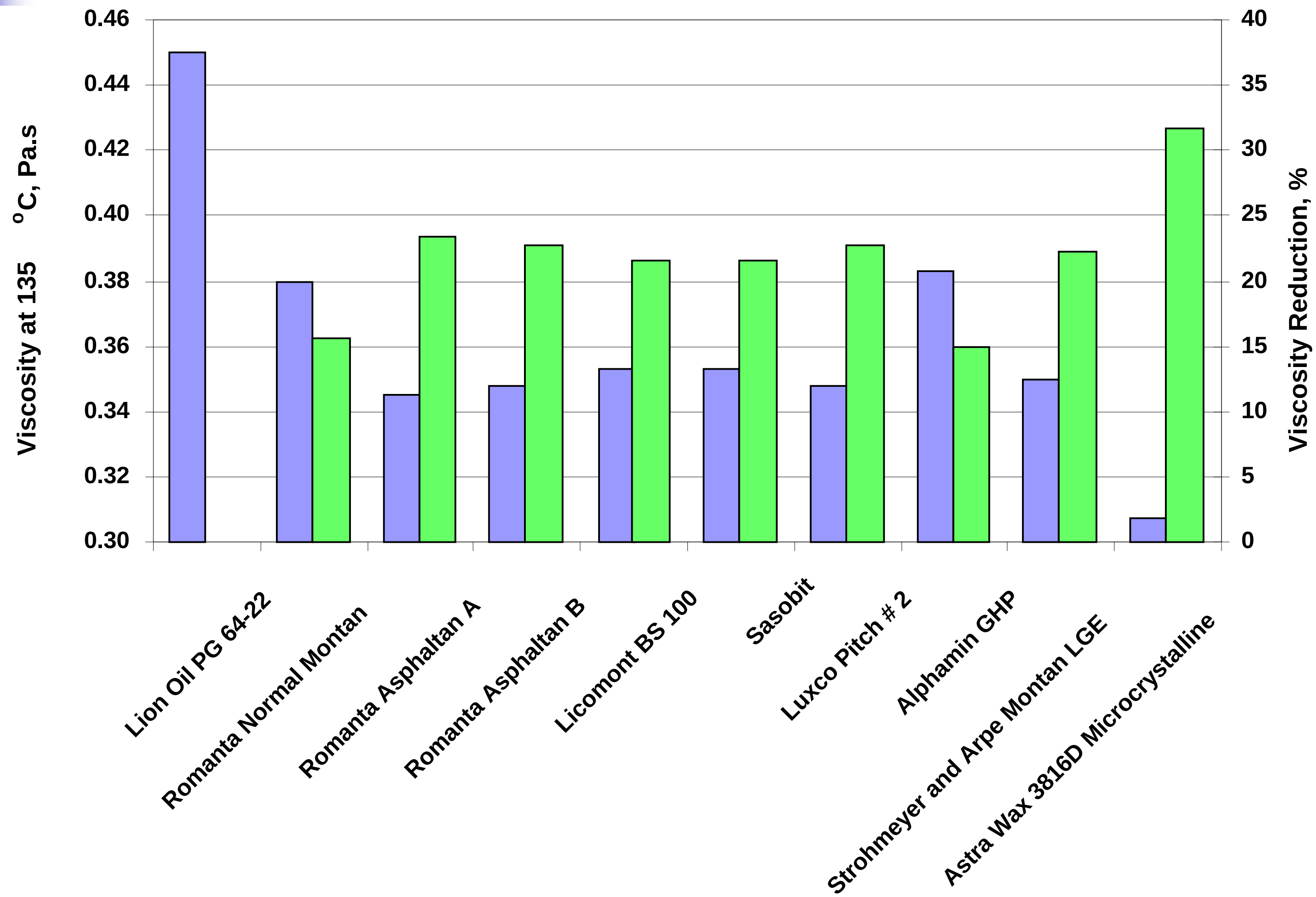
- Tested BBR beams at varying ageing
- Analysis extended to use 1000 second data
- Removed early part of test data to avoid effects of non-instantaneous startup

Binder test data

PG grading – AASHTO M320



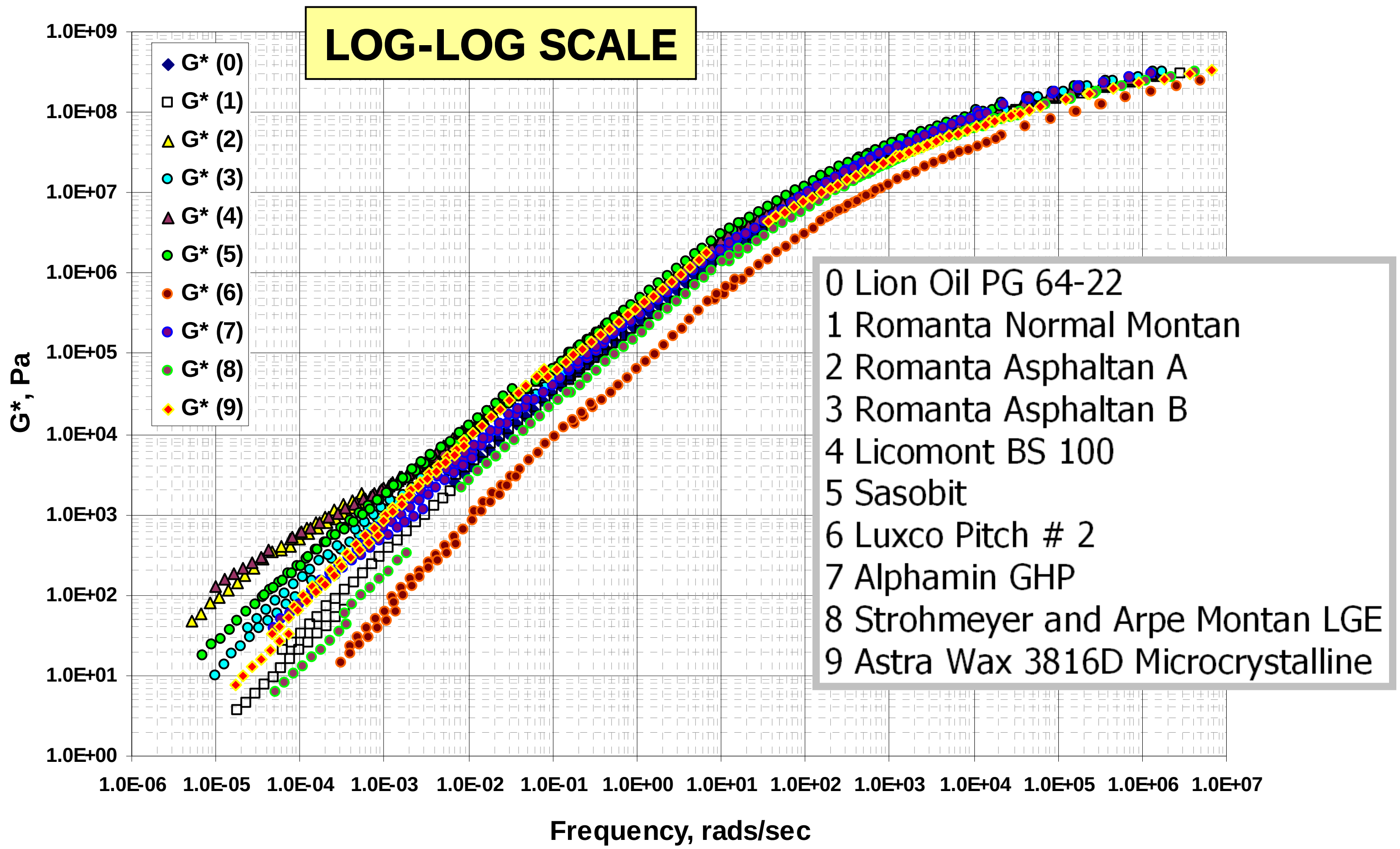
Viscosity changes



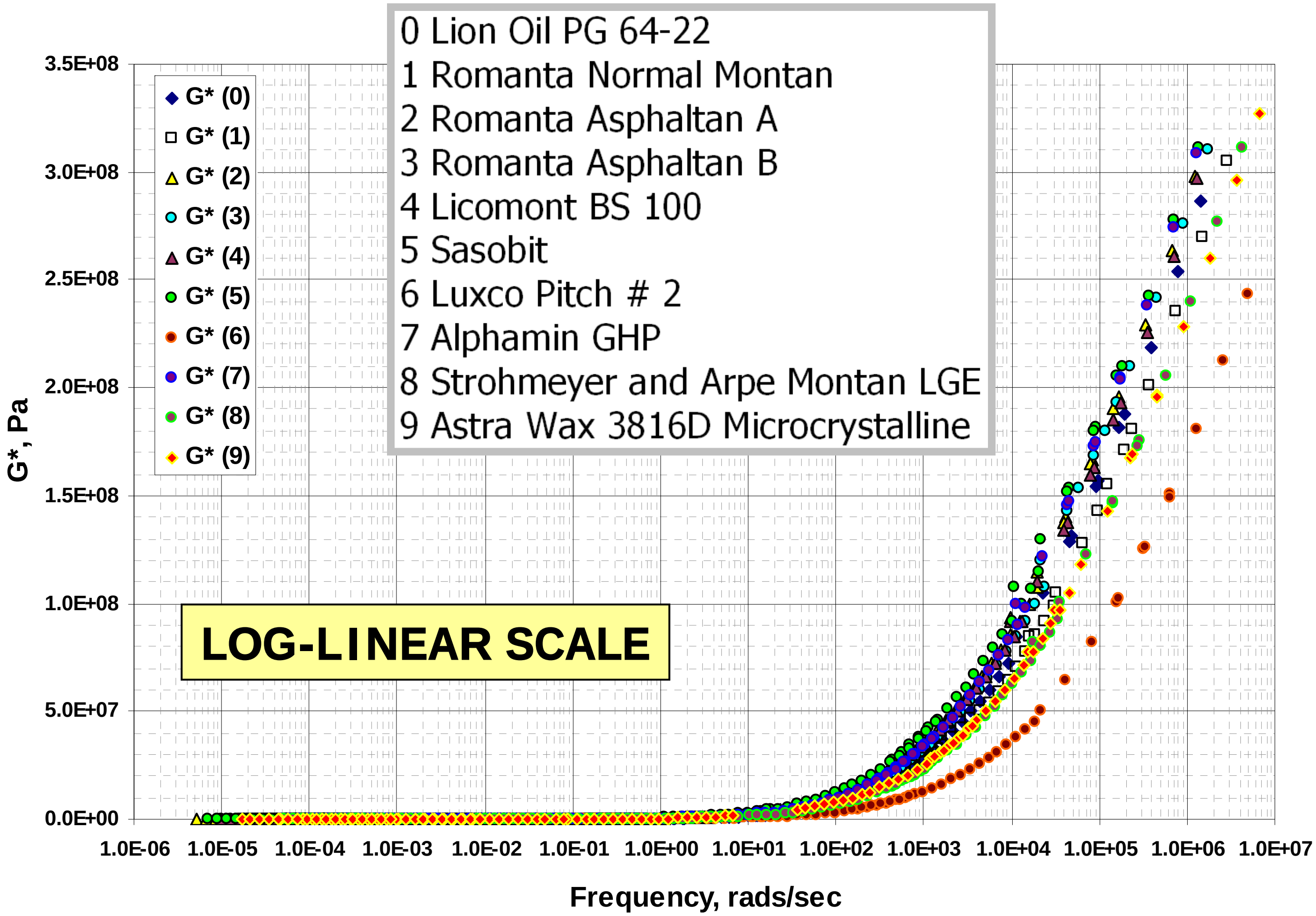
Binder – 0 day tests

- **RHE**OLOGY **A**NALYIS in Abatech RHEA Software
- RHEOLOGY OBSERVATIONS
  - 6 (Luxco Pitch # 2)– has lower G* mastercurve
  - Significant difference in G* at lower end of frequency range
  - δ with various binders show some type of network at low frequencies, more significant in 2 (Romanta Asphaltan A), 3 (Romanta Asphaltan B), 4 (Licomont BS 100), 5 (Sasobit) and 7 (Alphamin GHP)
  - Judging from δ *(at low temp/high freq.)*
    - 6 (Luxco Pitch # 2) appears to have best relaxation properties
    - 9 (Astra Wax 3816D Microcrystalline) has worse relaxation properties

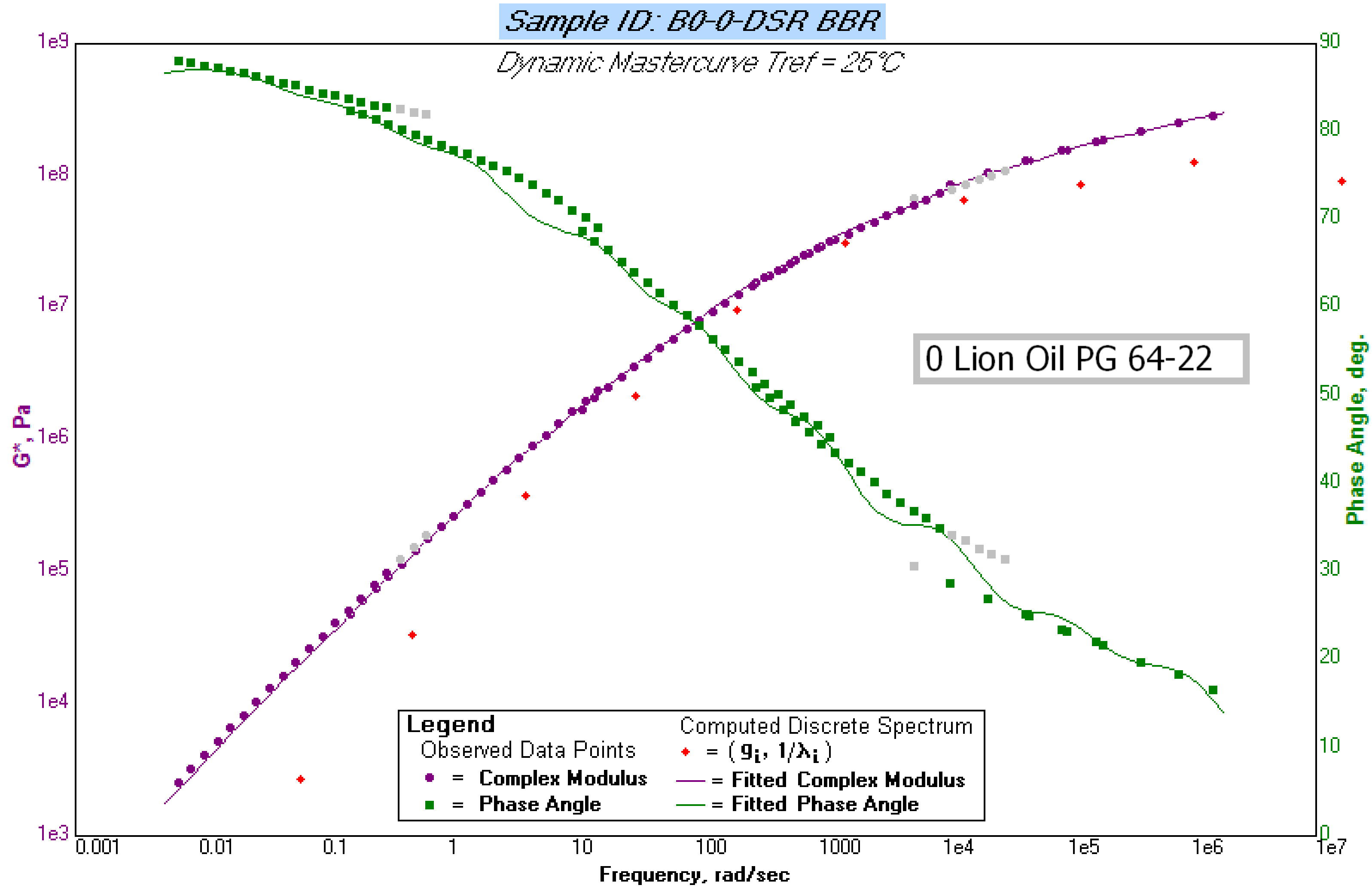
Master curve E*, T_{ref} = 25°C



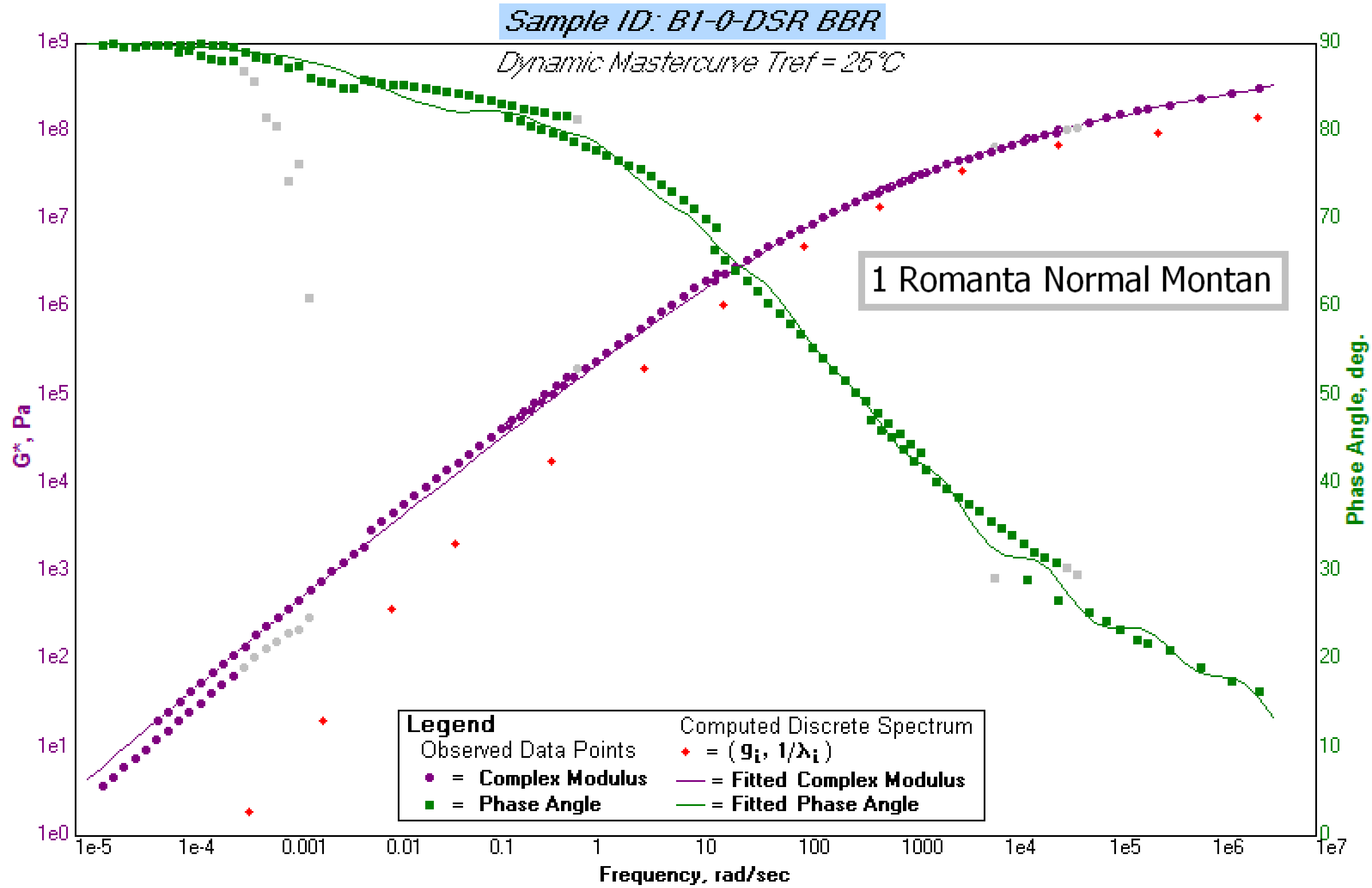
Master curve E*, T_{ref} = 25ºC



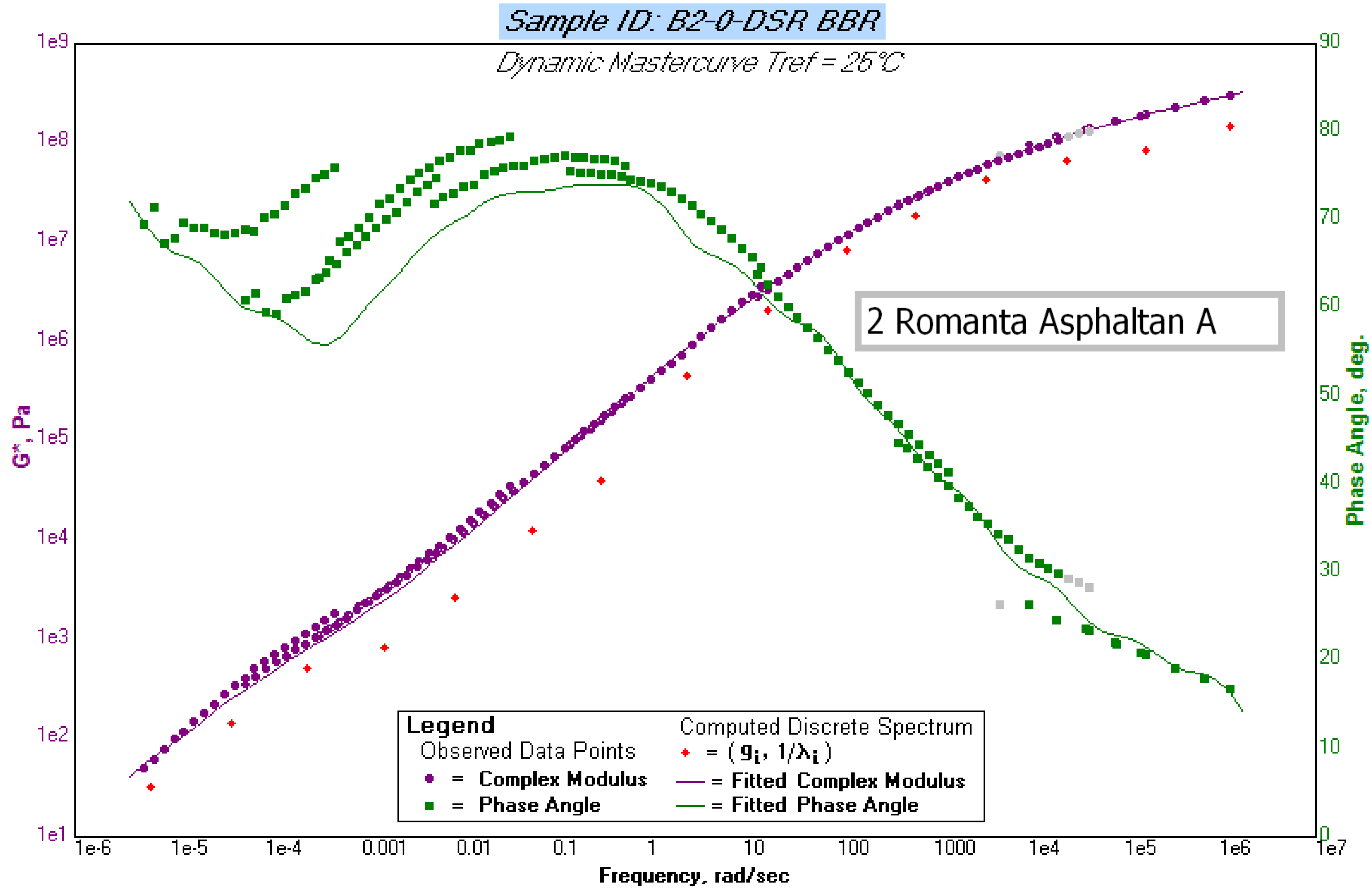
Binder 0 – 0 days



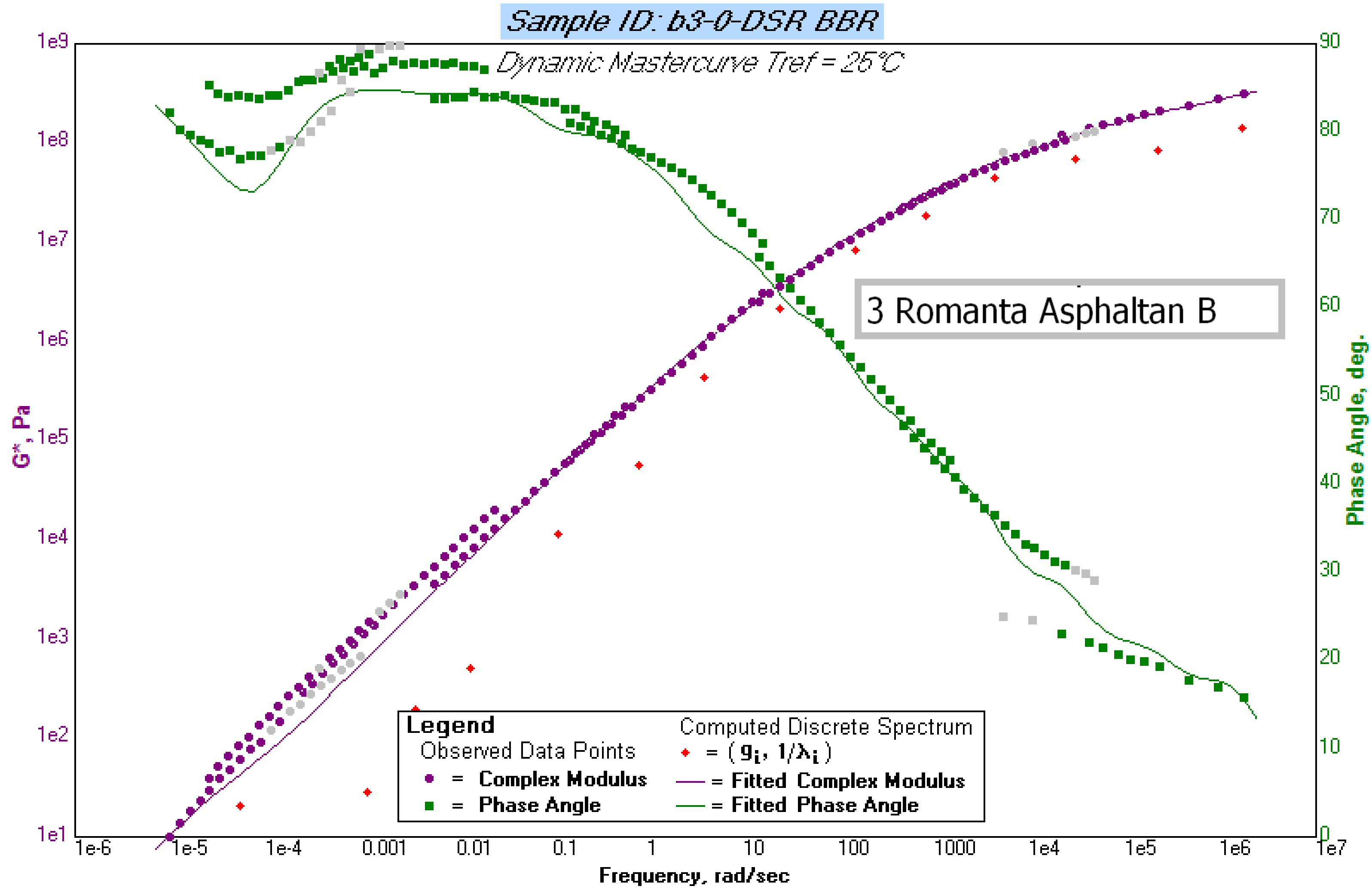
Binder 1 – 0 days



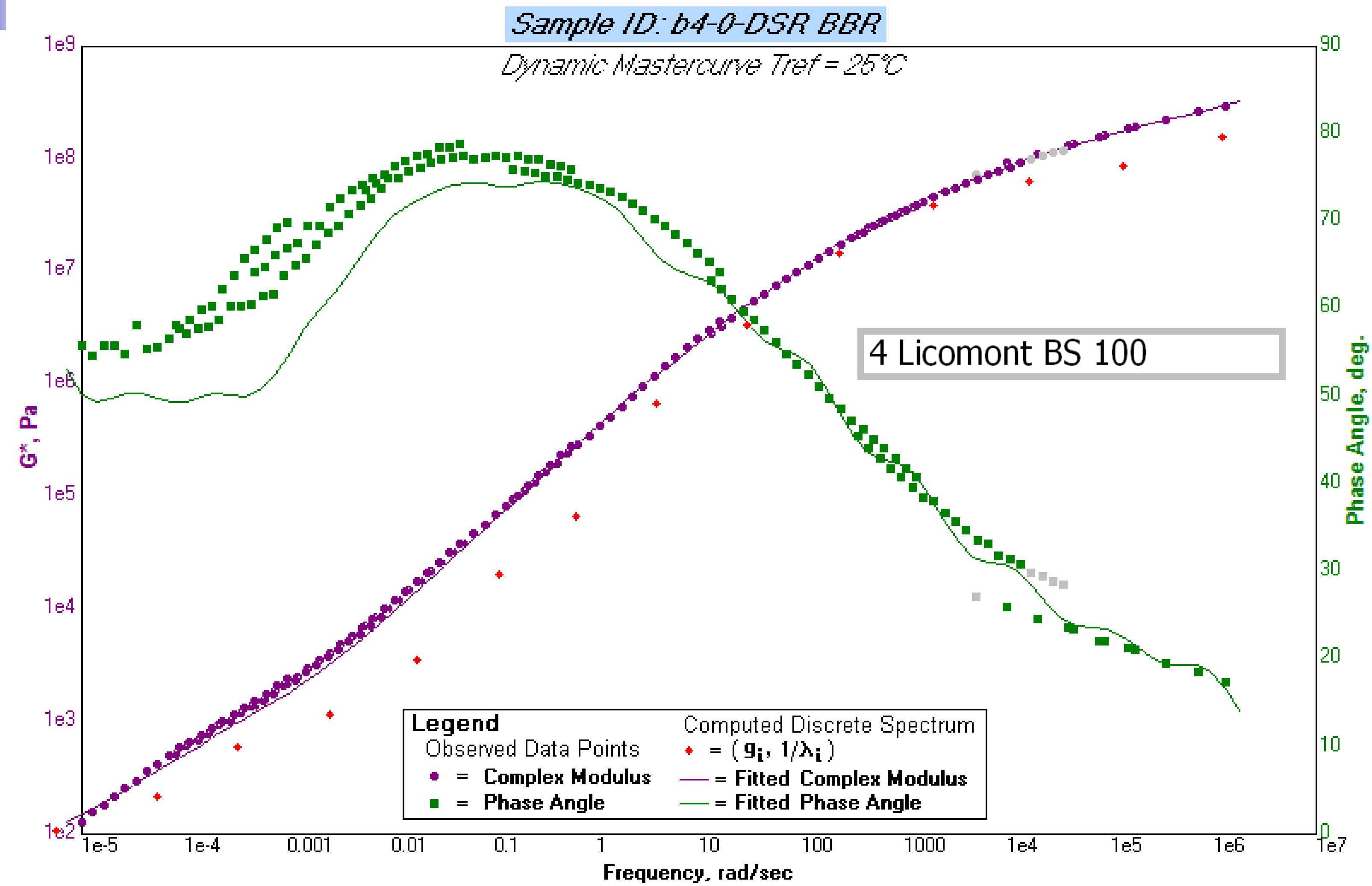
Binder 2 – 0 days



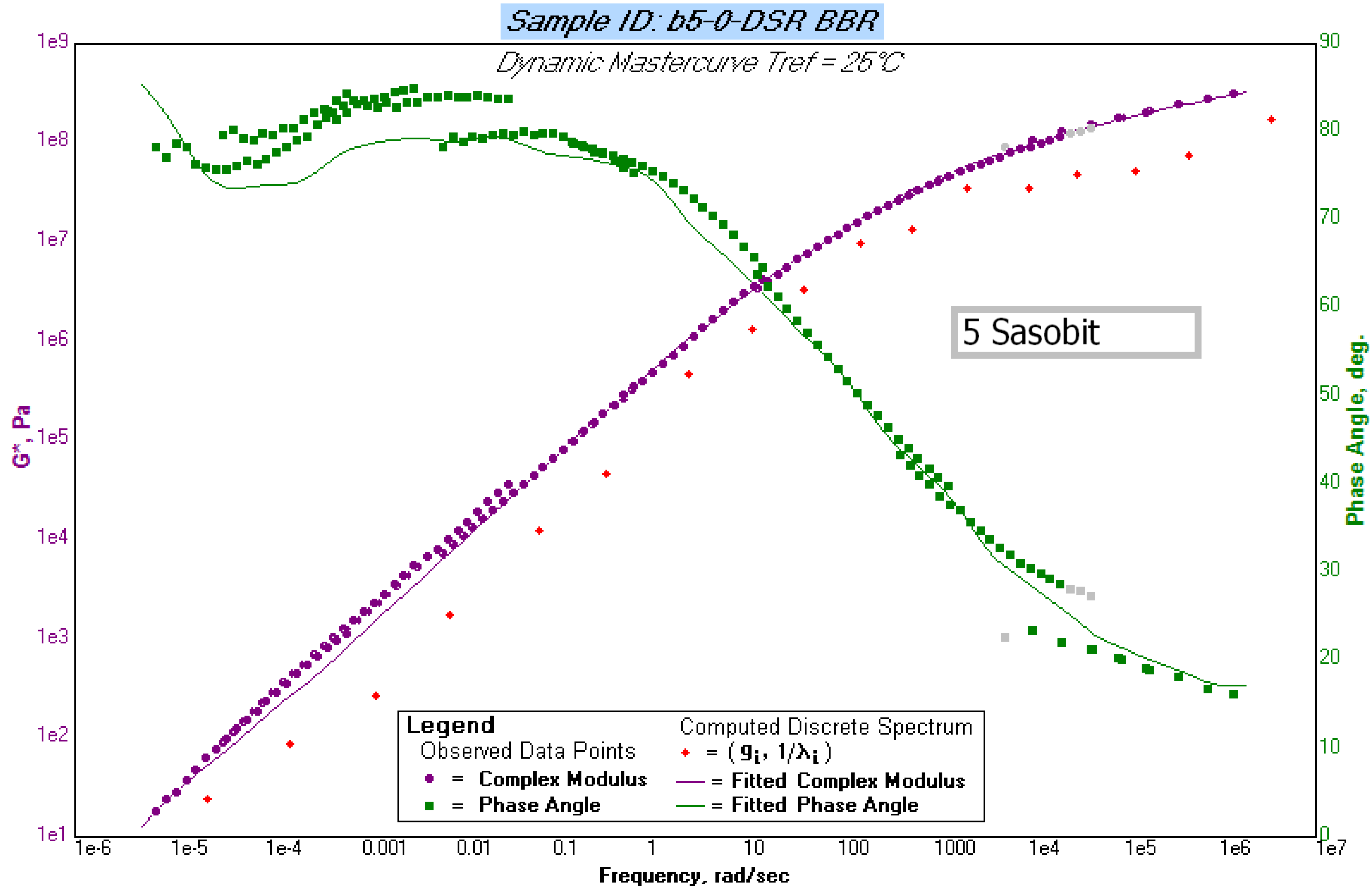
Binder 3 – 0 days



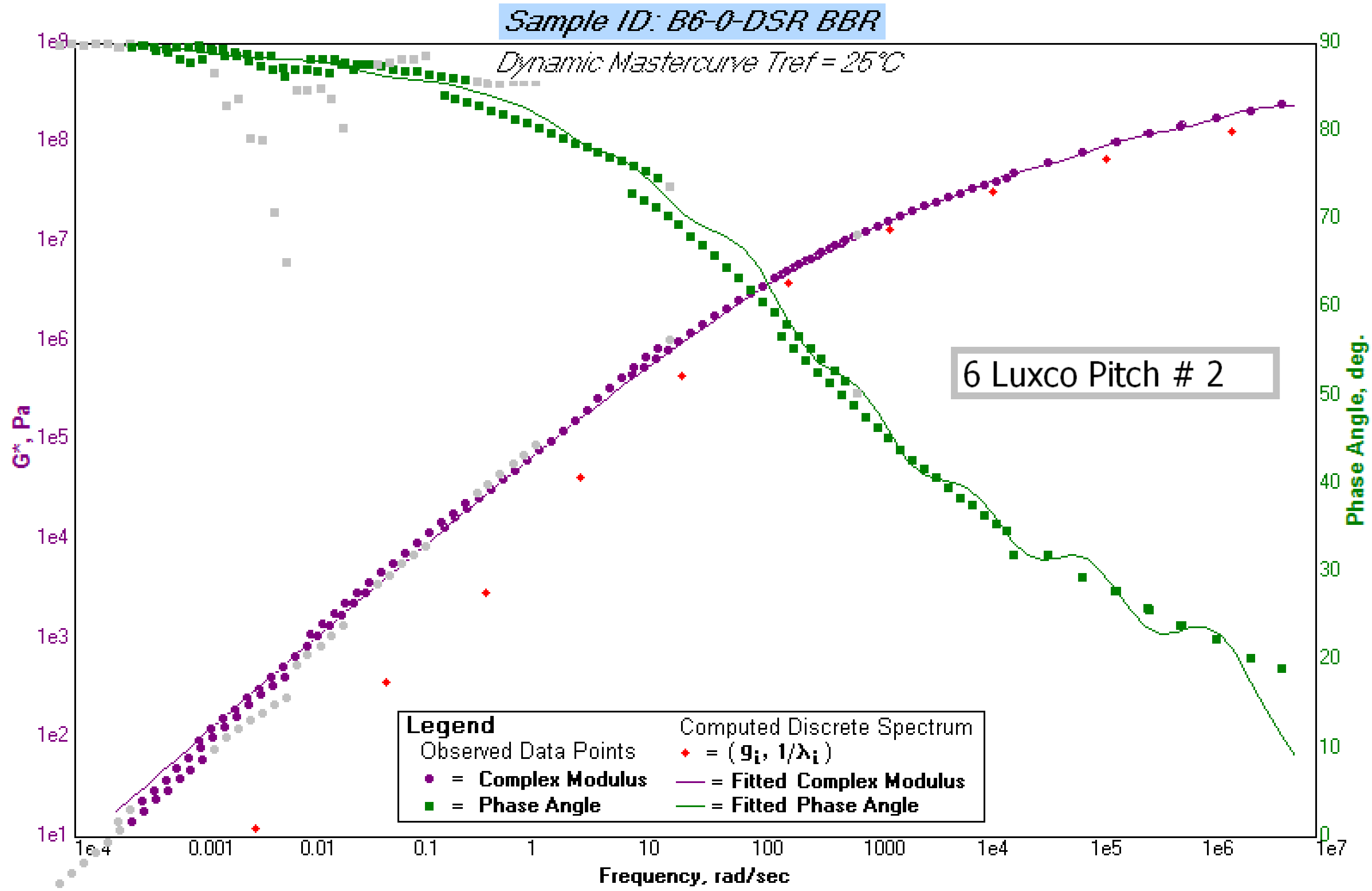
Binder 4 – 0 days



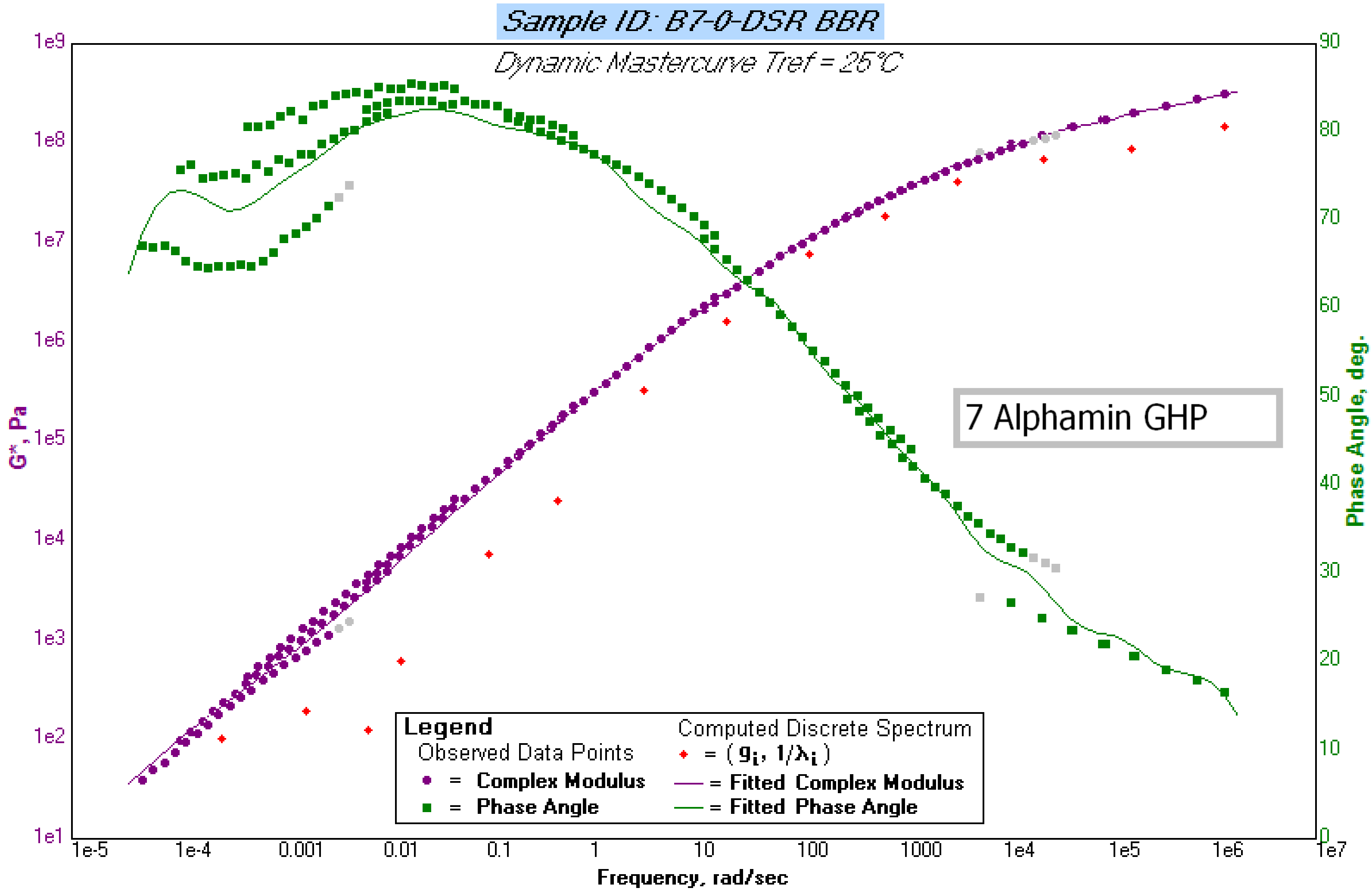
Binder 5 – 0 days



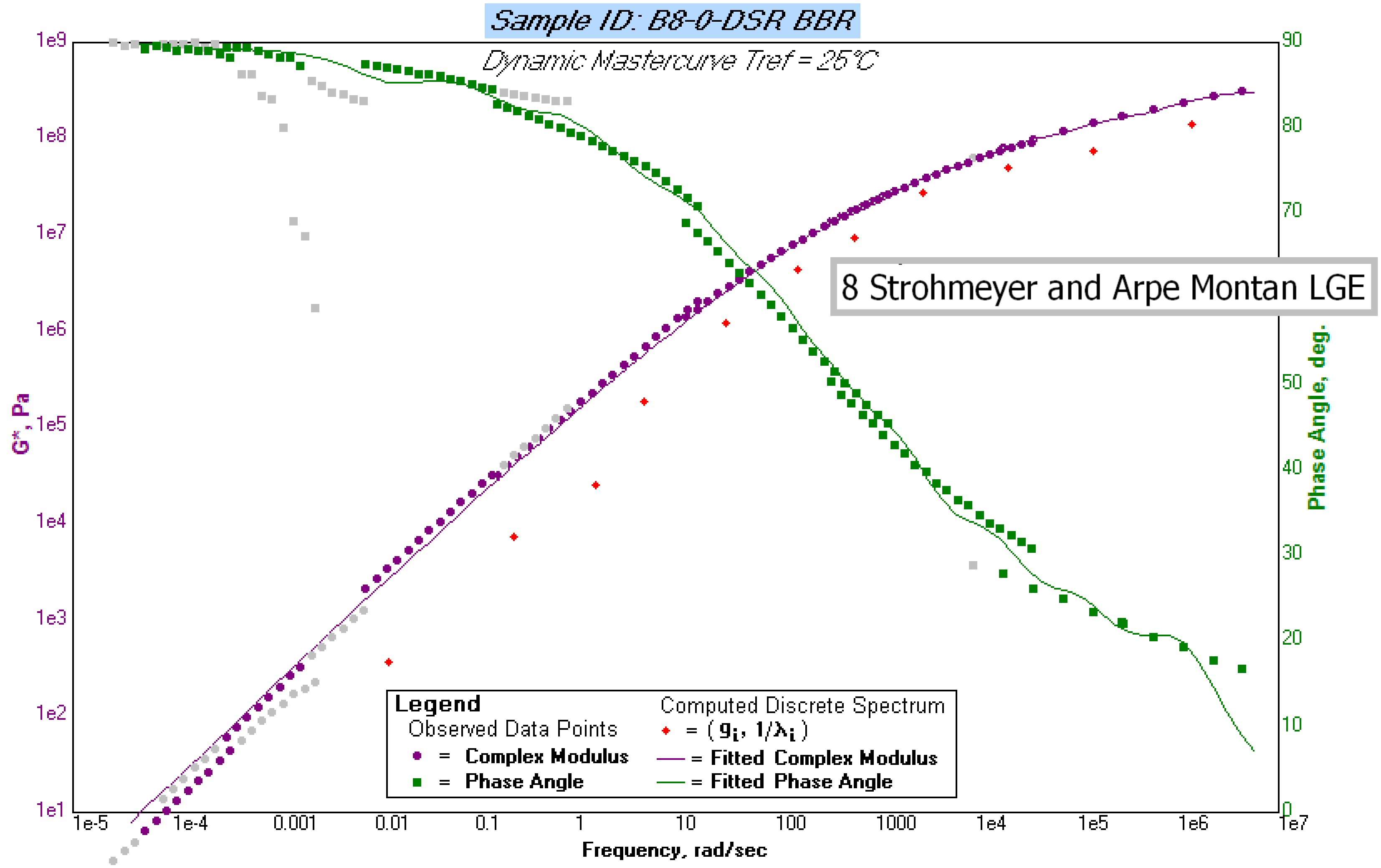
Binder 6 – 0 days



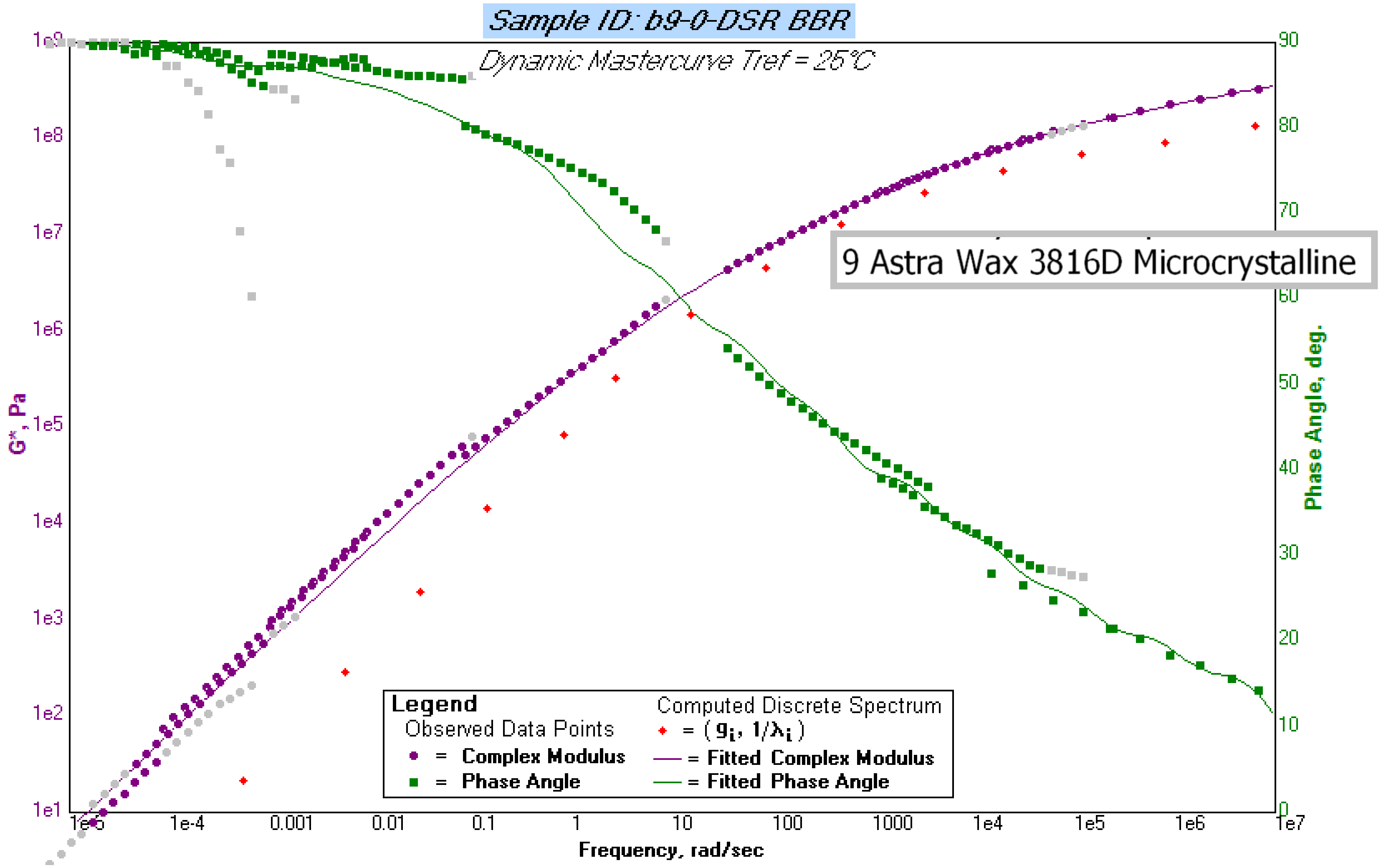
Binder 7 – 0 days



Binder 8 – 0 days



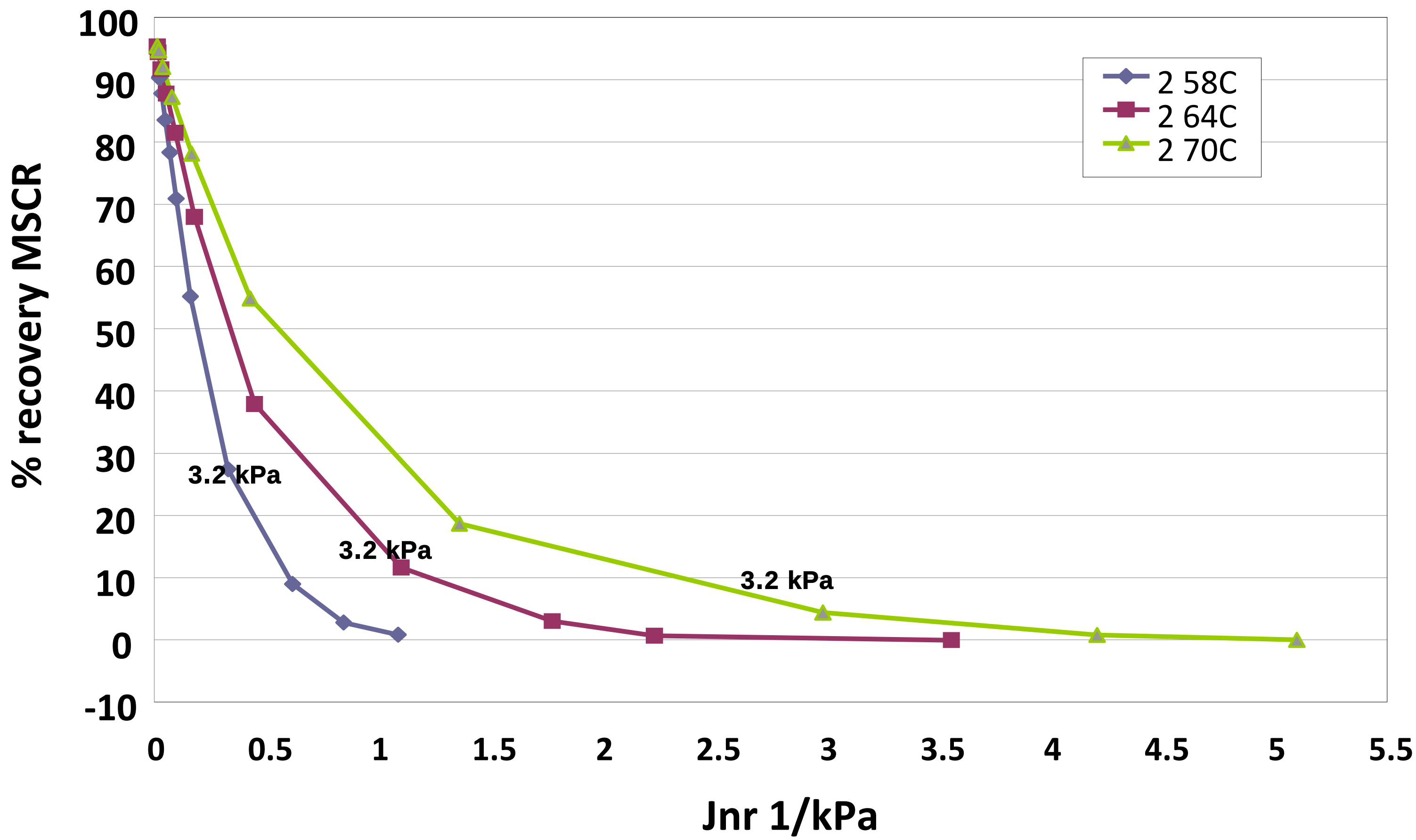
Binder 9 – 0 days



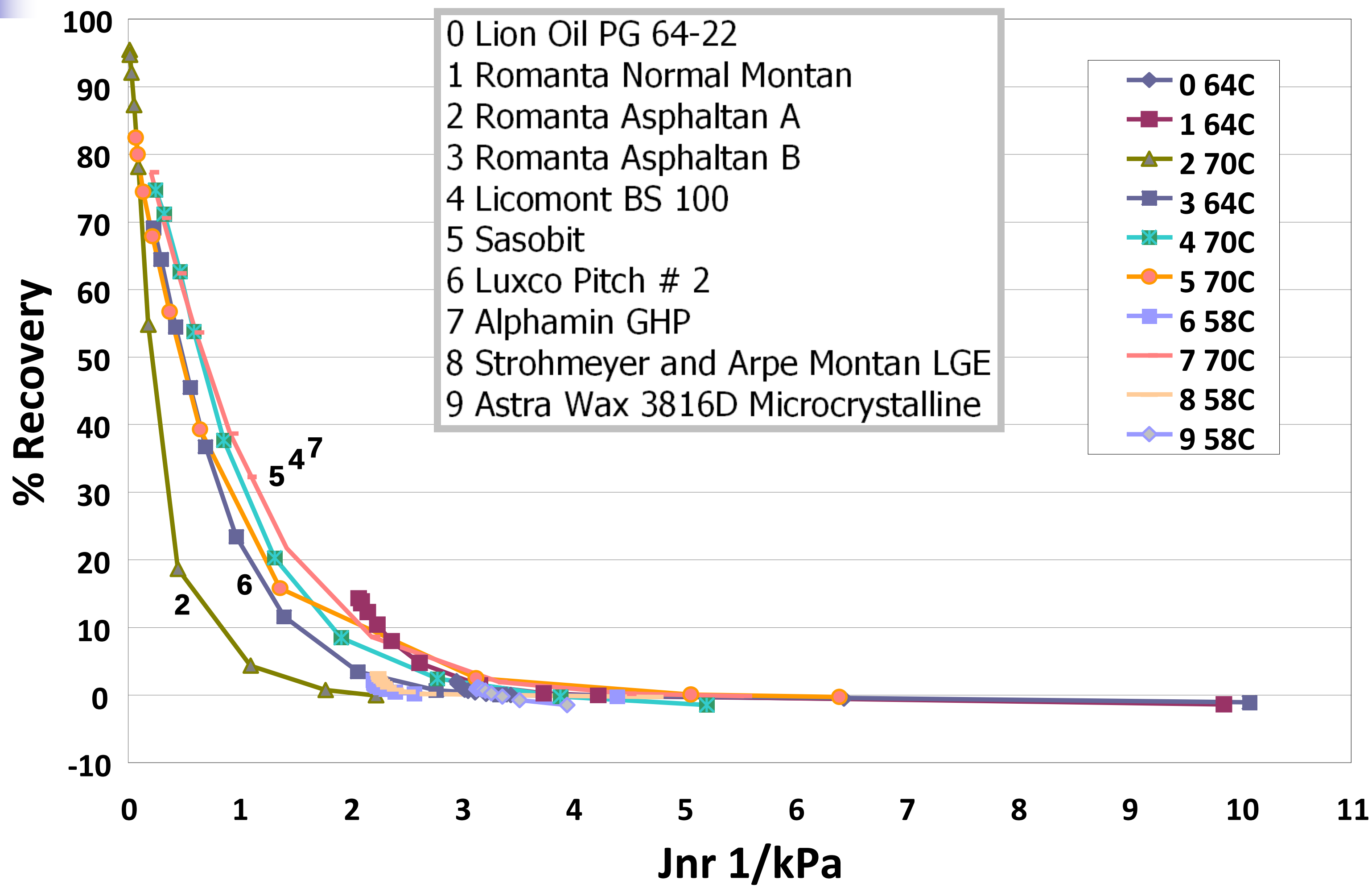
Jnr

- Tests conducted at three temperatures
  - 58, 64, 70^{o}C
- Jnr evaluated at 3.2 kPa and 4 (1/kPa)
- Elastic recovery – v. high for some products at low stress levels
- Certain products are more stress dependent that conventional binders

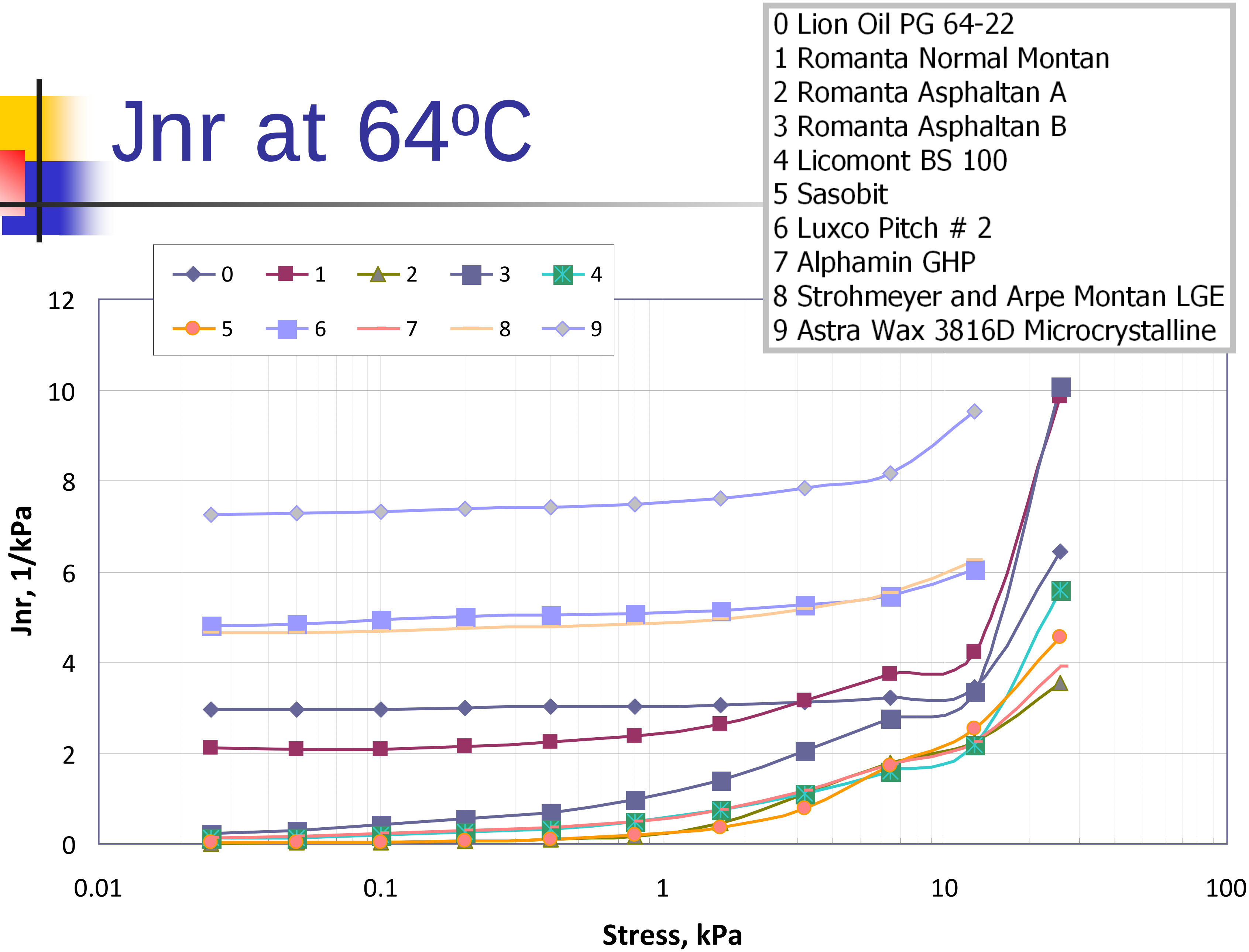
2 – % Recovery 58 to 64C



Recovery – near grade temp



Jnr at 64°C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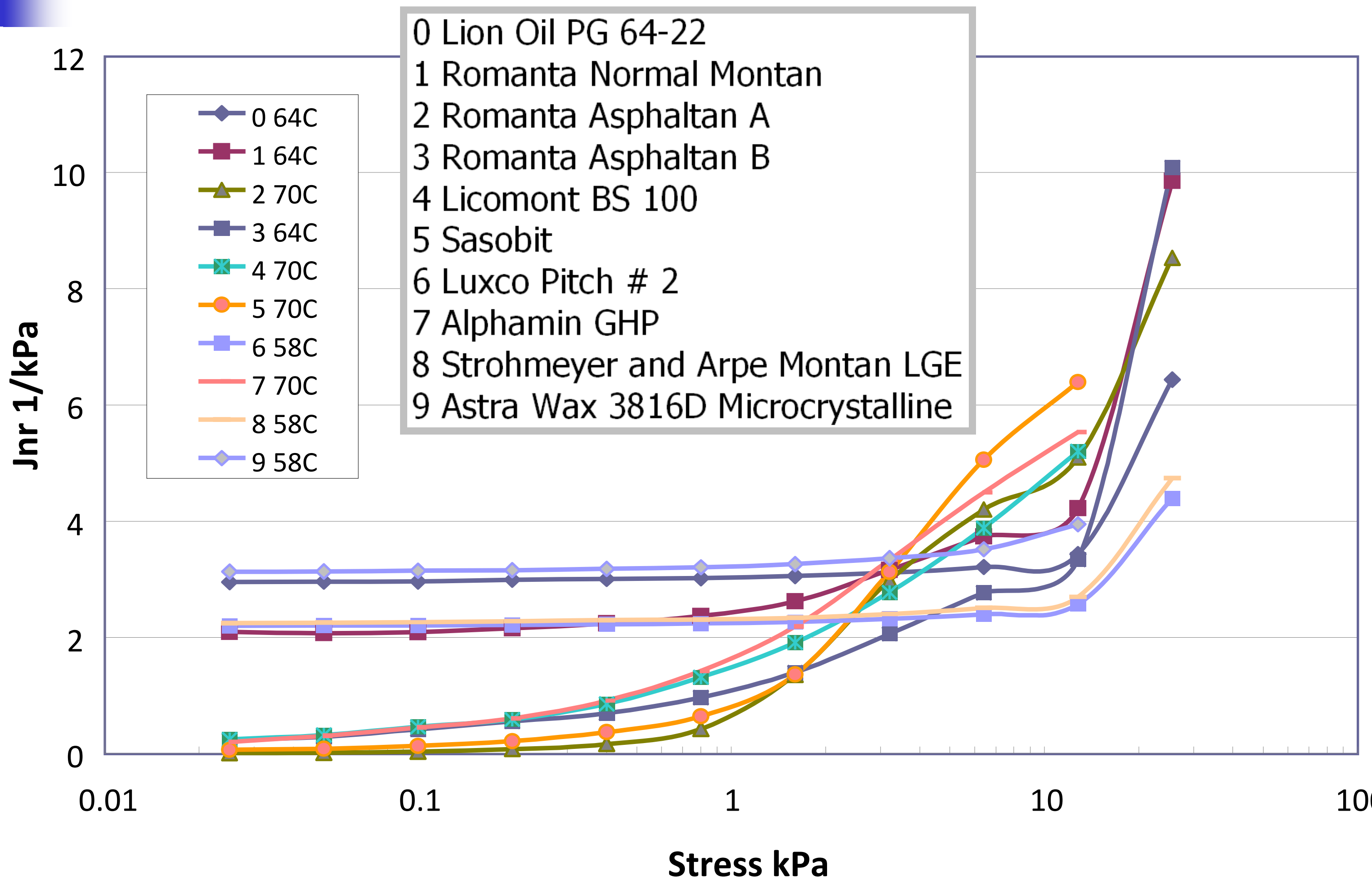
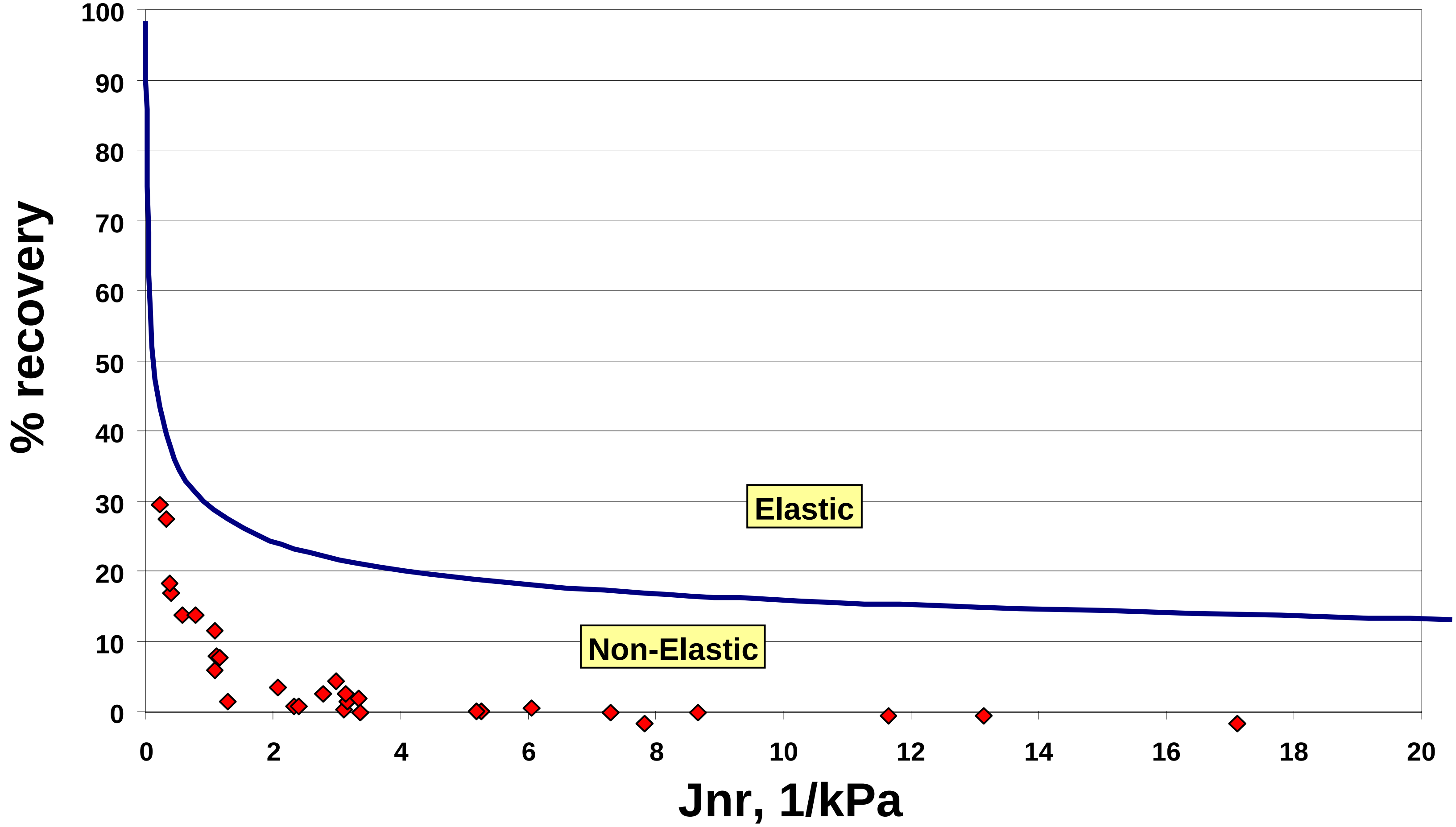
4 Licomont BS 100
5 Sasobit
6 Luxco Pitch # 2
7 Alphamin GHP
8 Strohmeyer and Arpe Montan LGE
9 Astra Wax 3816D Microcrystalline
0 1 2 3 4 5 6 7 8 9
Jnr, 1/kPa
0
2
4
6
8
10
12
0.01
0.1
1
10
100
Stress, kPa

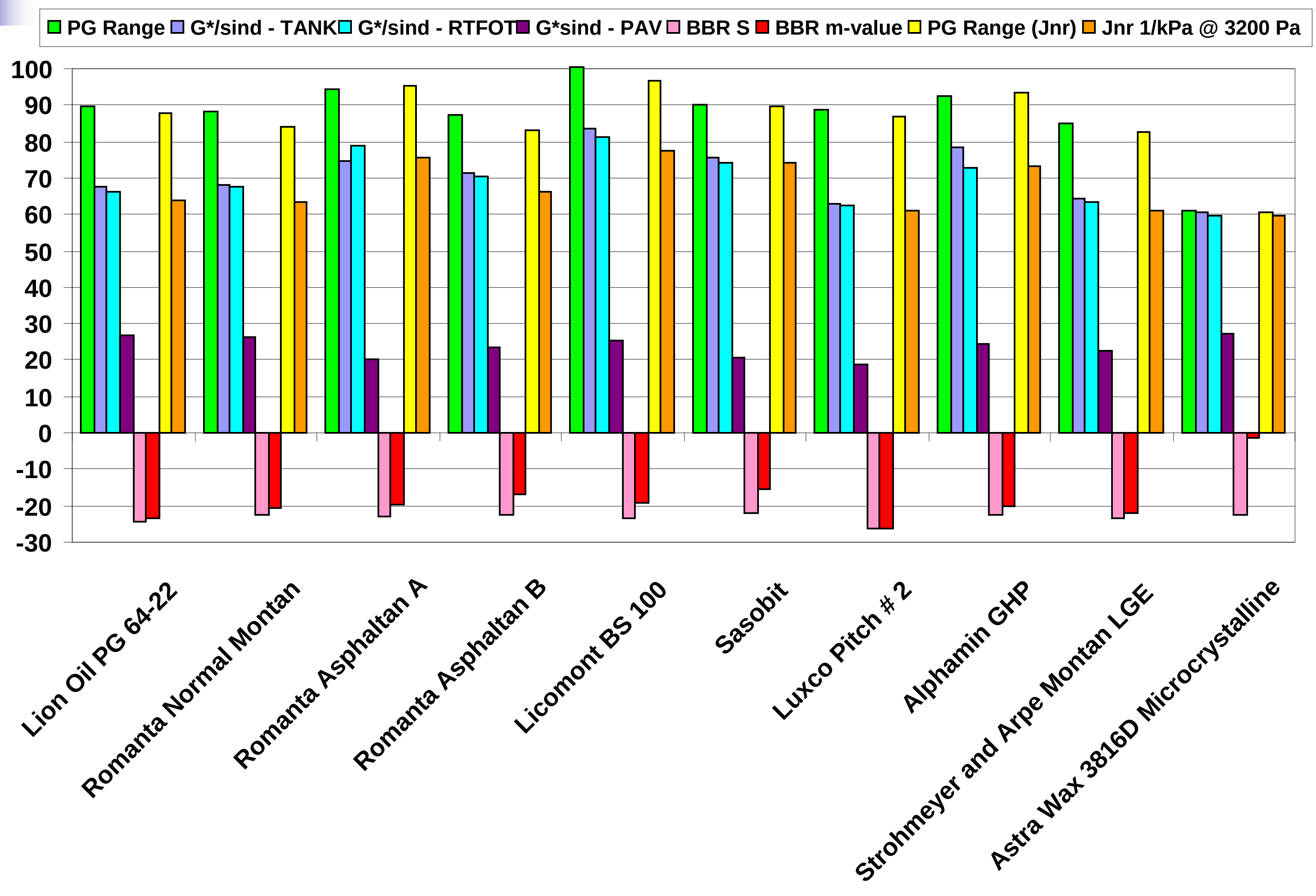
Jnr – near grade temperature



Jnr versus % recovery



PG grades – M320 Table 3



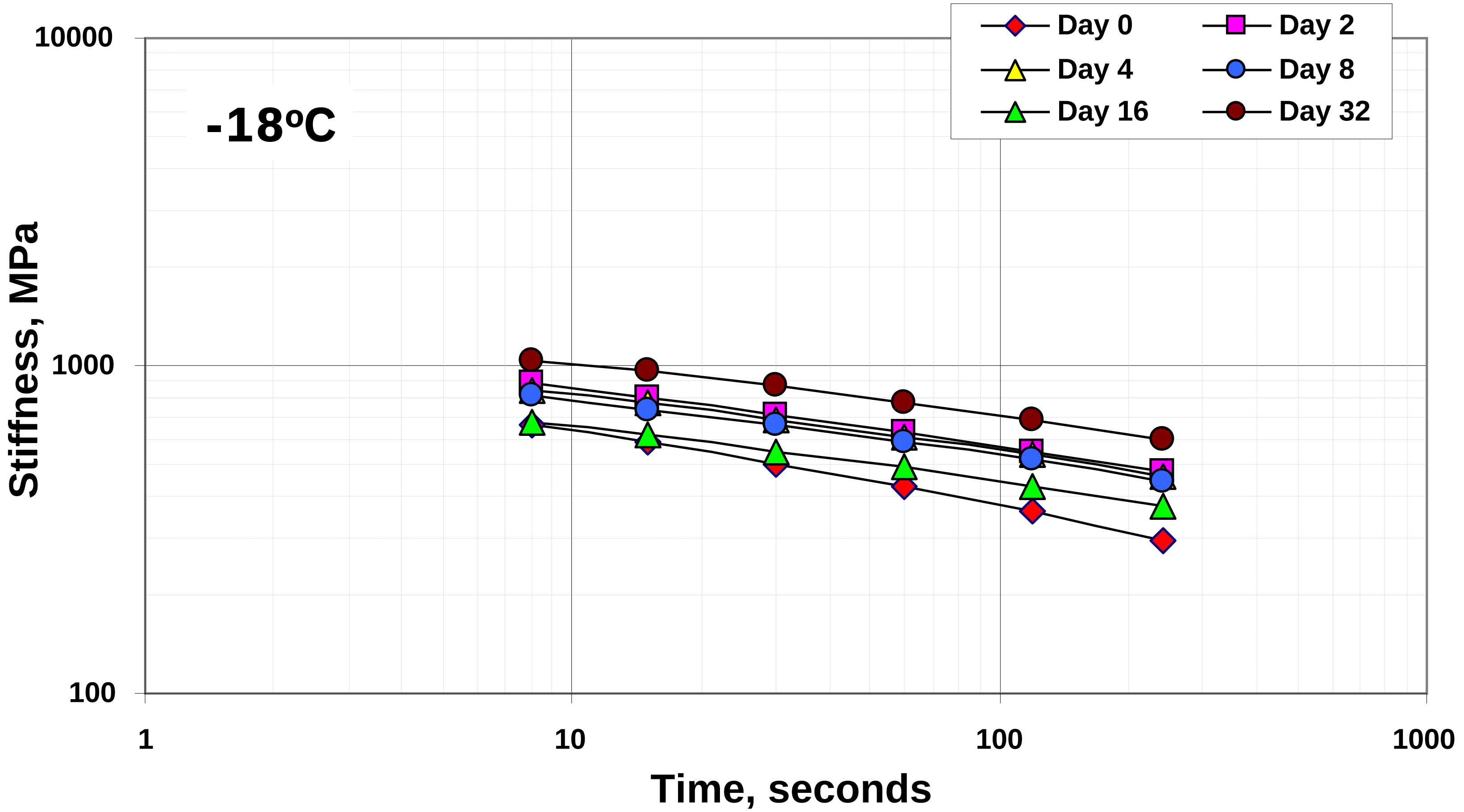
Difference in performance

- Binders grade different in Jnr evaluation
- Can be as much ½ PG grade
- Early products that show network – 2 effected from 5
  - 2 (Romanta Asphaltan A)
  - 3 (Romanta Asphaltan B)
  - 4 (Licomont BS 100)
  - 5 (Sasobit)
  - 7 (Alphamin GHP)
- Suggests importance of Jnr evaluation

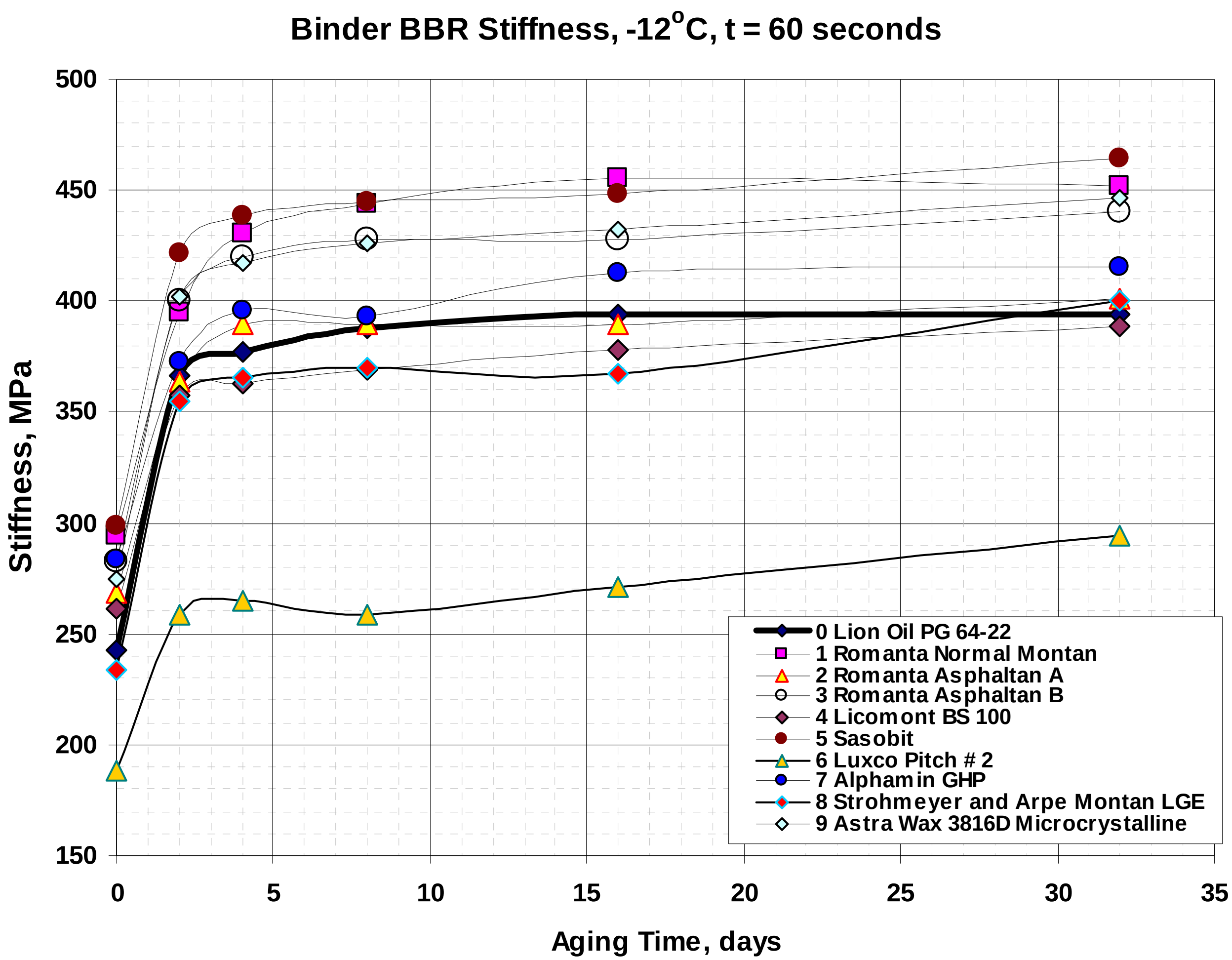
Ref	Diff
0	2.09
1	4.03
2	-0.71
3	4.22
4	3.80
5	0.33
6	1.67
7	-0.66
8	2.31
9	0.16

Aged tests - binder

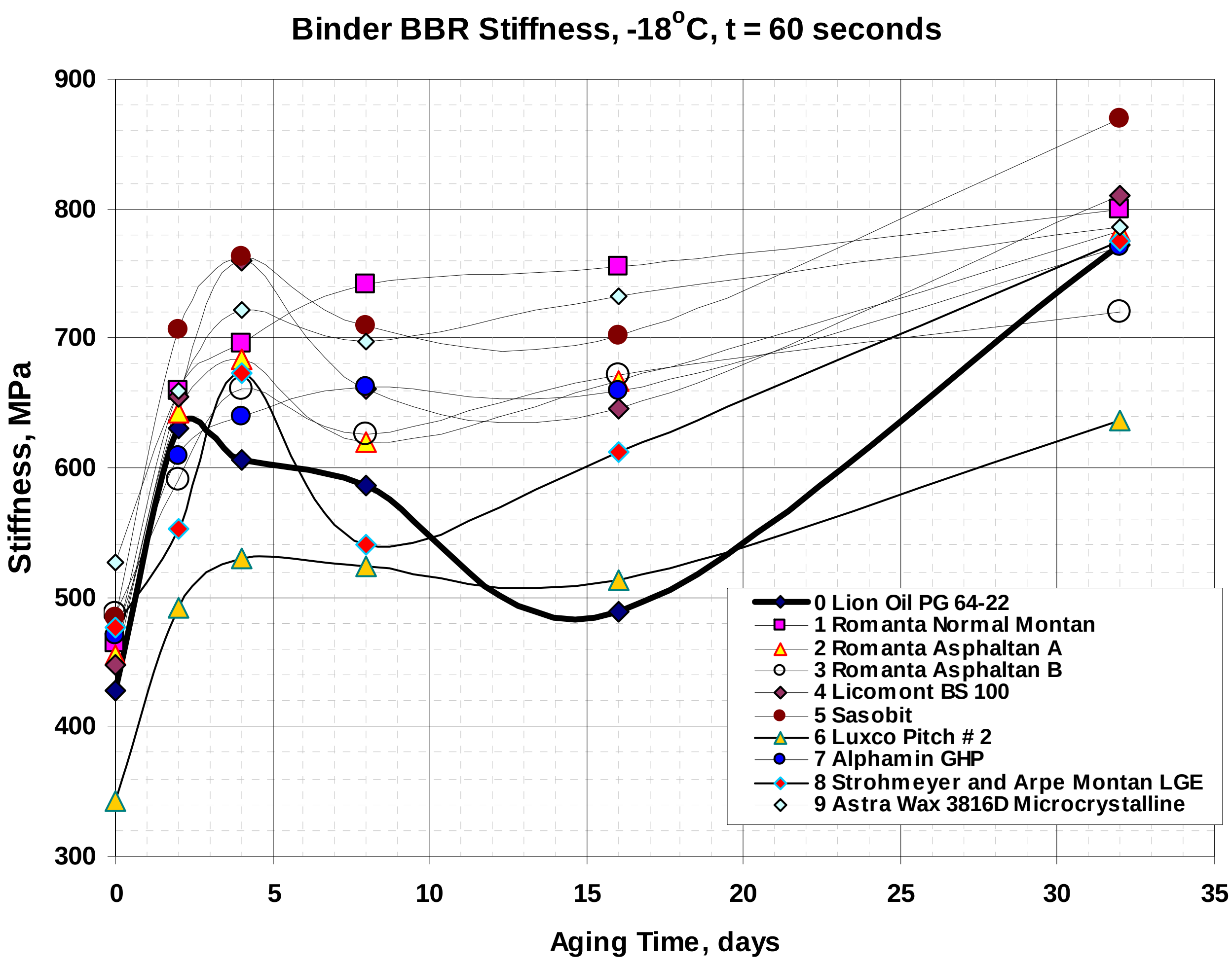
PG64-22 – aging to 32 days



Binder BBR S(t) at -12^{o}C



Binder BBR S(t) at -18ºC



BBR data

- Aging data showed that the -18^{o}C gave significantly more variability when compared to the -12^{o}C data

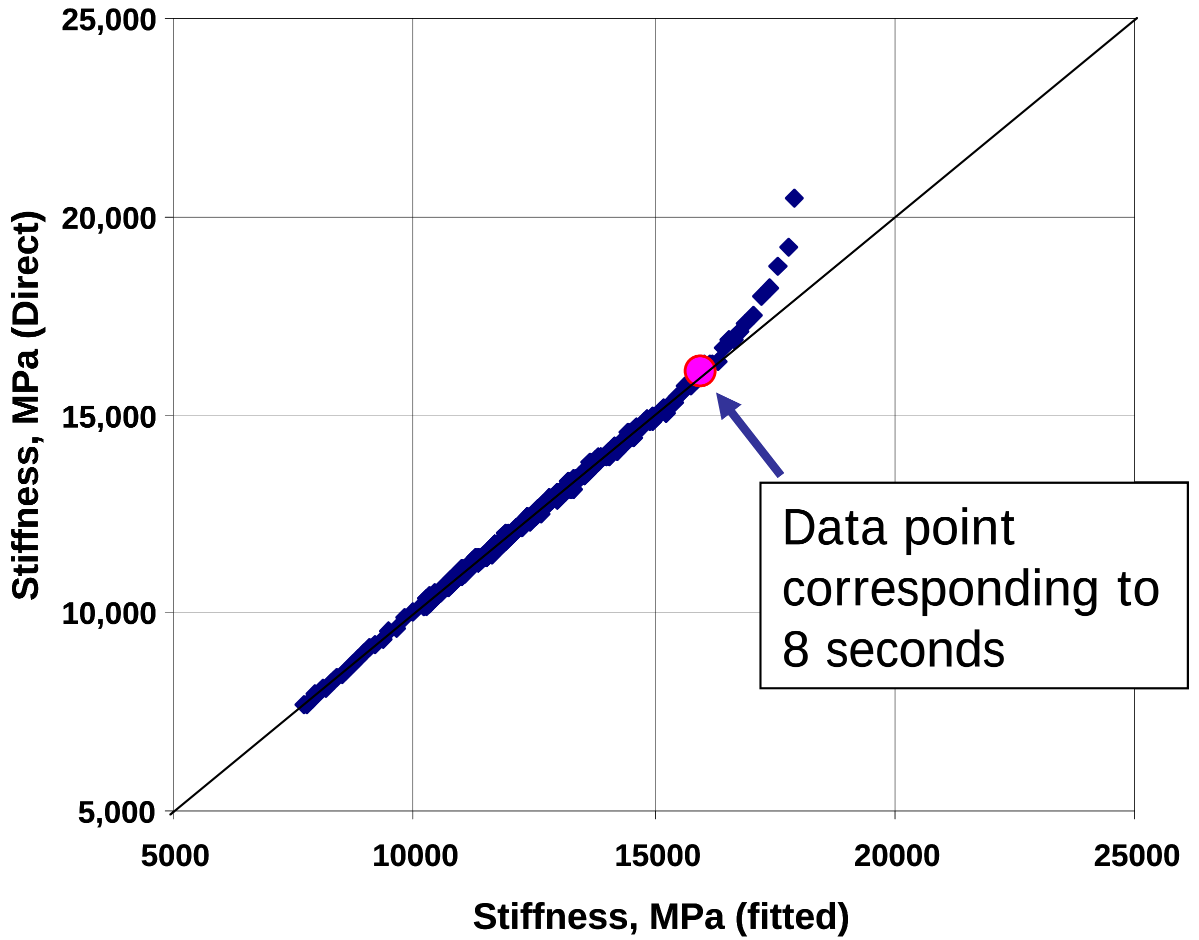
Mix test data

Mix BBR Data

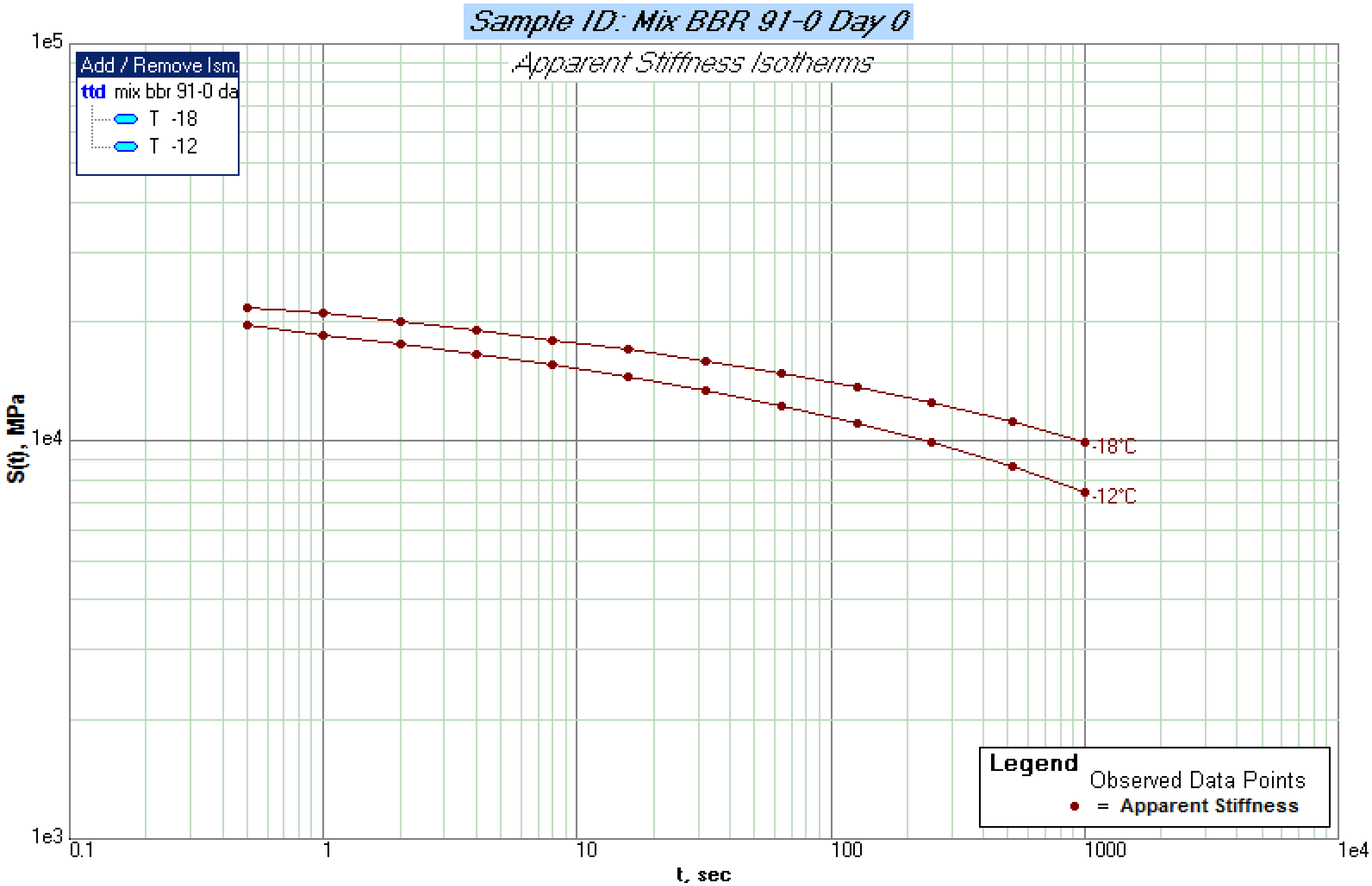
- Data processed to produce equal-log scale representation with approximate linear double of scale
- Several cases exist which colder temperature is less stiff than matching warm temperature data

Removal of early BBR data

- Data before 8-seconds is removed from analysis in similar manner to binder BBR data
- Shows fitted (polynomial) approach versus direct calculation
- Data before t=8 seconds is less reliable

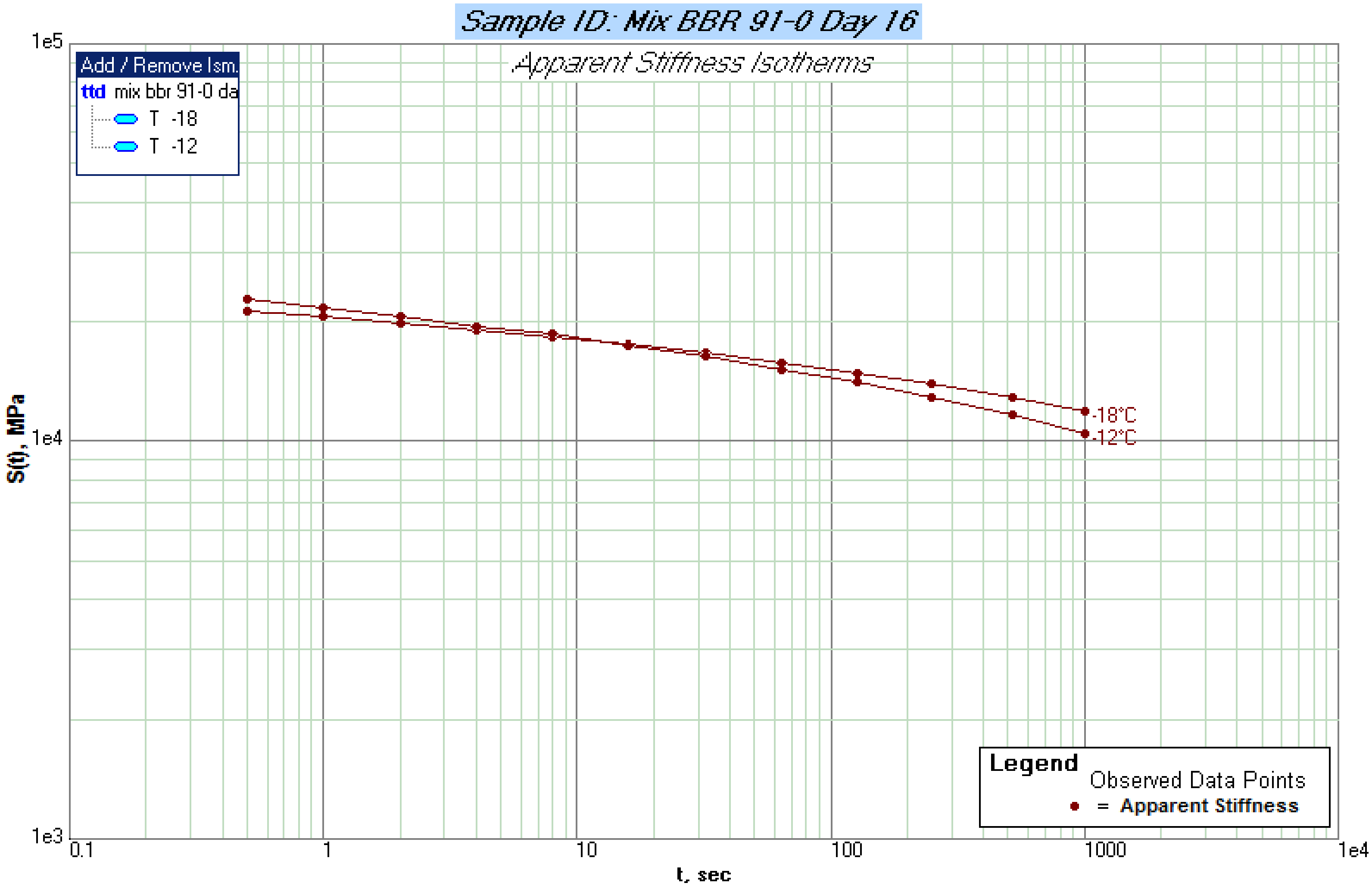


0-0



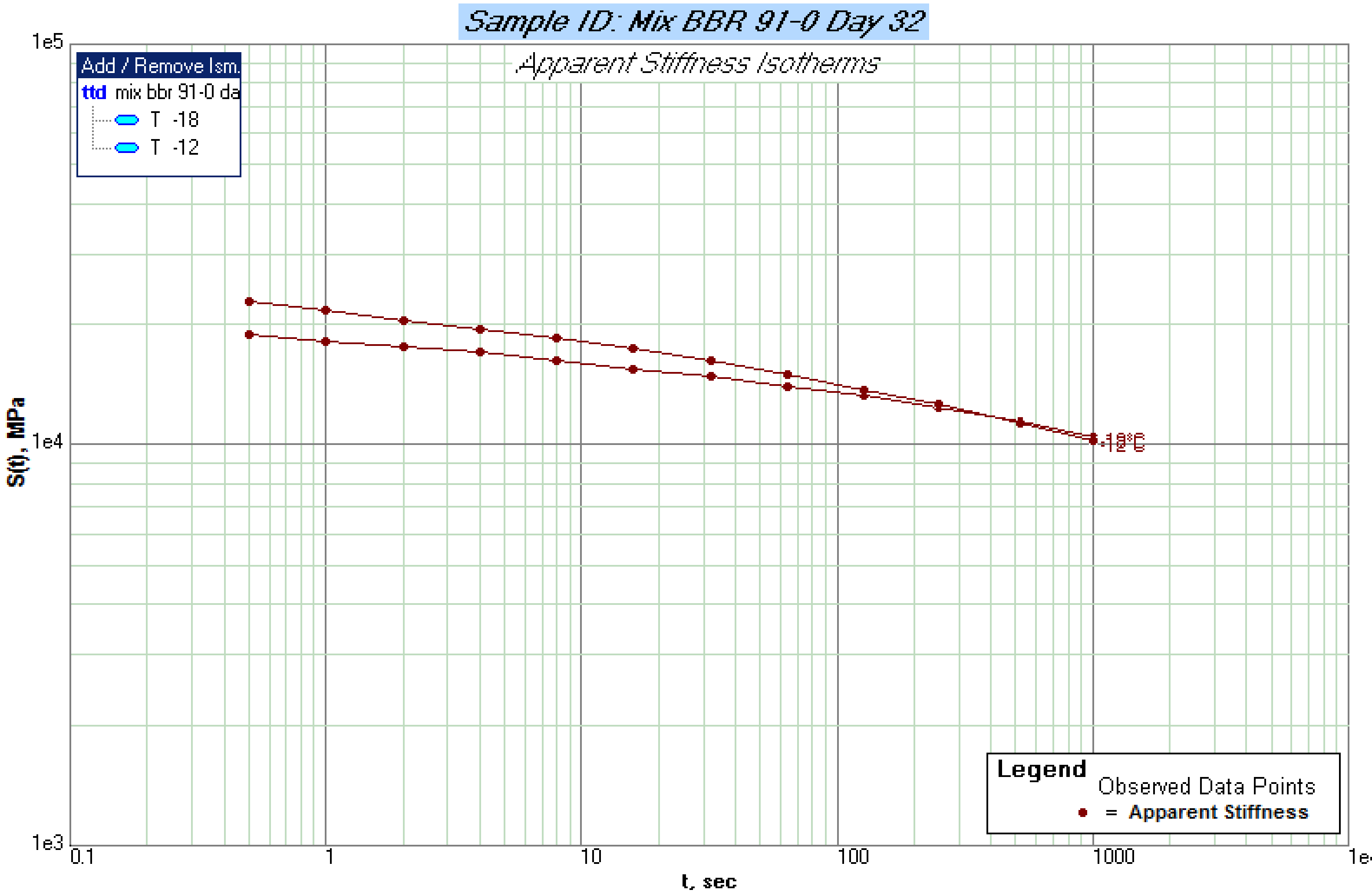
Sample ID: Mix BBR 91-0 Day 0
Apparent Stiffness Isotherms
Add / Remove Ism.
ttd mix bbr 91-0 da
T -18
T -12
S(t), MPa
1e5
1e4
1e3
t, sec
0.1
1
10
100
1000
1e4
-18°C
-12°C
Legend
Observed Data Points
= Apparent Stiffness

0-16



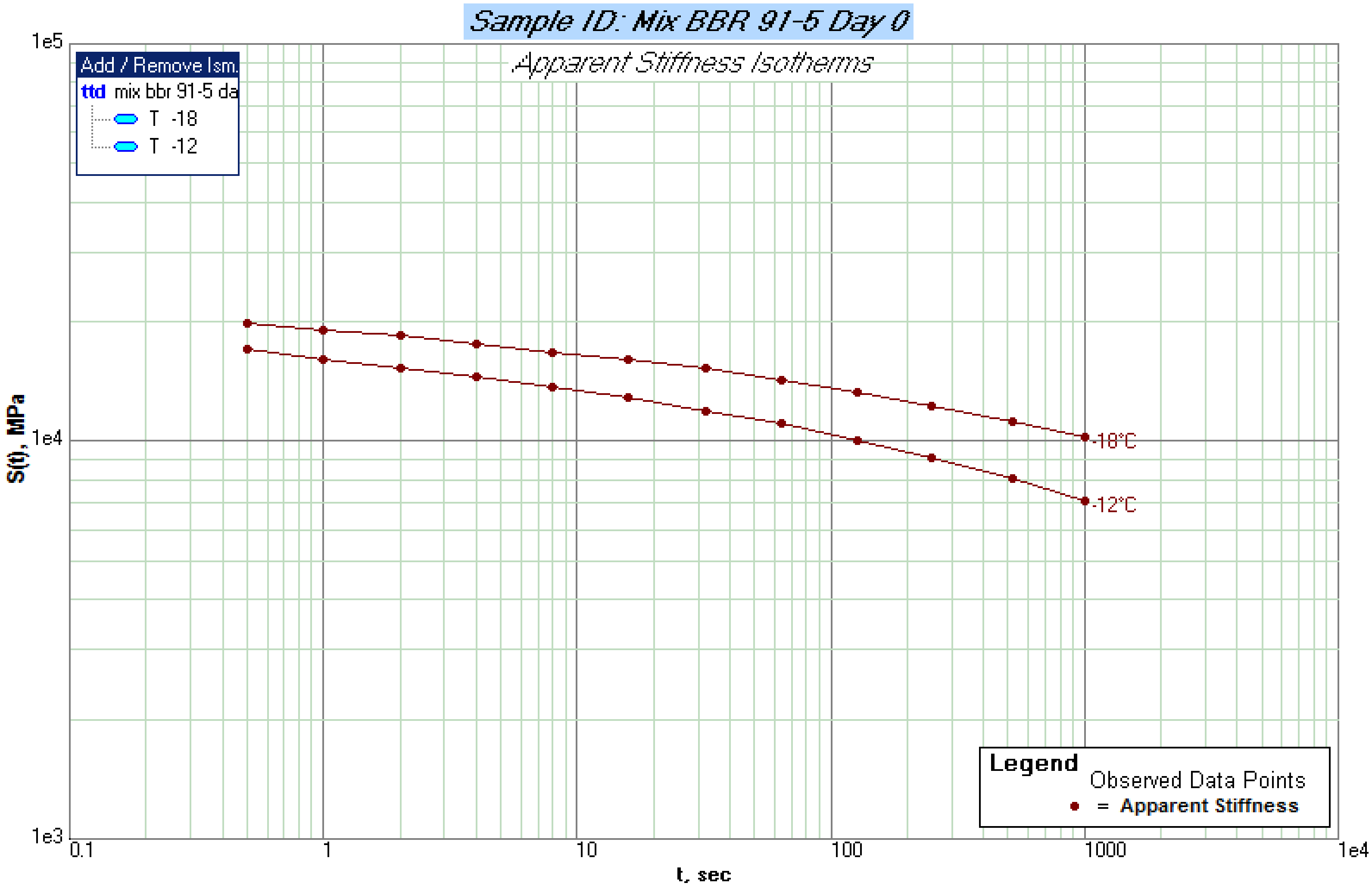
Sample ID: Mix BBR 91-0 Day 16
Apparent Stiffness Isotherms
Add / Remove Ism.
ttd mix bbr 91-0 da
T -18
T -12
1e5
1e4
1e3
S(t), MPa
0.1
1
10
100
1000
1e4
t, sec
-18°C
-12°C
Legend
Observed Data Points
= Apparent Stiffness

0-32



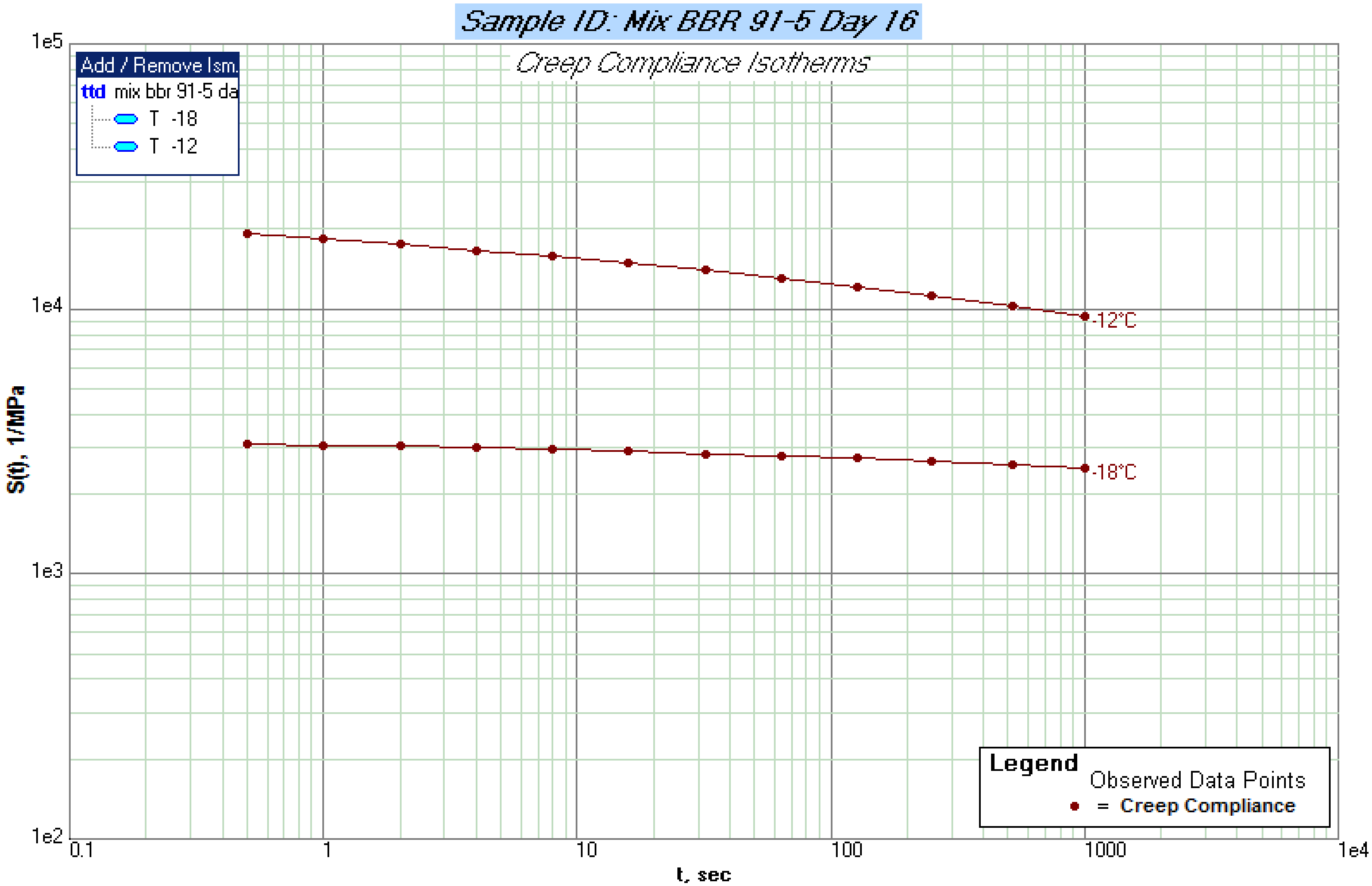
Sample ID: Mix BBR 91-0 Day 32
Apparent Stiffness Isotherms
Add / Remove Ism.
ttd mix bbr 91-0 da
T -18
T -12
S(t), MPa
1e5
1e4
1e3
0.1
1
10
100
1000
1e4
t, sec
Legend
Observed Data Points
= Apparent Stiffness

5-0

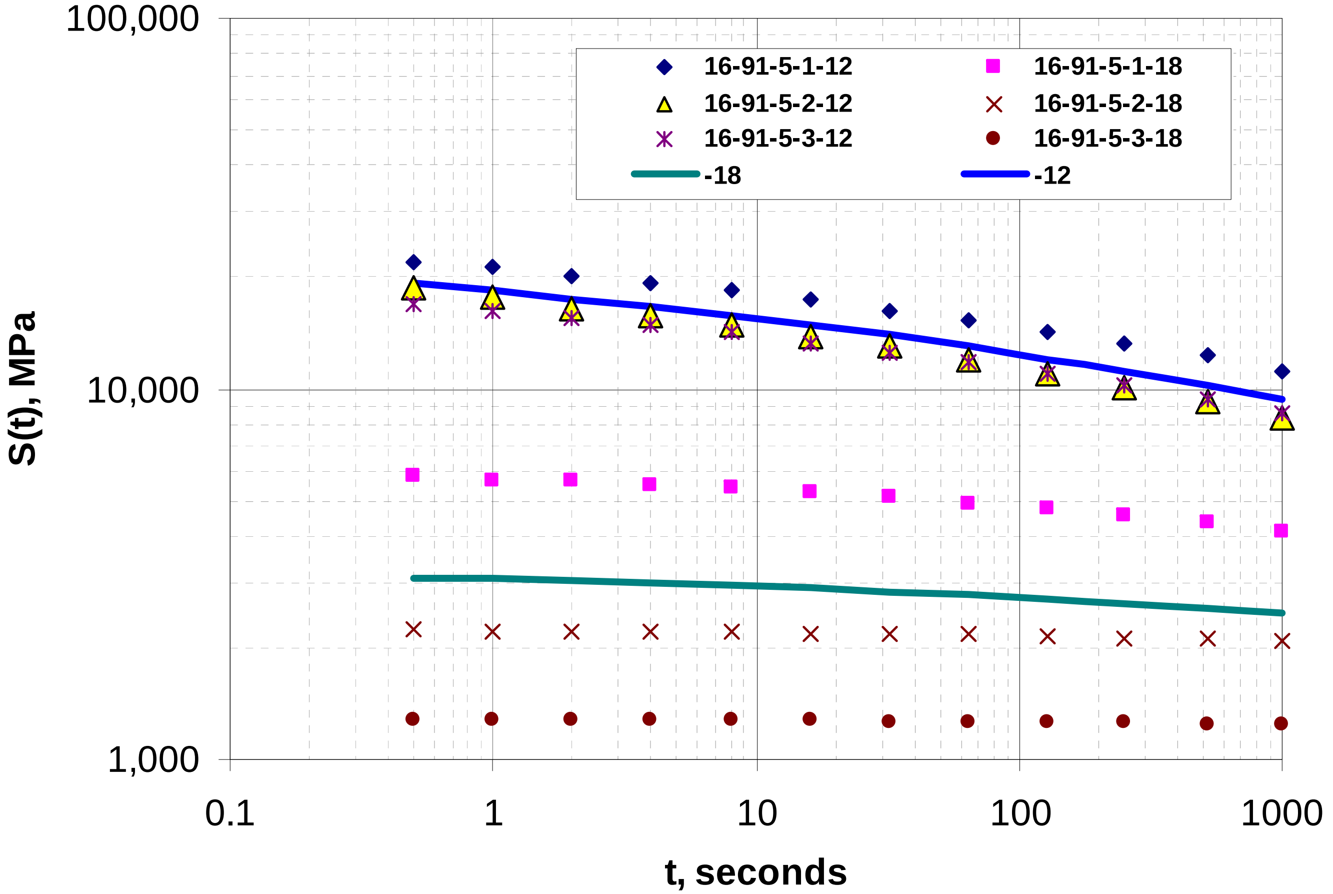


Sample ID: Mix BBR 91-5 Day 0
Apparent Stiffness Isotherms
Add / Remove Ism.
ttd mix bbr 91-5 da
T -18
T -12
S(t), MPa
1e5
1e4
1e3
0.1
1
10
100
1000
1e4
t, sec
-18°C
-12°C
Legend
Observed Data Points
= Apparent Stiffness

5-16


Sample ID: Mix BBR 91-5 Day 16
Creep Compliance Isotherms
Add / Remove Ism.
ttd mix bbr 91-5 da
T -18
T -12
-12°C
-18°C
1e5
1e4
1e3
1e2
S(t), 1/MPa
0.1
1
10
100
1000
1e4
t, sec
Legend
Observed Data Points
= Creep Compliance

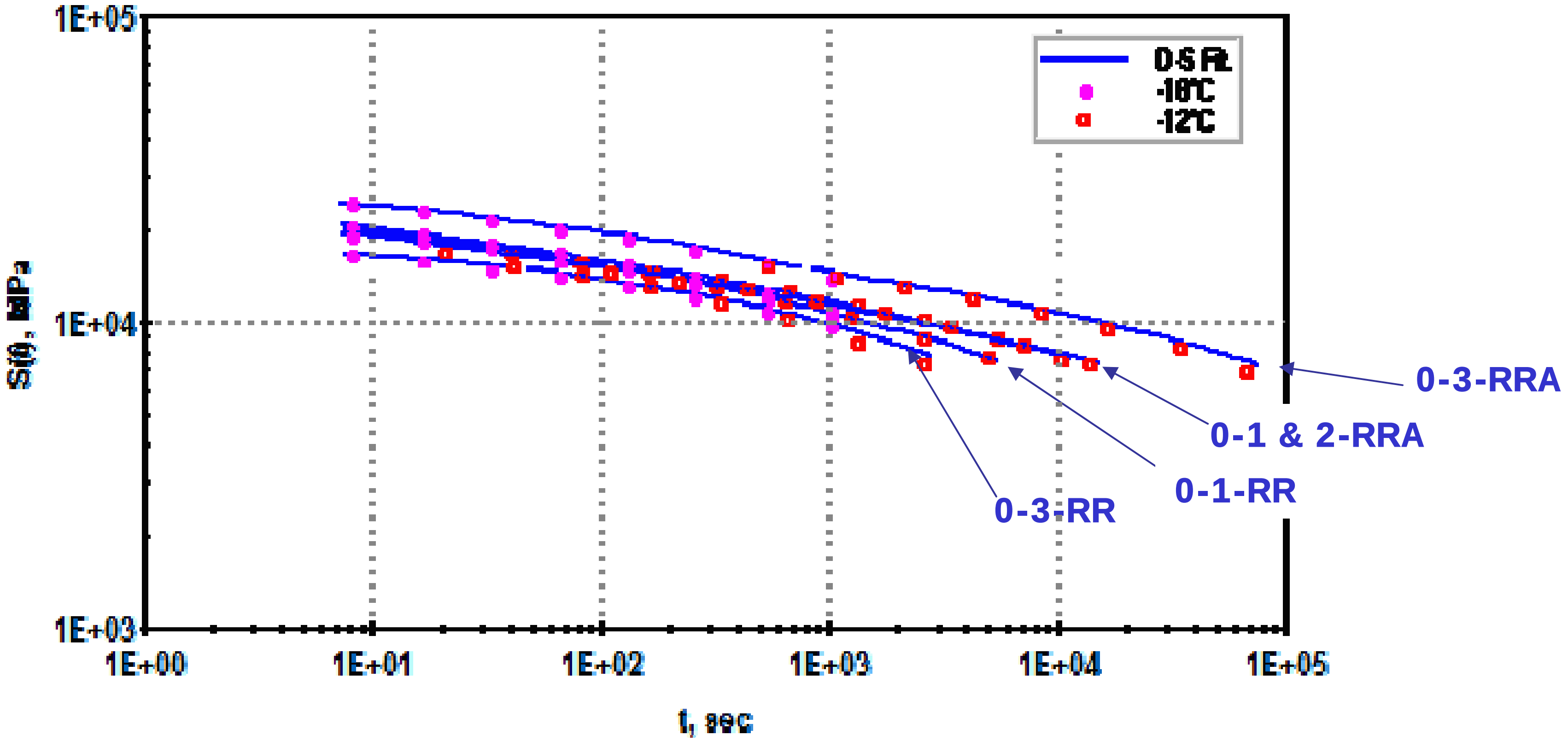
Material 5 - Day 16



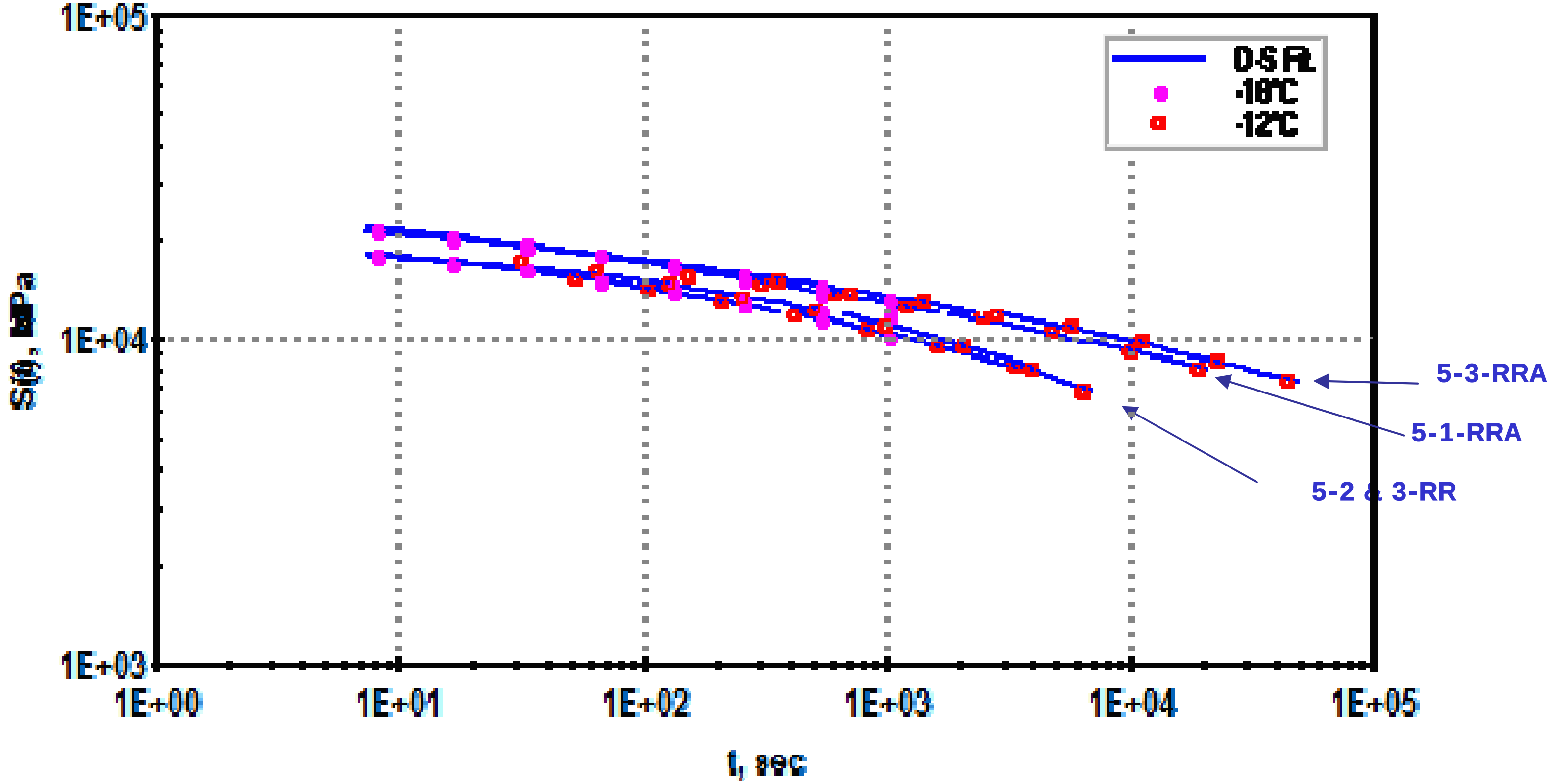
Re-tests of Mix Beams

- Testing of beams before and after annealing
- Annealing conducted at 64^{o}C overnight
- 64^{o}C chosen since it represents day at likely high-pavement temperature

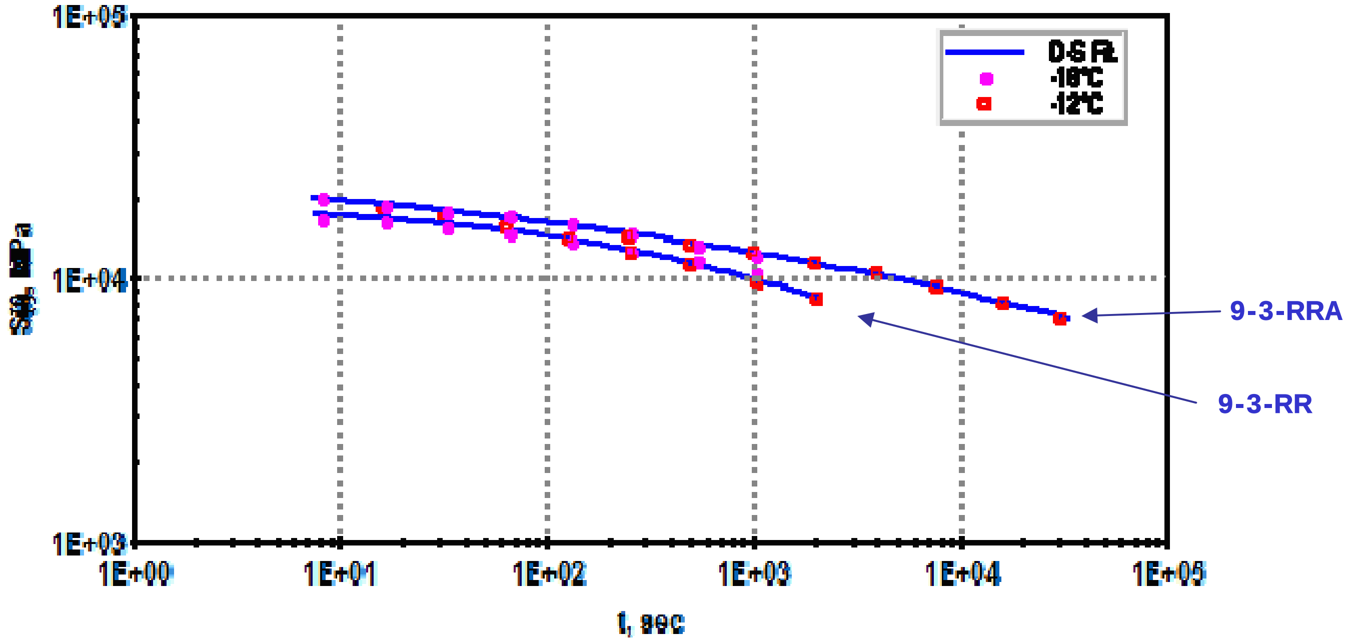
1 - PG64-22 - retests



5 - Sasobit -retests



9 - Astra Wax



1E+05
1E+04
1E+03
1E+00
1E+01
1E+02
1E+03
1E+04
1E+05
t, sec
-18°C
-12°C
9-3-RRA
9-3-RR

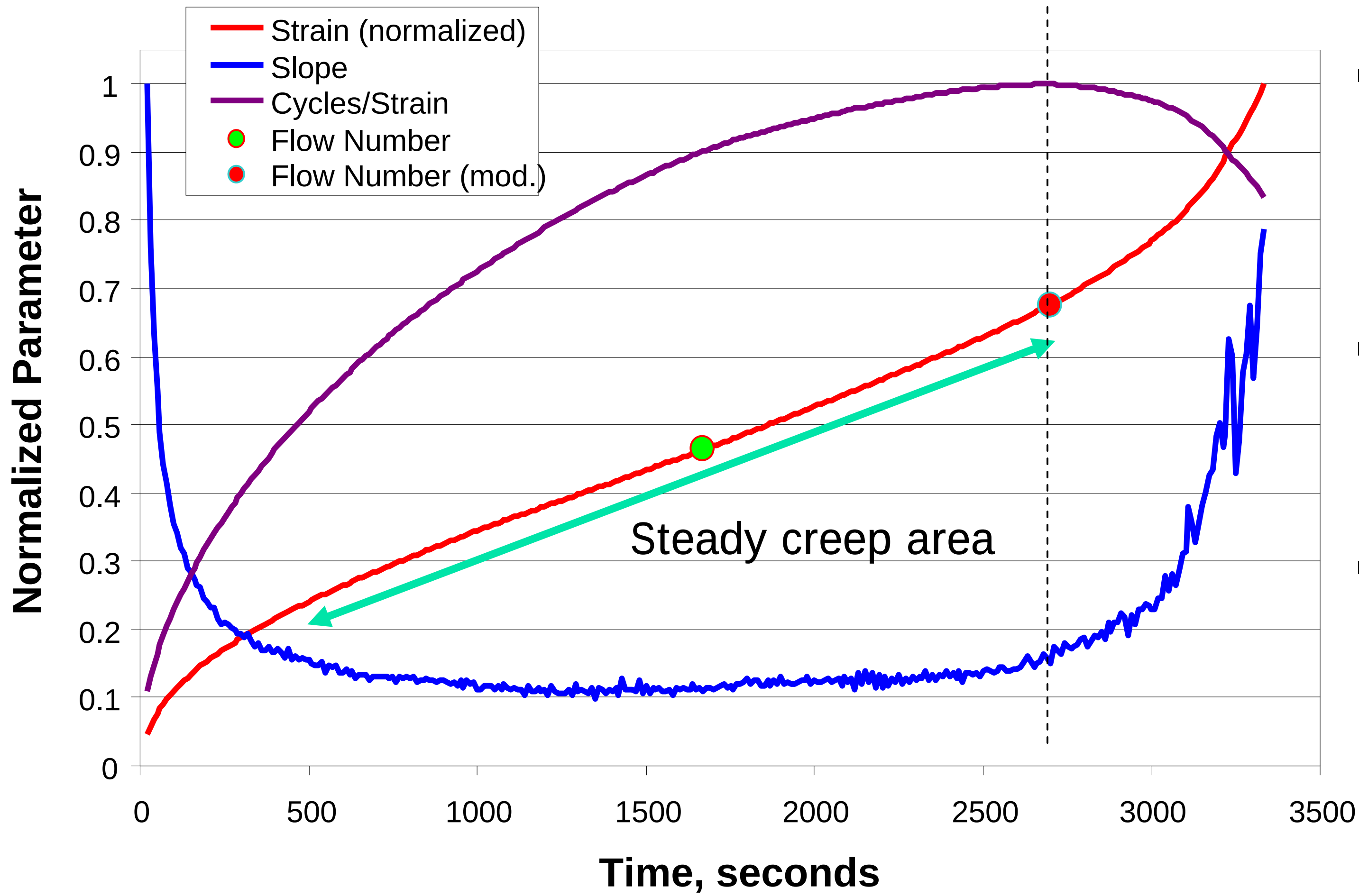
Results from retesting

- In all cases healing overnight increased the stiffness of the mastercurve
- Most significantly – it resulted in the BBR stiffness of the -18^{o}C isotherm being greater than the -12^{o}C isotherm – as expected!
- The “healing” is more significant for the -18^{o}C isotherm

Repeated creep torsion bar

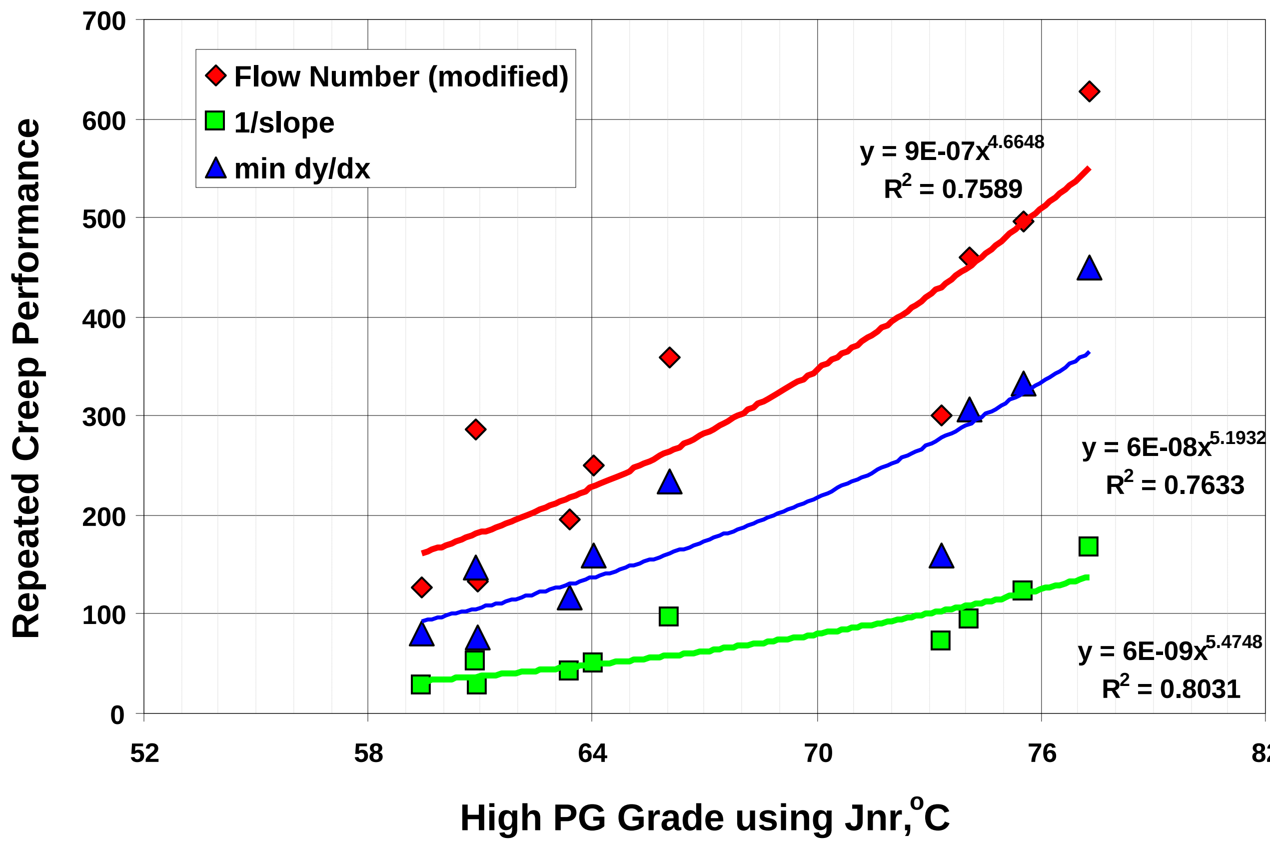
- Tests at two stress levels
  - 34 and 68 kPa
- Temperature = 64^{o}C
- 5 replicates – used results of middle 3
- Analysis of various parameters

Repeated load tests

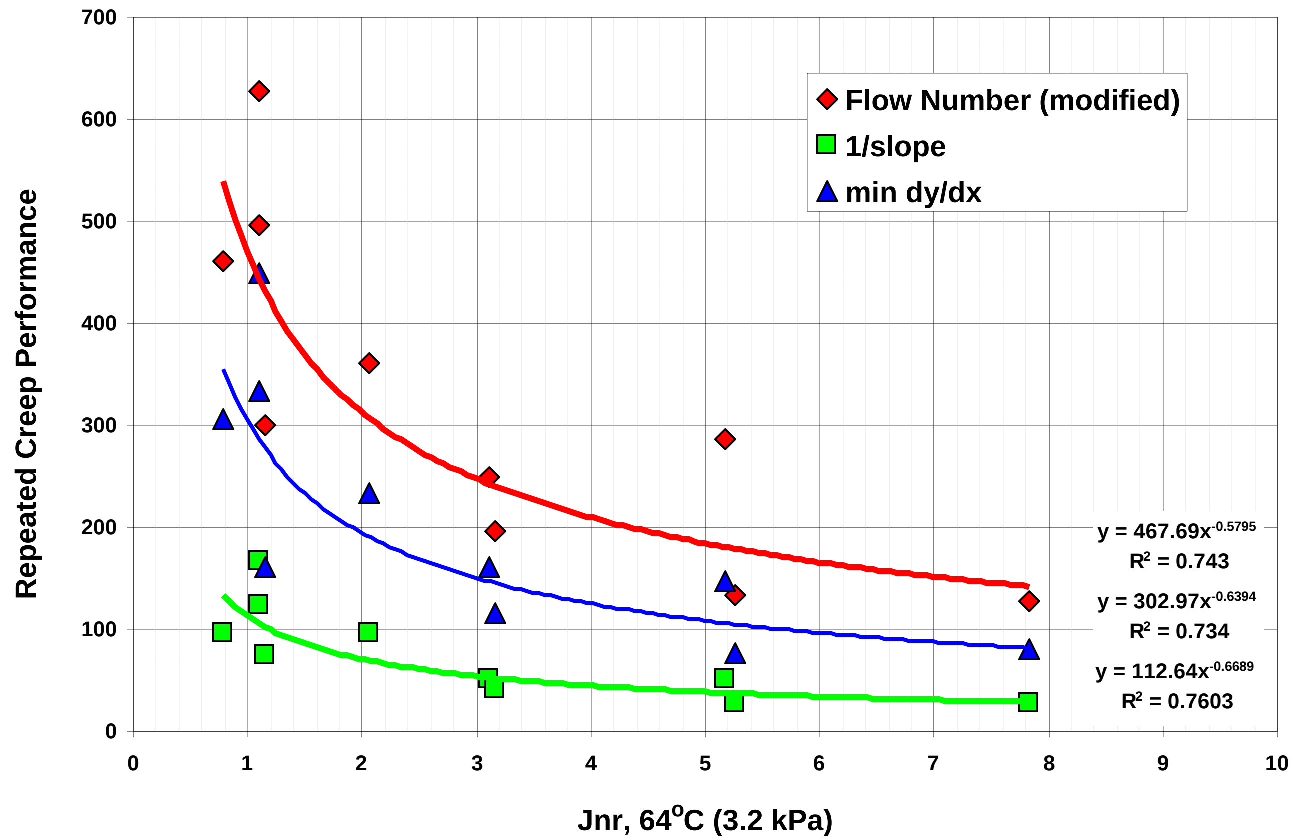


- Concept used in early 1990's with cyclic deformation tests
- Based on same concept as used for fatigue analysis
- Very ease to use to limit test time – stop test at say 5% less than max

Jnr Grade vs. Repeated Creep



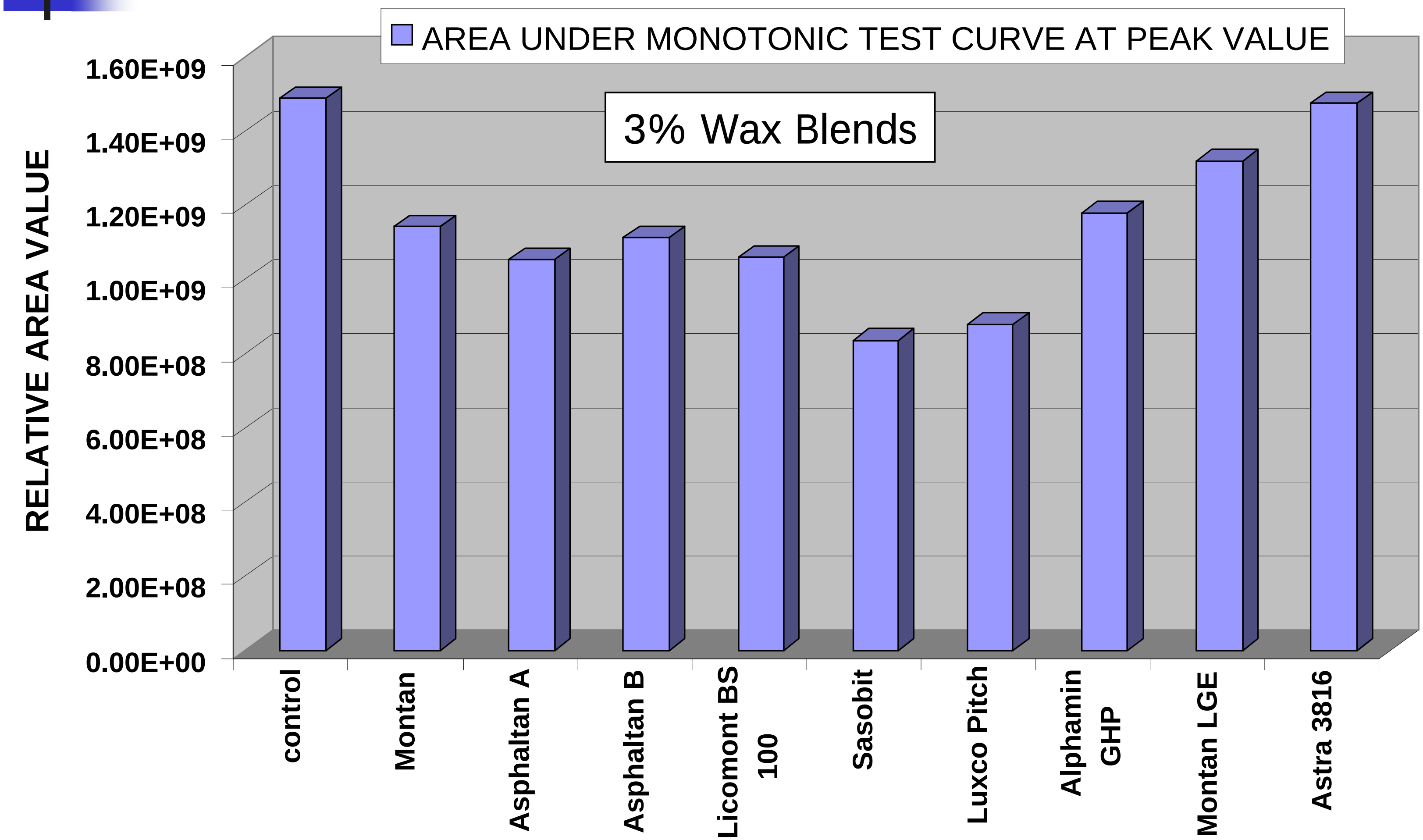
Jnr at 64^{o}C vs. Repeated Creep



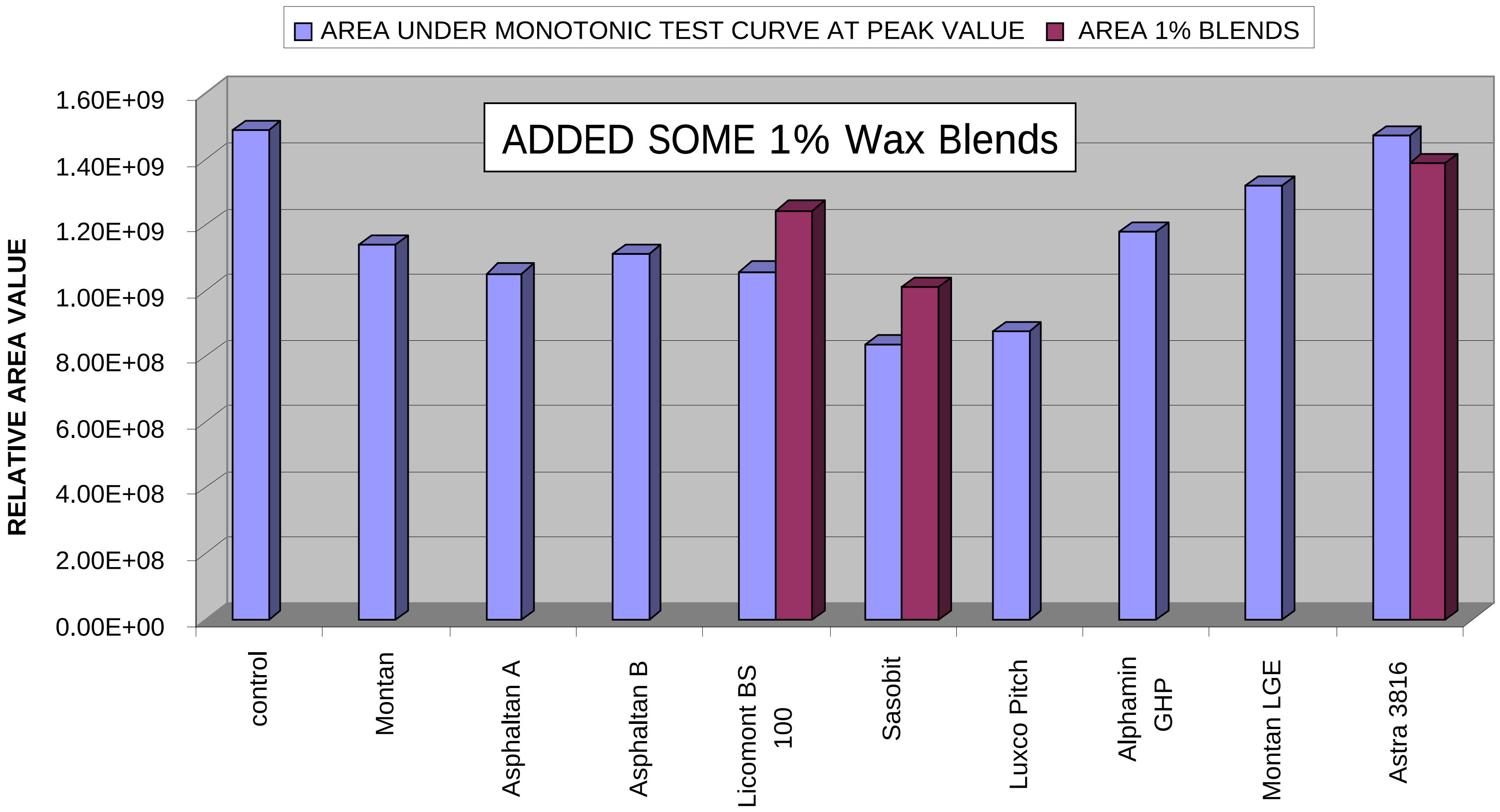
Fatigue

- Work conducted by MTE Services, Inc
- Monotonic loading test
- Sand cylinders repeated loading

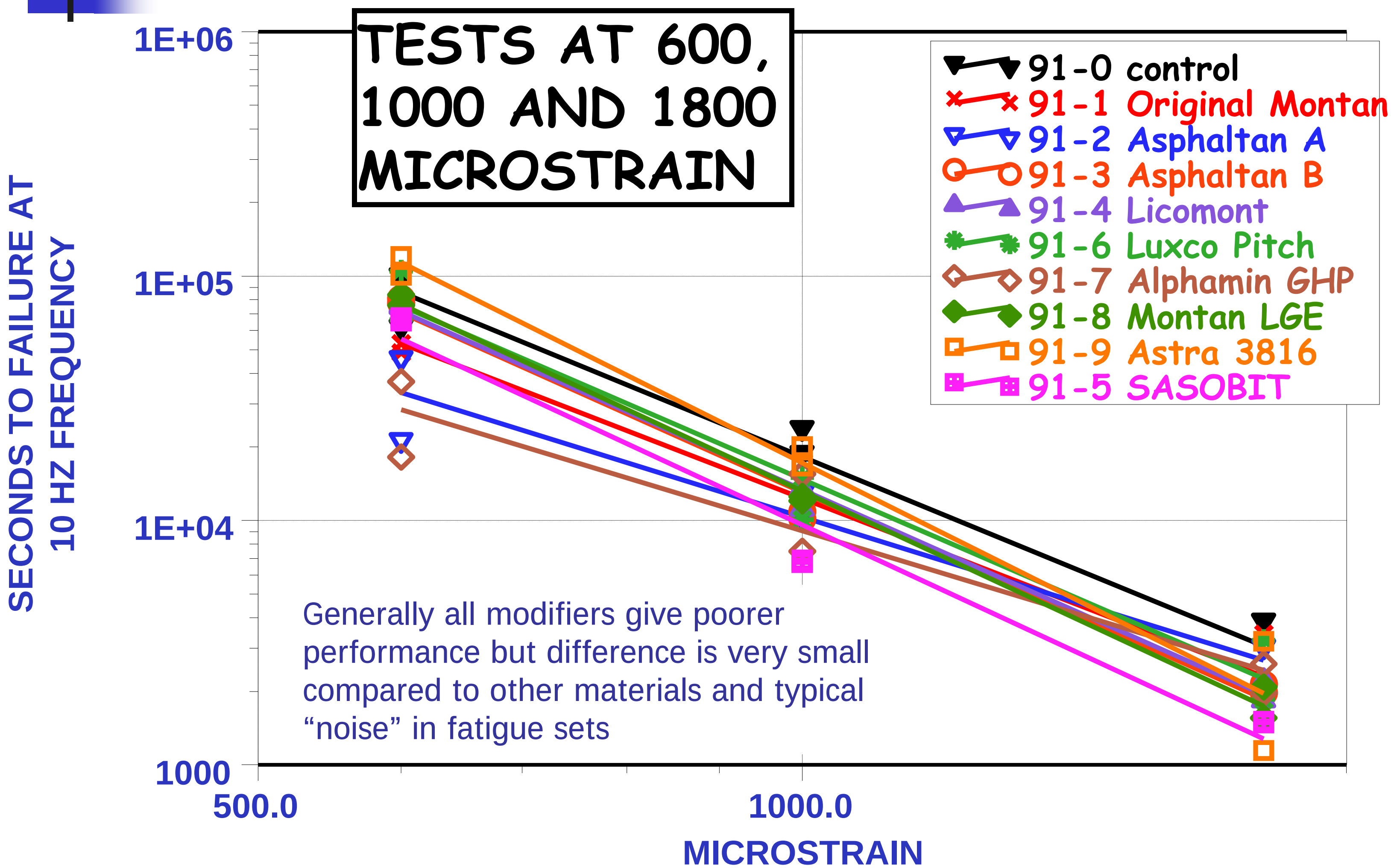
Monotonic tests



Monotonic tests

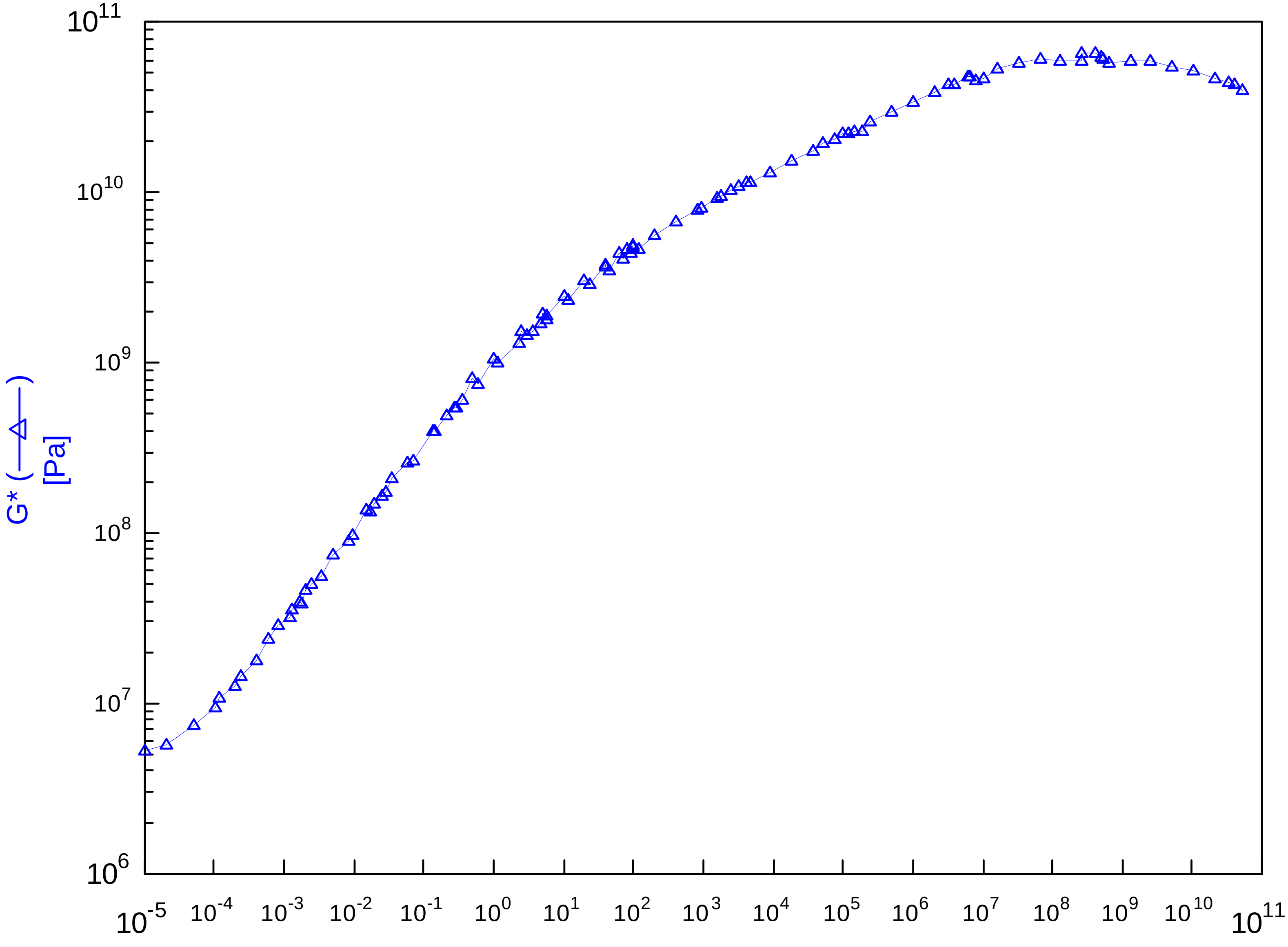


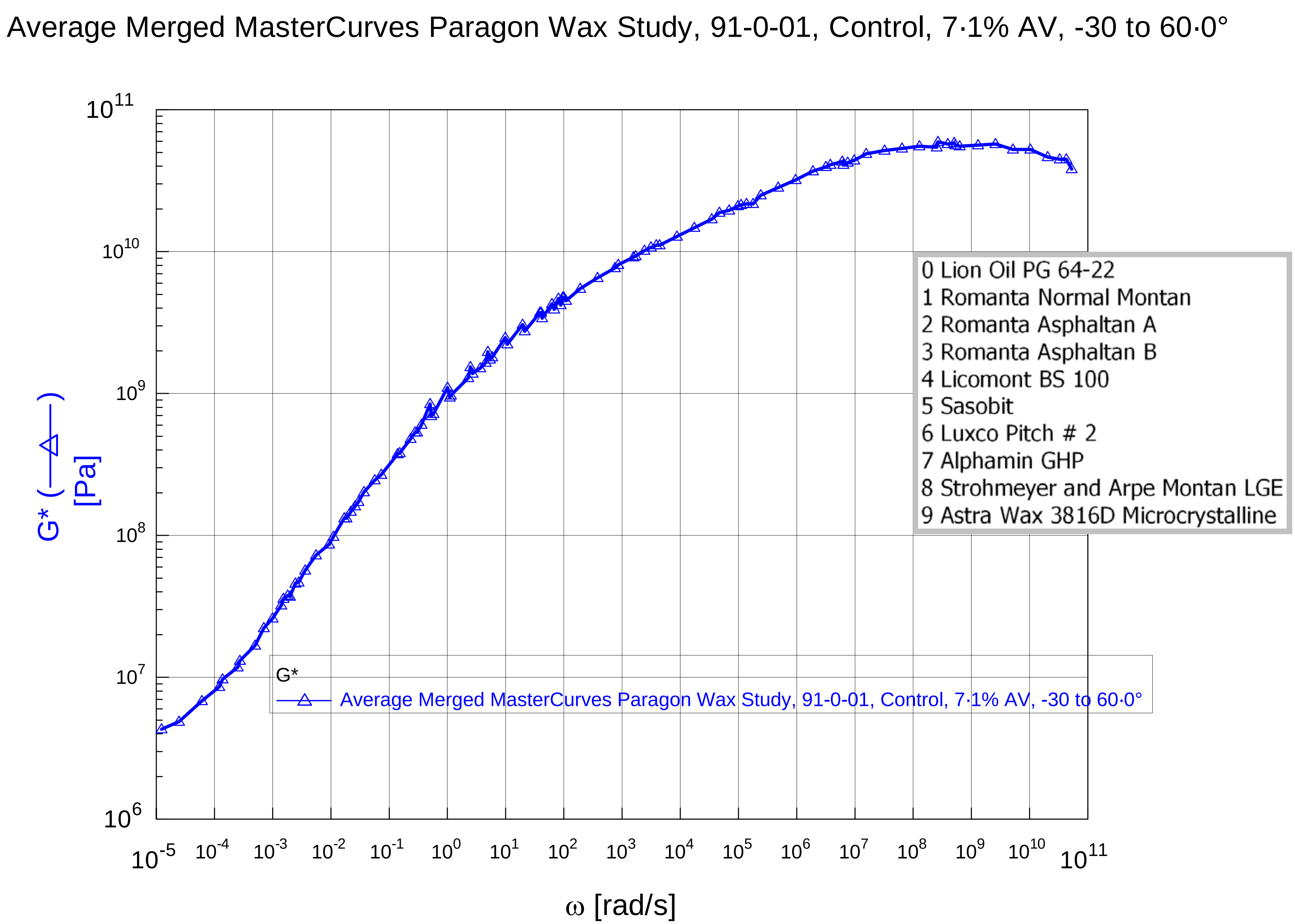
Sand Cylinder Fatigue



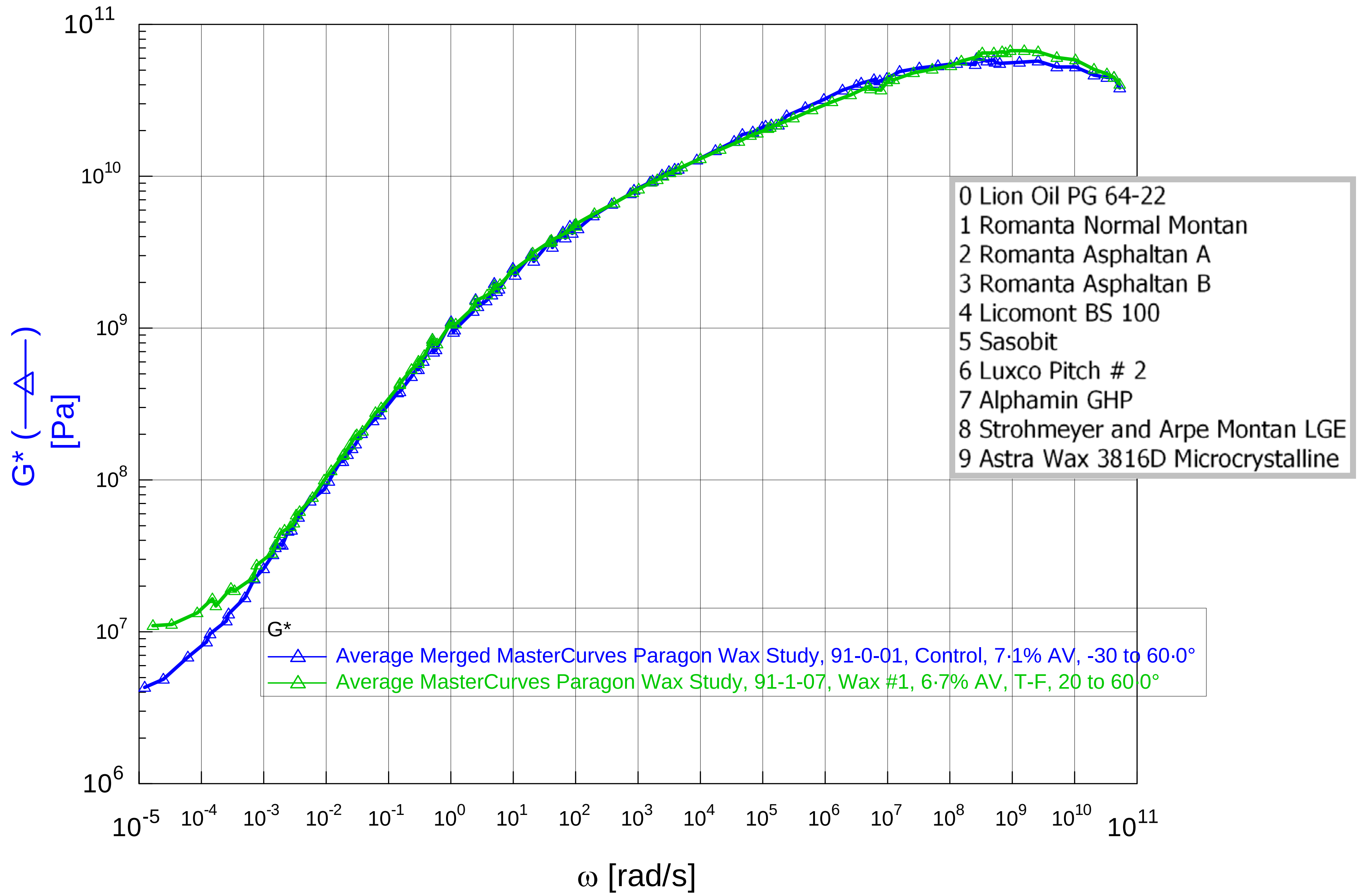
Master curves on sand-mix

Merged MasterCurve Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0° #1

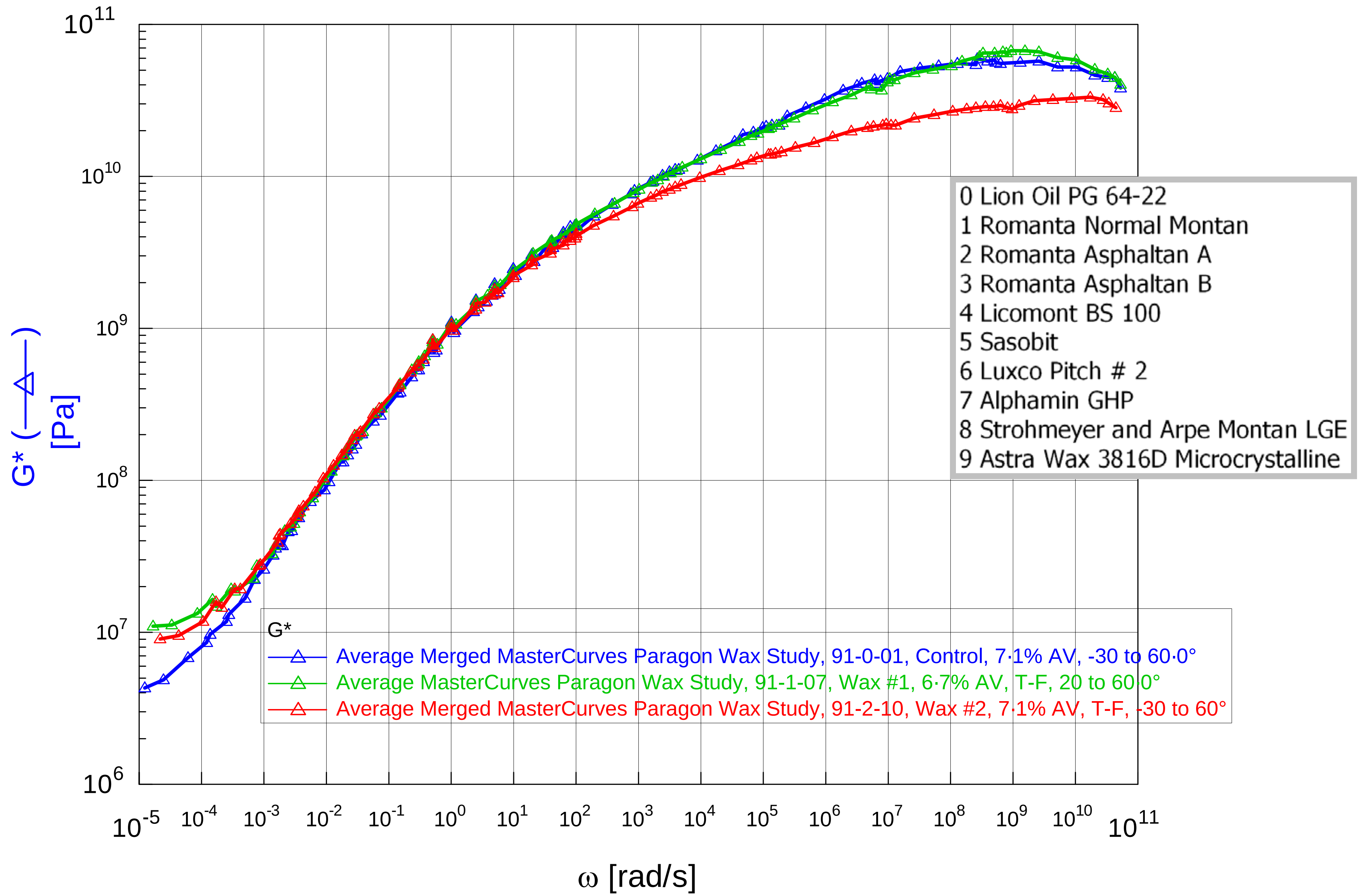


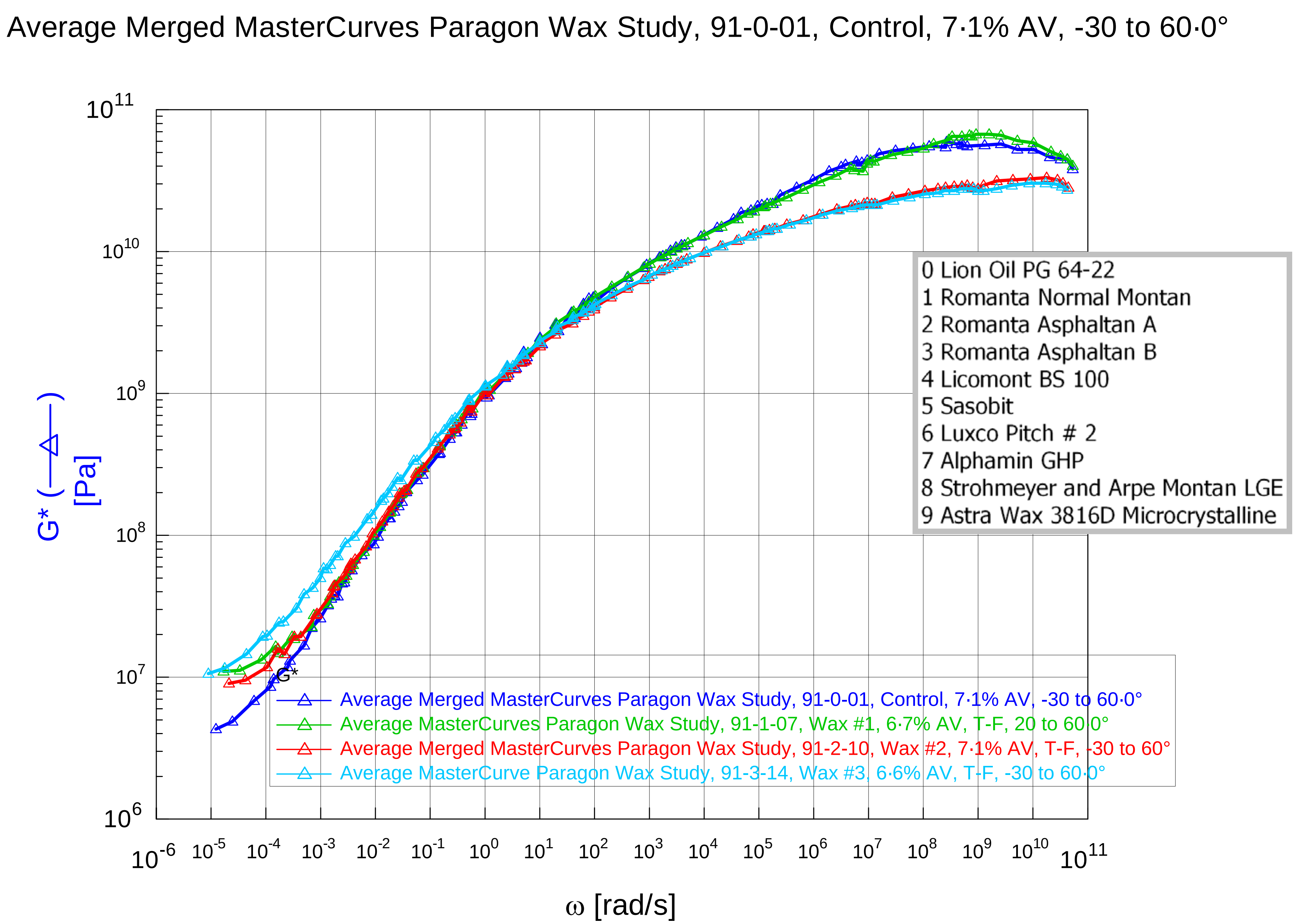

Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°
G* (—△—) [Pa]
ω [rad/s]
0 Lion Oil PG 64-22
1 Romanta Normal Montan
2 Romanta Asphaltan A
3 Romanta Asphaltan B
4 Licomont BS 100
5 Sasobit
6 Luxco Pitch # 2
7 Alphamin GHP
8 Strohmeyer and Arpe Montan LGE
9 Astra Wax 3816D Microcrystalline
G*
Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°

Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°



Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°

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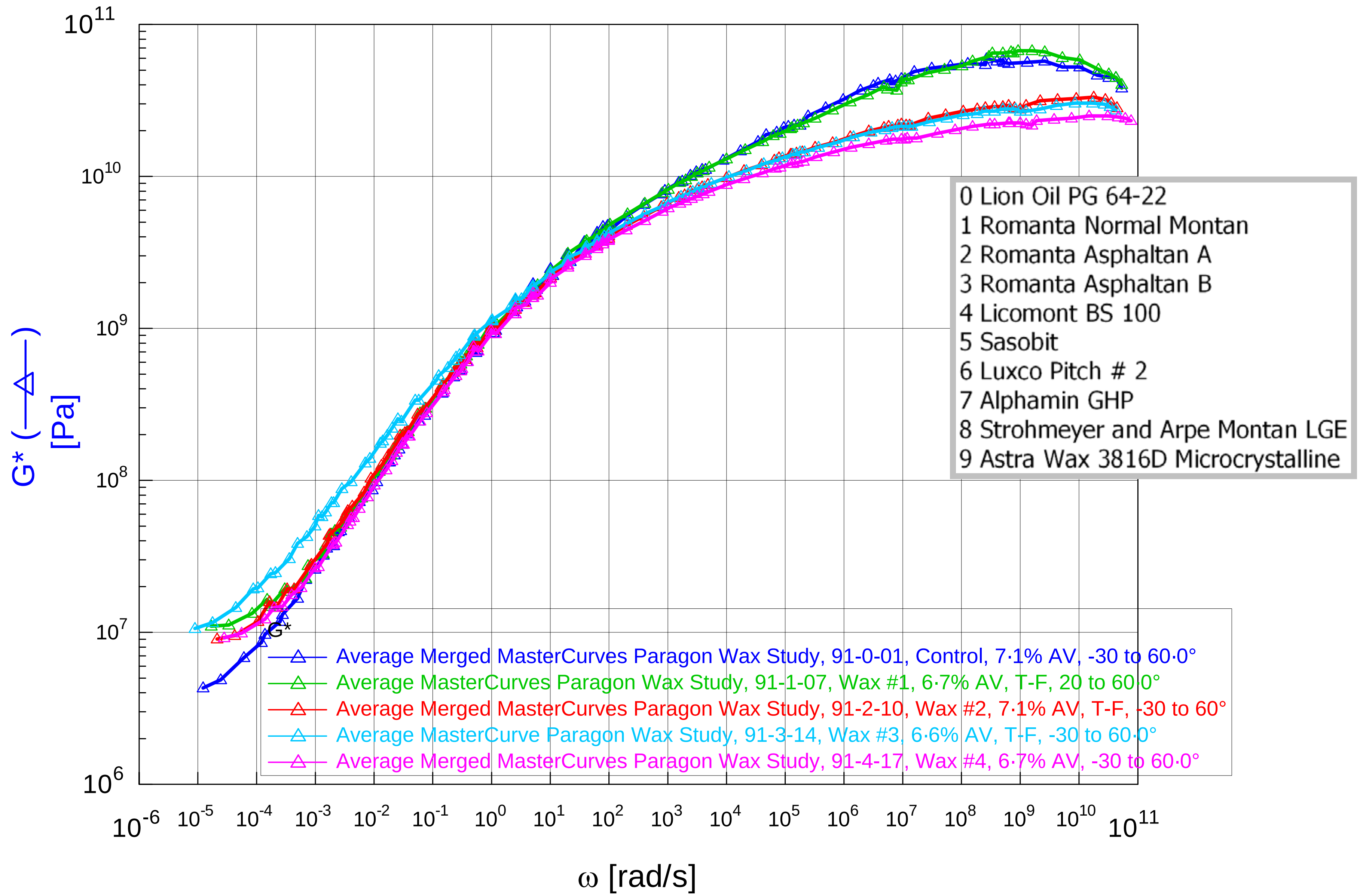
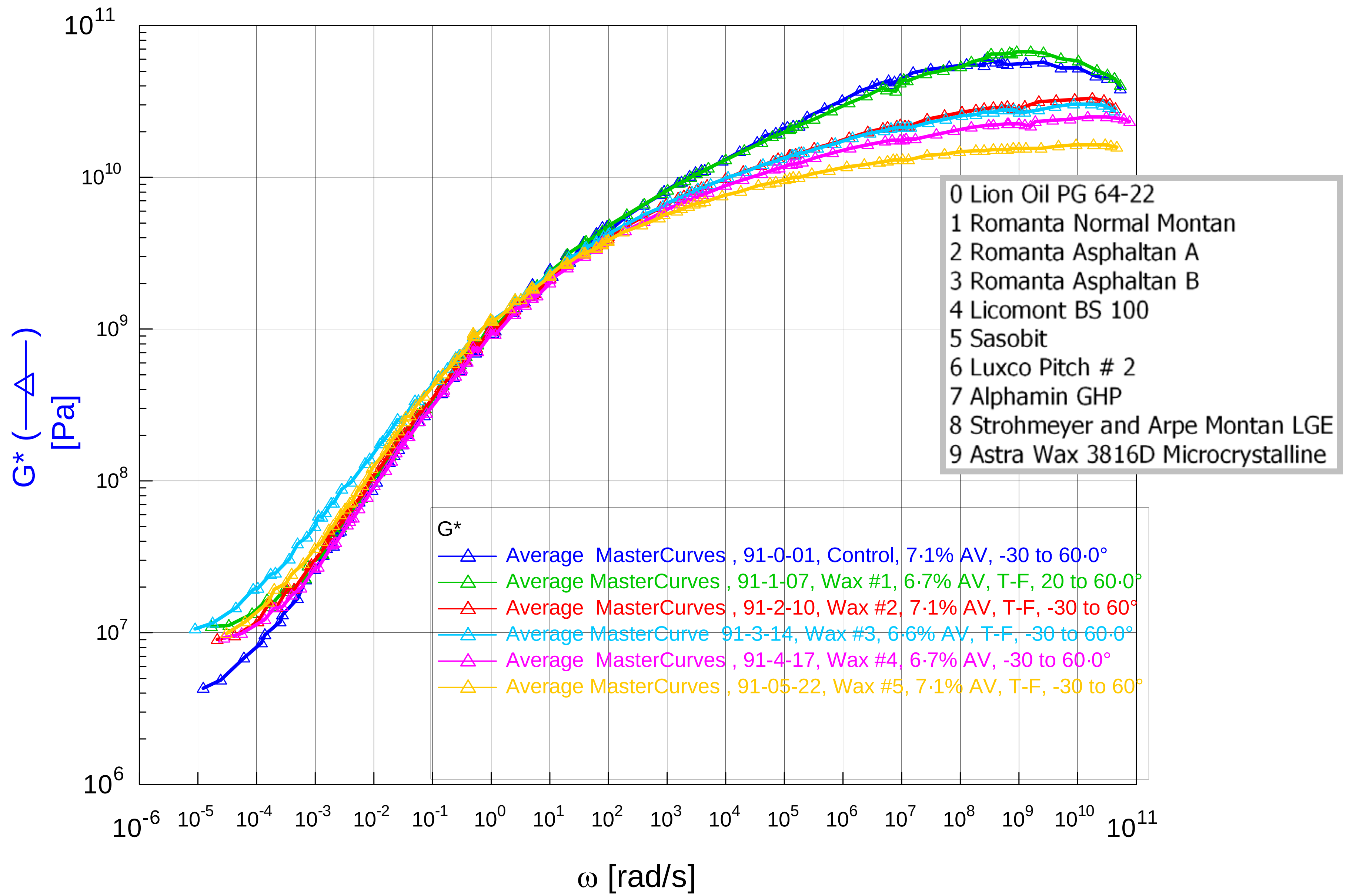
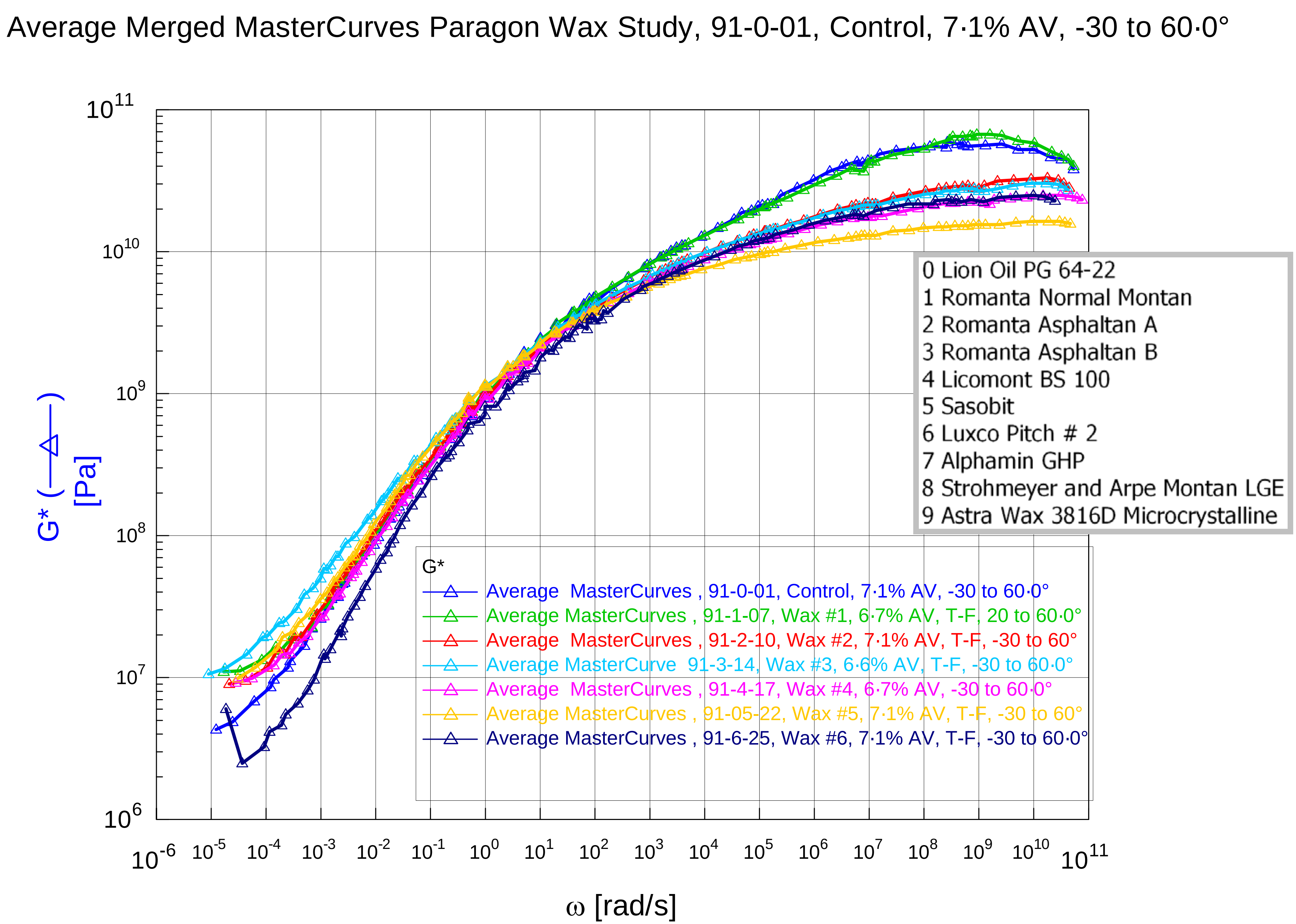
G*
Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°
Average MasterCurves Paragon Wax Study, 91-1-07, Wax #1, 6·7% AV, T-F, 20 to 60·0°
Average Merged MasterCurves Paragon Wax Study, 91-2-10, Wax #2, 7·1% AV, T-F, -30 to 60°
Average MasterCurve Paragon Wax Study, 91-3-14, Wax #3, 6·6% AV, T-F, -30 to 60·0°

Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°



Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°





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G* (—△—) [Pa]
ω [rad/s]
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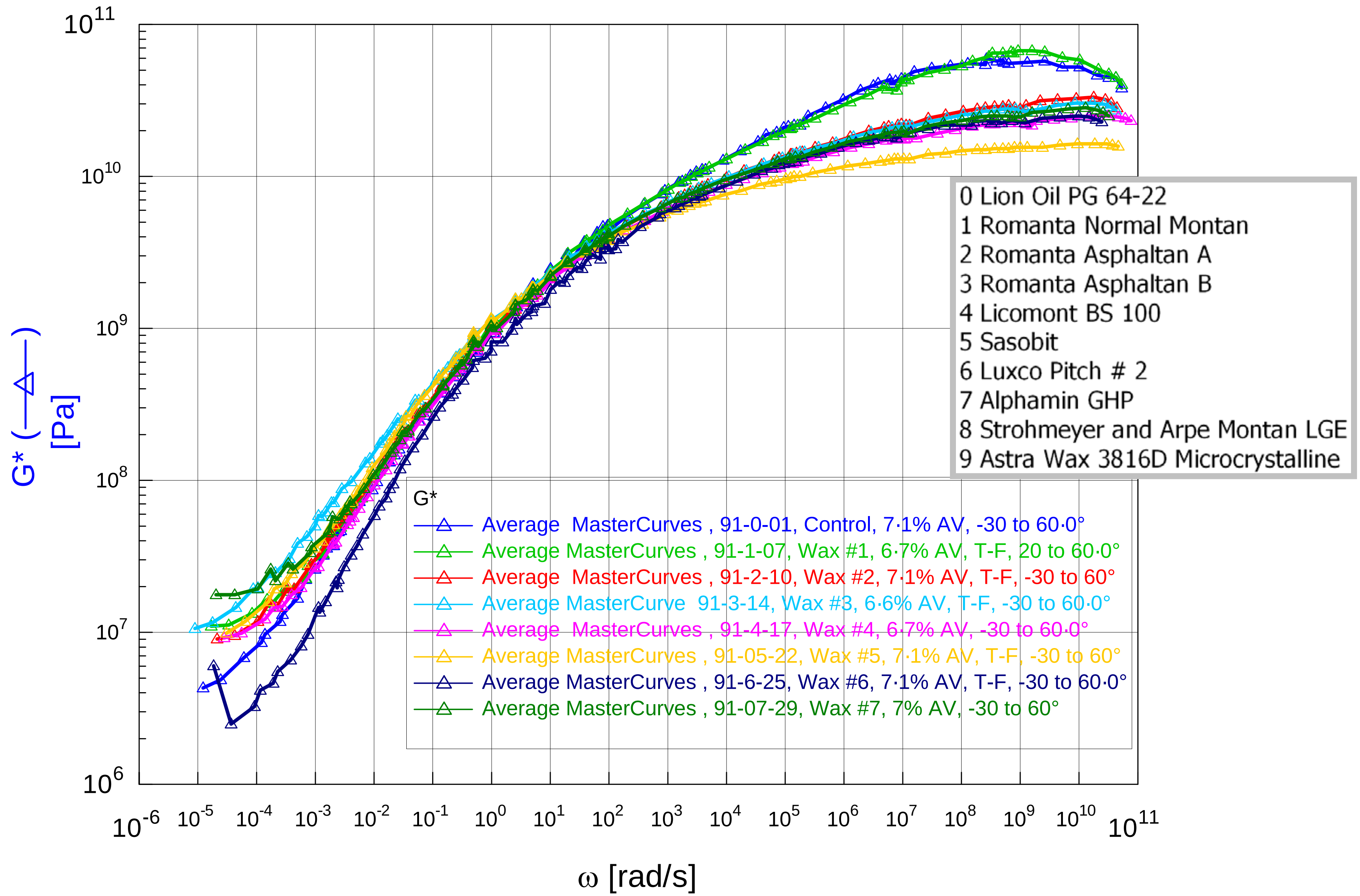
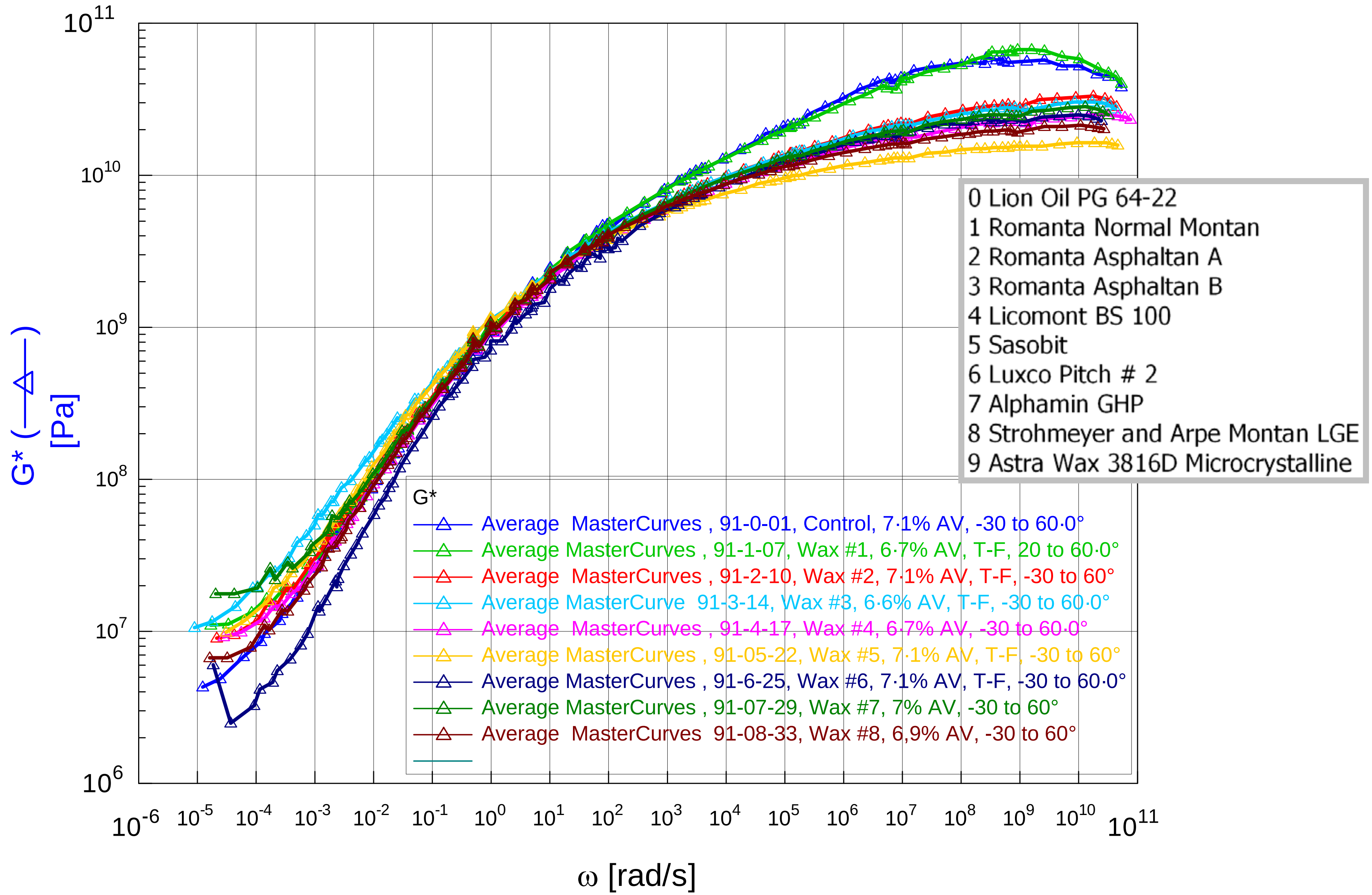
6 Luxco Pitch # 2
7 Alphamin GHP
8 Strohmeyer and Arpe Montan LGE
9 Astra Wax 3816D Microcrystalline
G*
Average MasterCurves , 91-0-01, Control, 7·1% AV, -30 to 60·0°
Average MasterCurves , 91-1-07, Wax #1, 6·7% AV, T-F, 20 to 60·0°
Average MasterCurves , 91-2-10, Wax #2, 7·1% AV, T-F, -30 to 60°
Average MasterCurve 91-3-14, Wax #3, 6·6% AV, T-F, -30 to 60·0°
Average MasterCurves , 91-4-17, Wax #4, 6·7% AV, -30 to 60·0°
Average MasterCurves , 91-05-22, Wax #5, 7·1% AV, T-F, -30 to 60°
Average MasterCurves , 91-6-25, Wax #6, 7·1% AV, T-F, -30 to 60·0°

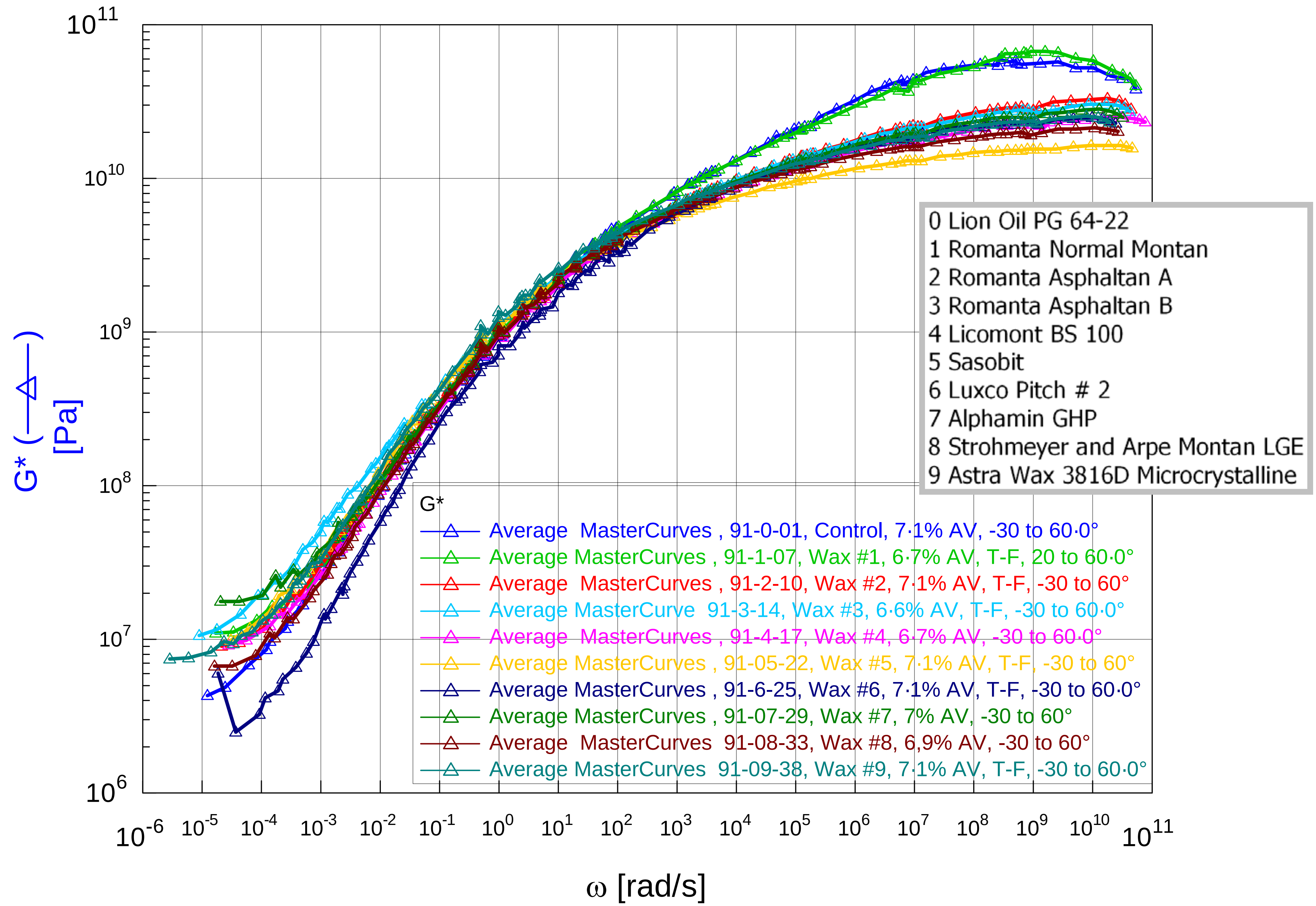
Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°



Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°



Average Merged MasterCurves Paragon Wax Study, 91-0-01, Control, 7·1% AV, -30 to 60·0°



Summary – Binder tests

- Significant differences in PG grades with different modifiers
  - All had some loss of performance at low end of specification
- Master curves show different structures in binder – note low strain level
- Jnr – results show that binder is stress sensitive
  - Wax products generally vary more with stress level
  - Have apparently good behavior at low stress levels
  - As stress level increases performance drops
  - The wax materials are a non-elastic modifier
    - Note δ can confuse the analysis such as used in some specifications
- Aging of BBR binder beams over extended time shows significant change in properties
  - Data at -12C was more in line with that expected
  - Data at -18C appears to be confounded

Summary – mix tests

- BBR
  - Avoid using early part of isotherm
  - Issues with -18C data after extended aging
  - Some damage/healing evident in data
  - Annealing at 64C showed that rankings could be restored to that expected
  - -18C is poorer than -12C data
- Repeated creep
  - Data lines up with Jnr results
  - Some suggestions for data analysis
- Fatigue
  - Monotonic tests show difference in performance
  - Preliminary – 1% and 3% wax show some different results
  - Repeated loading shows again significant differences – all waxes generally give lower performance but difference is small
- Master curves
  - Differences evident in G* master curves
  - Should be able to look at these combined with BBR master curves

What to do

- More work with 1% wax content
- Some additional analysis of data
  - Maybe combine G* and S(t) master curves for mix to look at trends – do they match binder?
- DTT with notched specimens
- Develop report

Questions, comments and discussion – please !!??