November 13, 2009

# RAP Plant Mix Study Progress Report

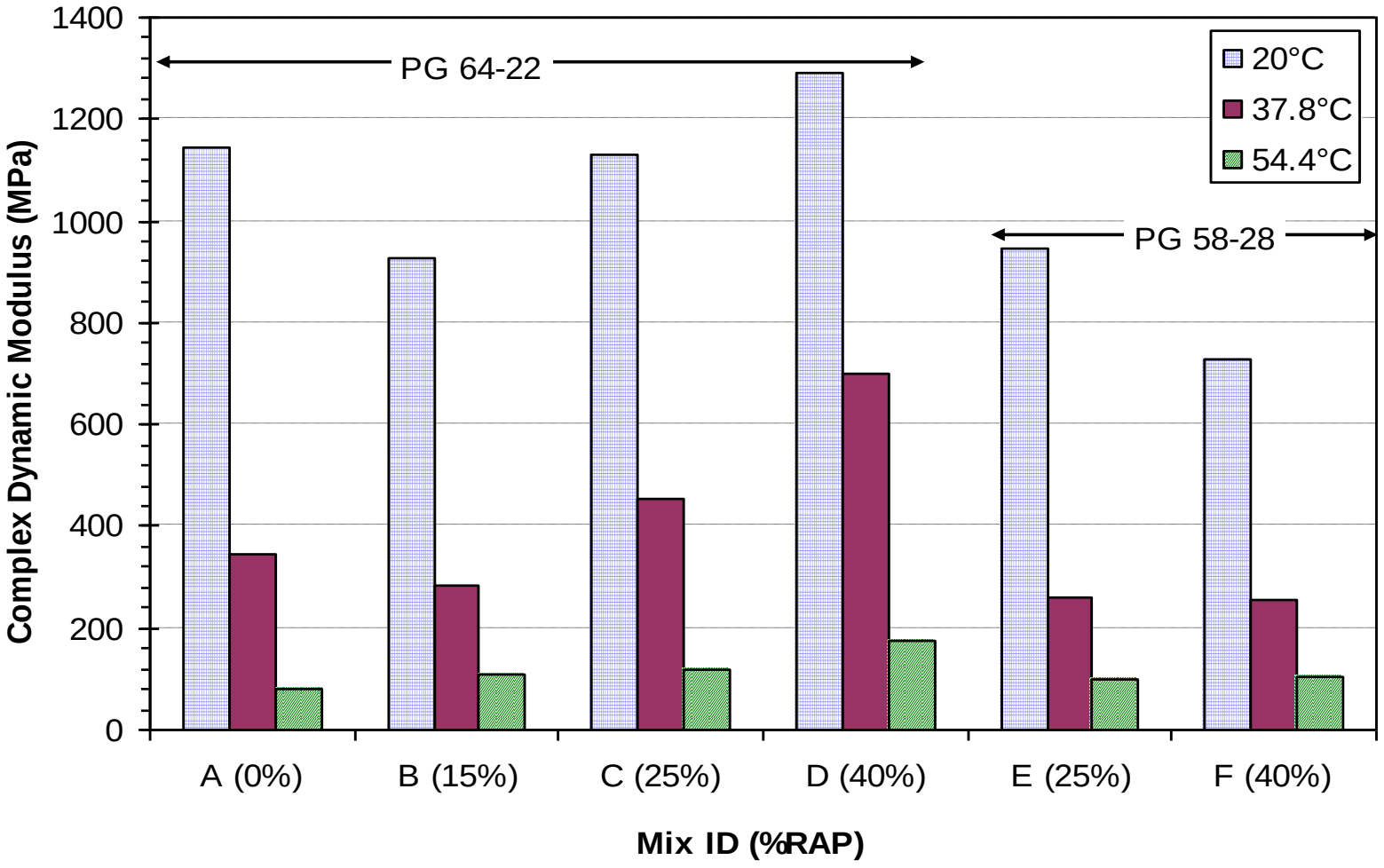
# Outline

- Review of Phase I
- Review of Work Plan
- Summary of Results
- Discuss Potential Recommendations

# Experimental Design

| | Reclaimed Asphalt Pavement | | | |
|---|---|---|---|---|
| Binder Grade | 0% | 15% | 25% | 40% |
| PG 58-28 | | | X | X |
| PG 64-22 | X | X | X | X |

# Phase 1 Data


1400
1200
1000
800
600
400
200
0
Complex Dynamic Modulus (MPa)
PG 64-22
PG 58-28
20°C
37.8°C
54.4°C
A (0%)
B (15%)
C (25%)
D (40%)
E (25%)
F (40%)
Mix ID (%RAP)

# Critical Cracking Temperatures

| Mix | RAP Content | Tc (°C) |
|---|---|---|
| A – PG64-22 | 0 | -28.9 |
| B – PG64-22 | 15 | -23.3 |
| C – PG64-22 | 25 | -25.6 |
| D – PG64-22 | 40 | -22.8 |
| E – PG58-28 | 25 | -27.2 |
| F – PG58-28 | 40 | -23.9 |

# 2006 Results

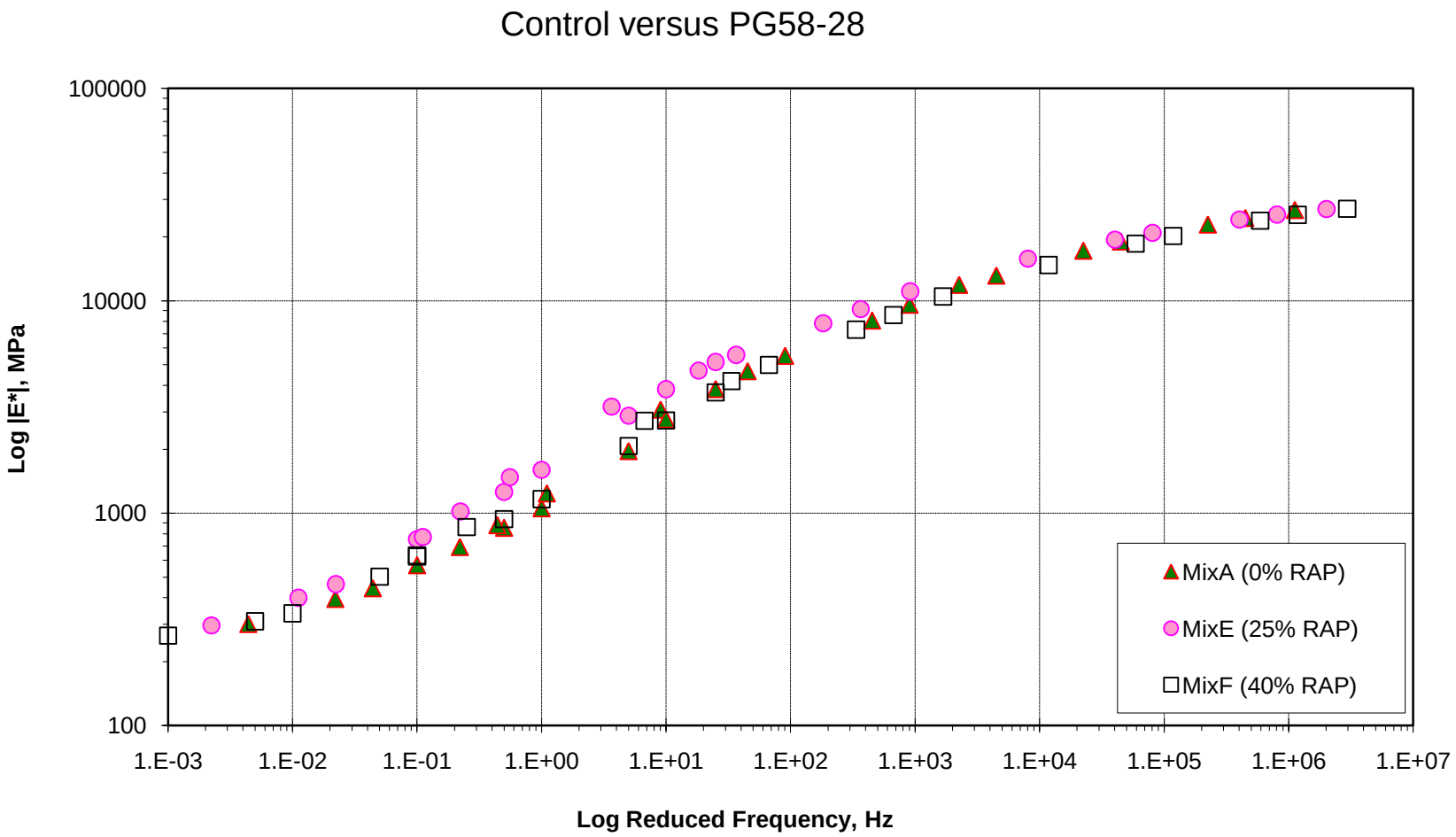
- For these materials and this plant, the RAP mixes were not as stiff as expected.
- The binder did not stiffen linearly with increasing RAP content.
- In this case, dropping the virgin grade to PG58-28 for 25% RAP was not necessary.

# Tests (being) Conducted

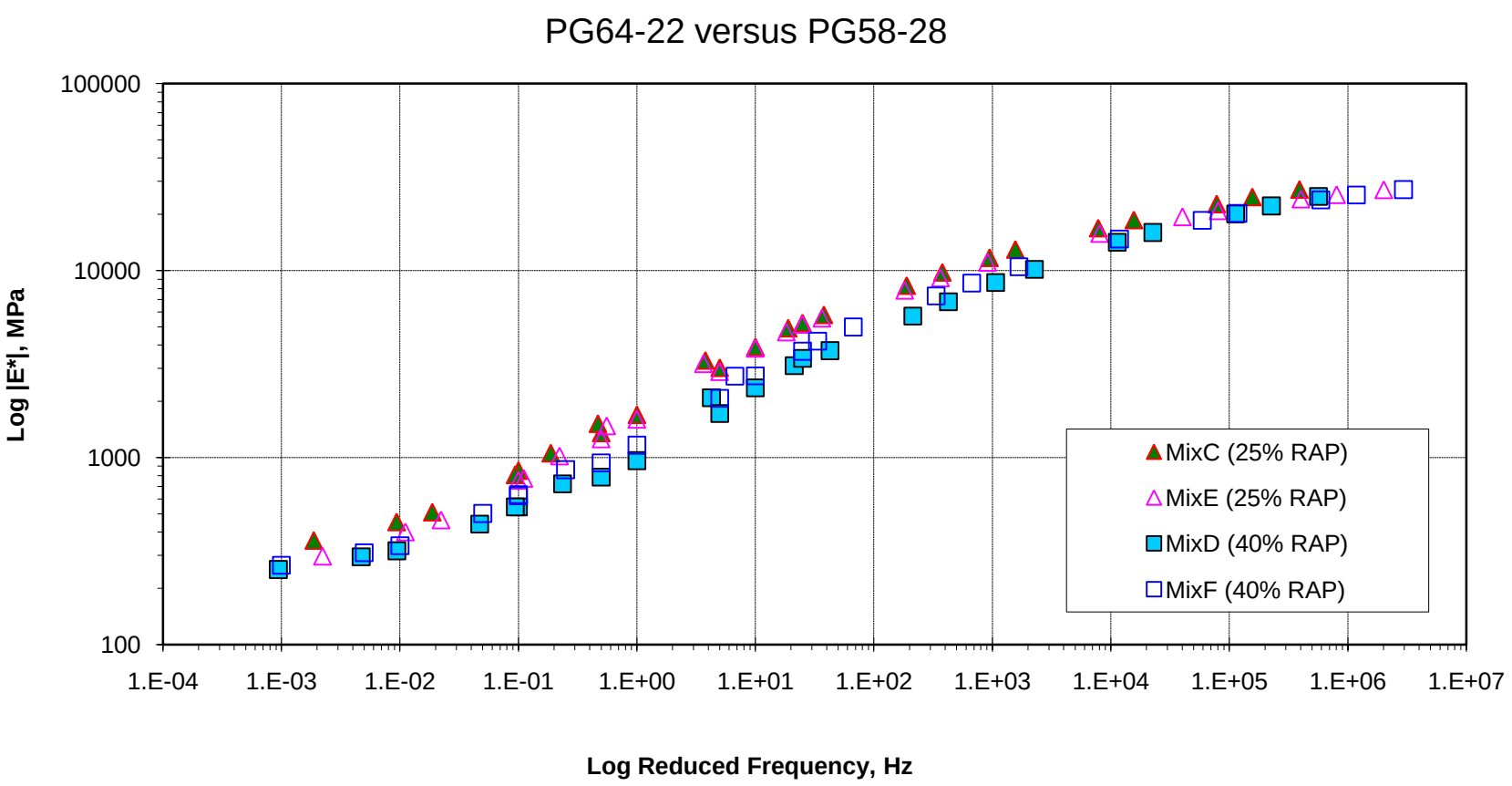
- Dynamic Modulus |E*|
  - High and intermediate modulus, blending
- Indirect Tension
  - Low temperature
- Binder extraction/recovery and PG grade
  - Blending analysis
- Fatigue Testing – at FHWA TFHRC
  - Samples delivered November 19, 2008

# Phase 2 Results

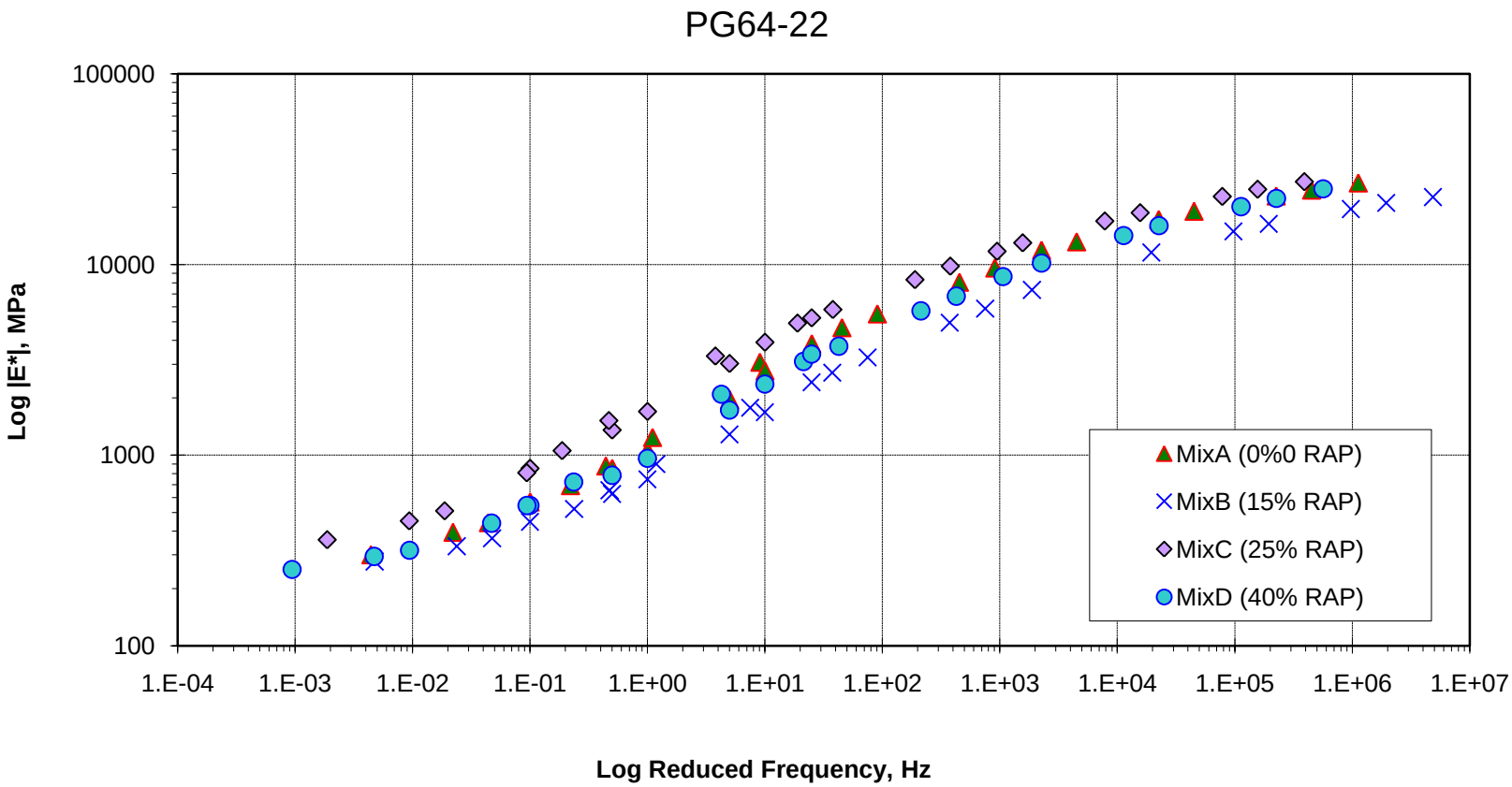
# E&B Mix |E*|


Control versus PG58-28
100000
10000
1000
100
Log |E*|, MPa
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Log Reduced Frequency, Hz
MixA (0% RAP)
MixE (25% RAP)
MixF (40% RAP)

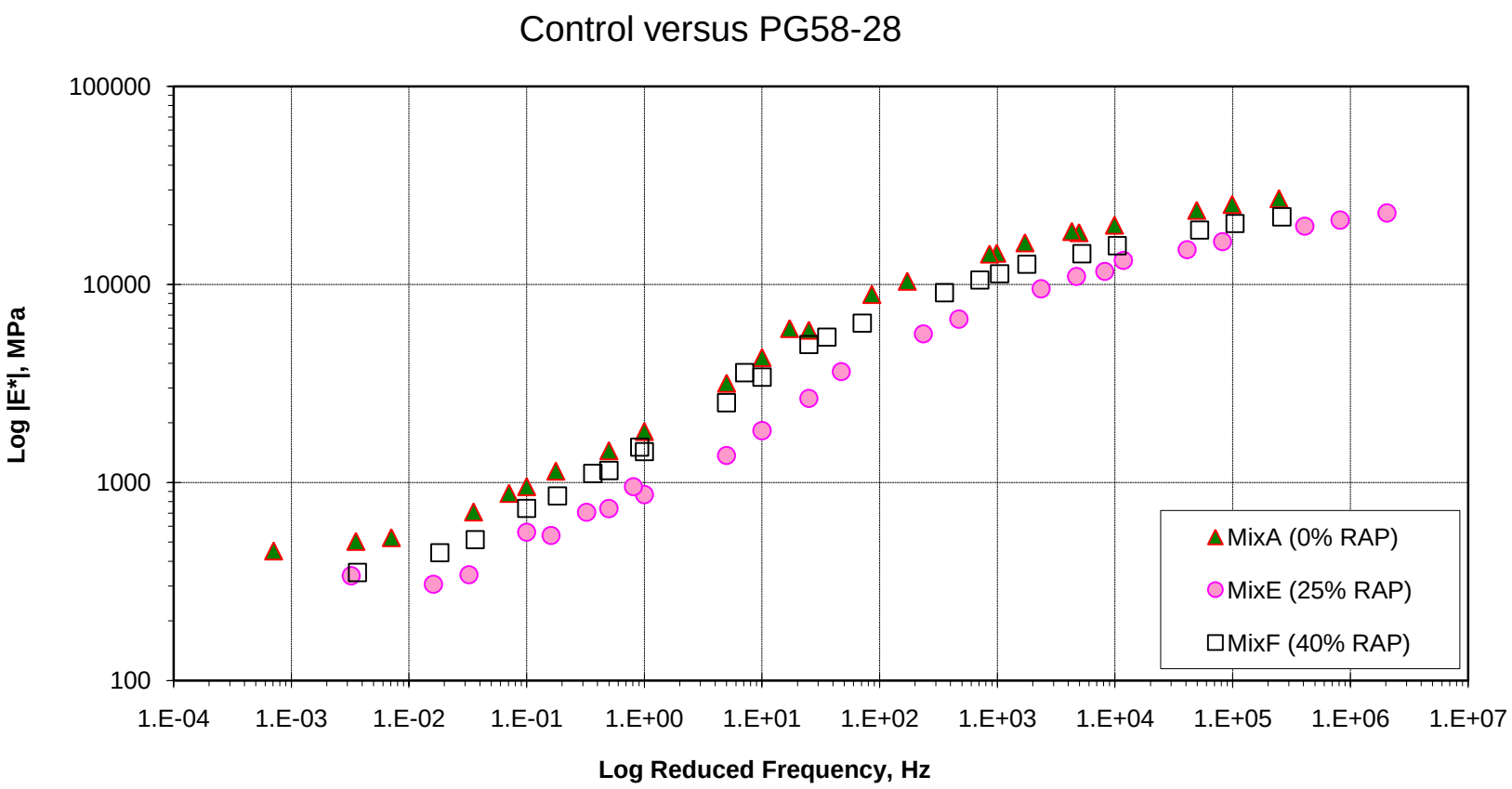
# E&B Mix |E*|


PG64-22 versus PG58-28
100000
10000
1000
100
Log |E*|, MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Log Reduced Frequency, Hz
MixC (25% RAP)
MixE (25% RAP)
MixD (40% RAP)
MixF (40% RAP)

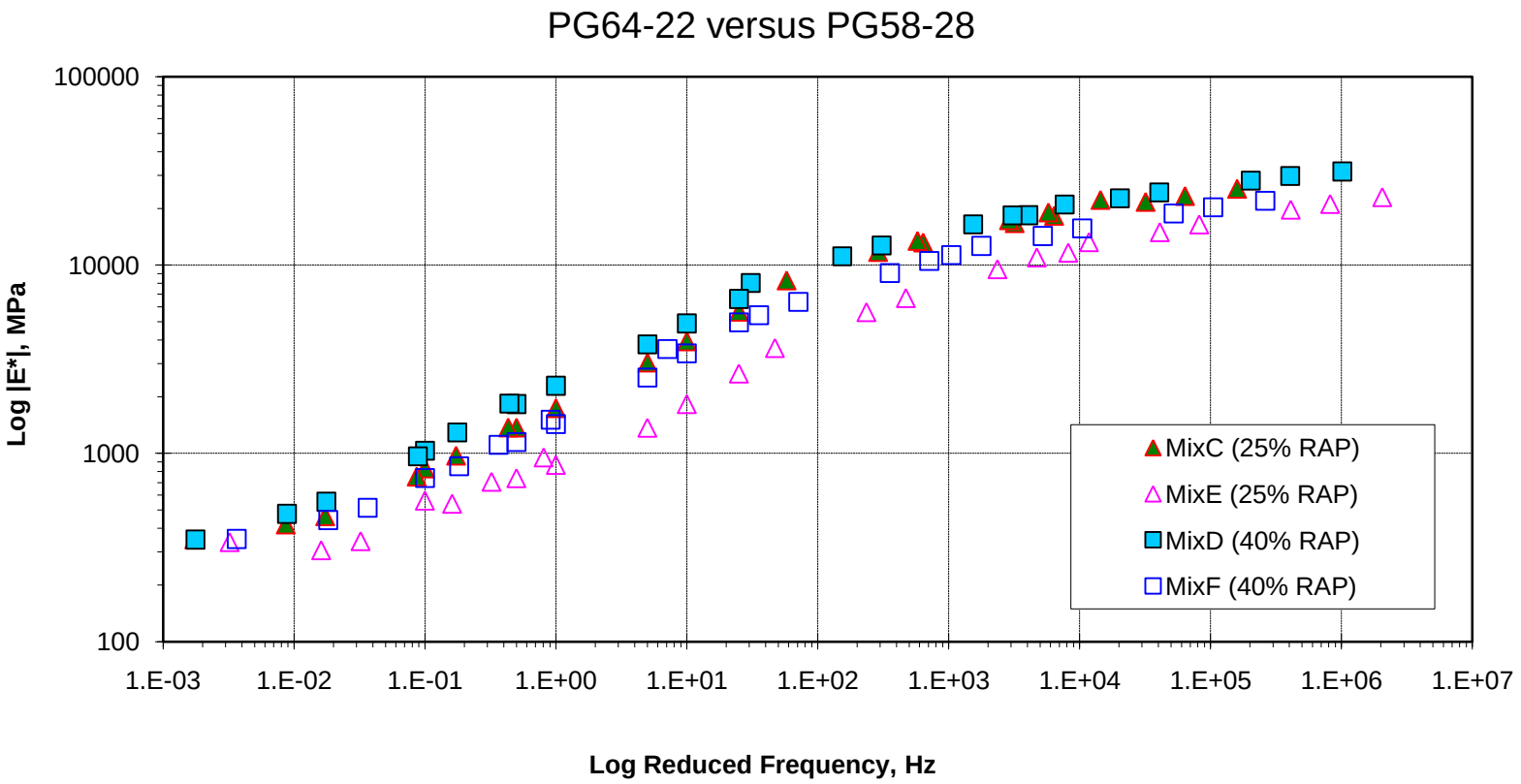
# E&B Mix |E*|


PG64-22
100000
10000
1000
100
Log |E*|, MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Log Reduced Frequency, Hz
MixA (0%0 RAP)
MixB (15% RAP)
MixC (25% RAP)
MixD (40% RAP)

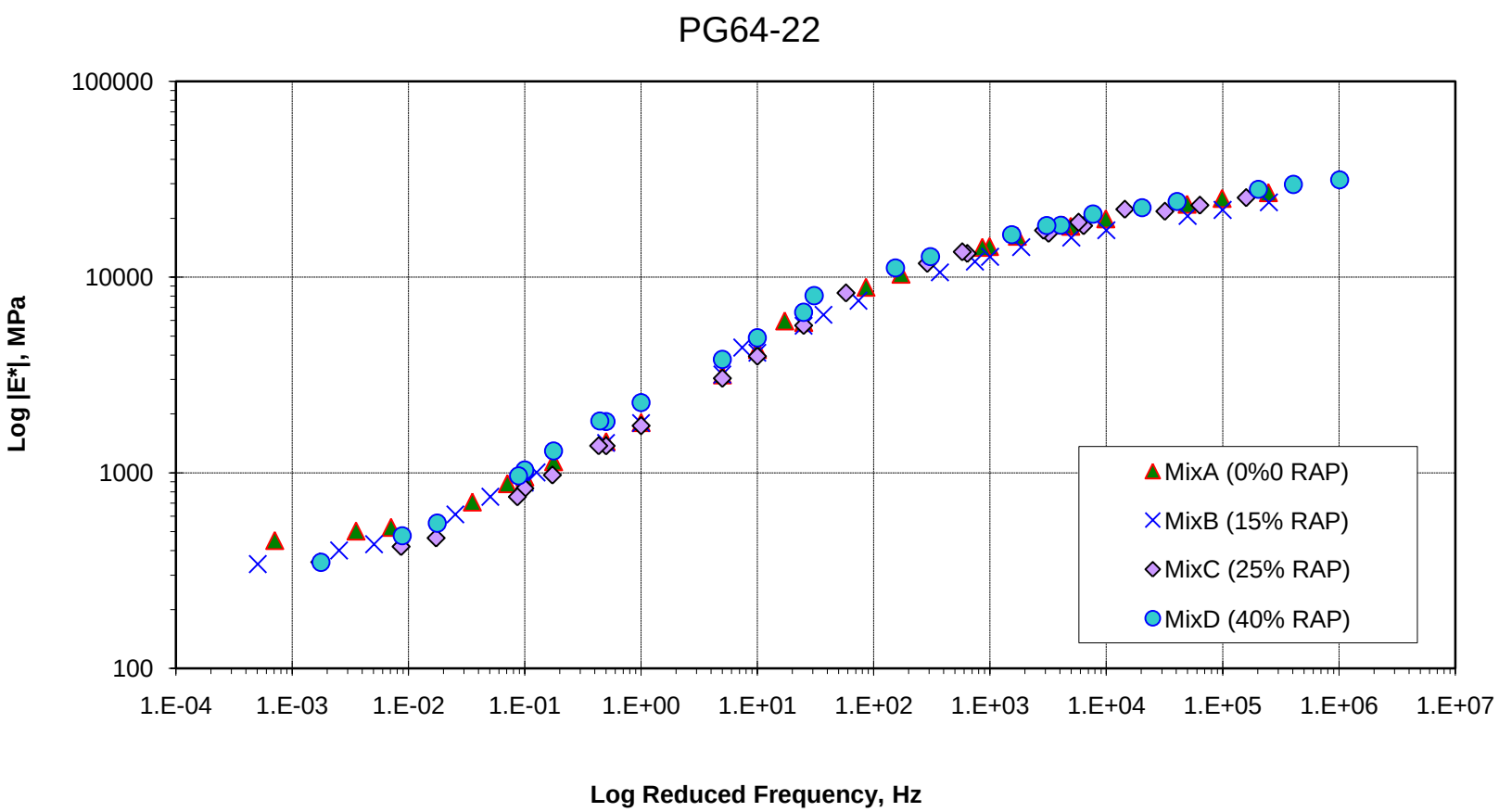
# JHR Mix |E*|


Control versus PG58-28
100000
10000
1000
100
Log |E*|, MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Log Reduced Frequency, Hz
MixA (0% RAP)
MixE (25% RAP)
MixF (40% RAP)

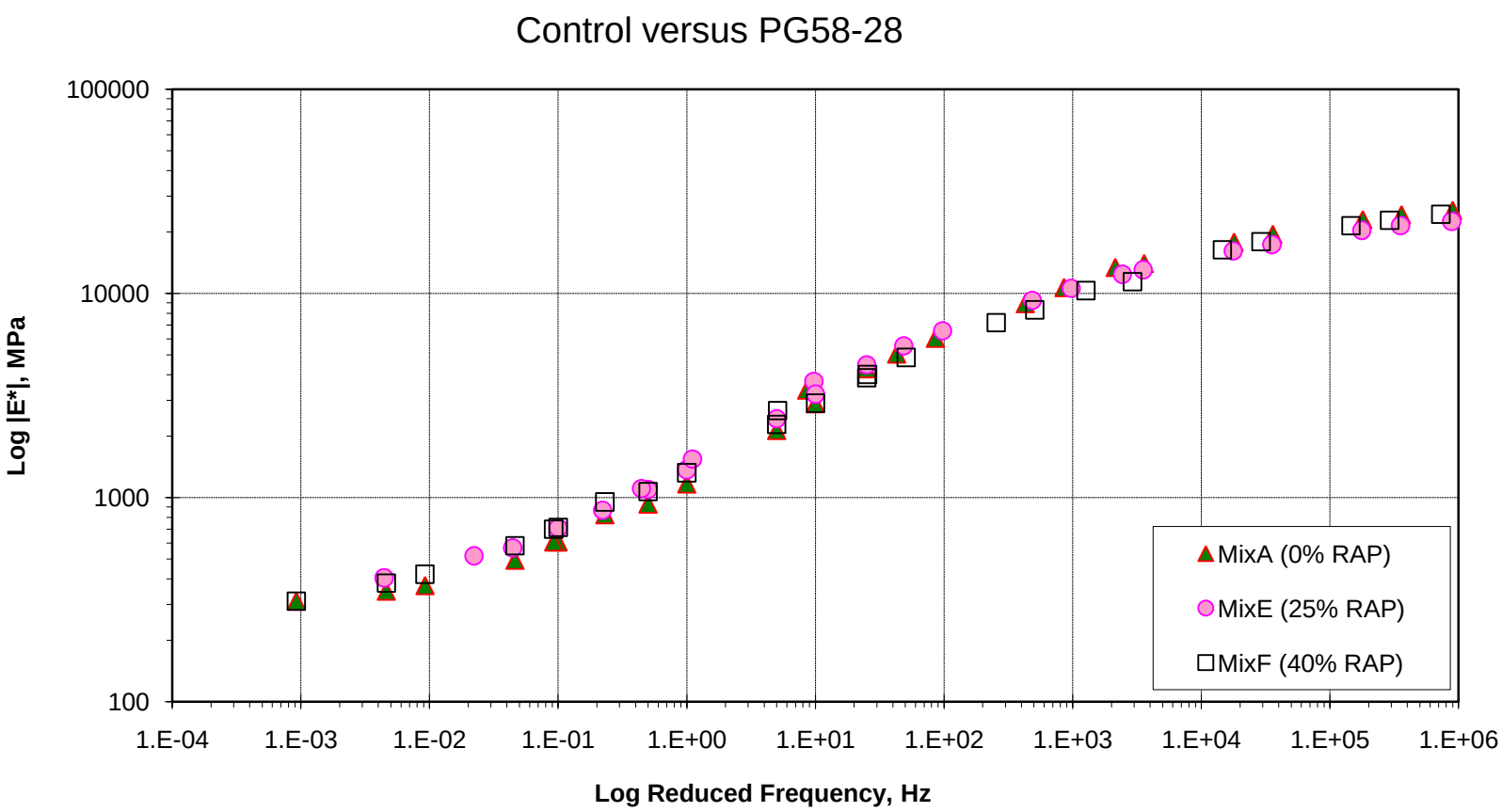
# JHR Mix |E*|


PG64-22 versus PG58-28
Log |E*|, MPa
100000
10000
1000
100
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Log Reduced Frequency, Hz
MixC (25% RAP)
MixE (25% RAP)
MixD (40% RAP)
MixF (40% RAP)

# JHR Mix |E*|


PG64-22
100000
10000
1000
100
Log |E*|, MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Log Reduced Frequency, Hz
MixA (0%0 RAP)
MixB (15% RAP)
MixC (25% RAP)
MixD (40% RAP)

# P&B Mix |E*|


Control versus PG58-28
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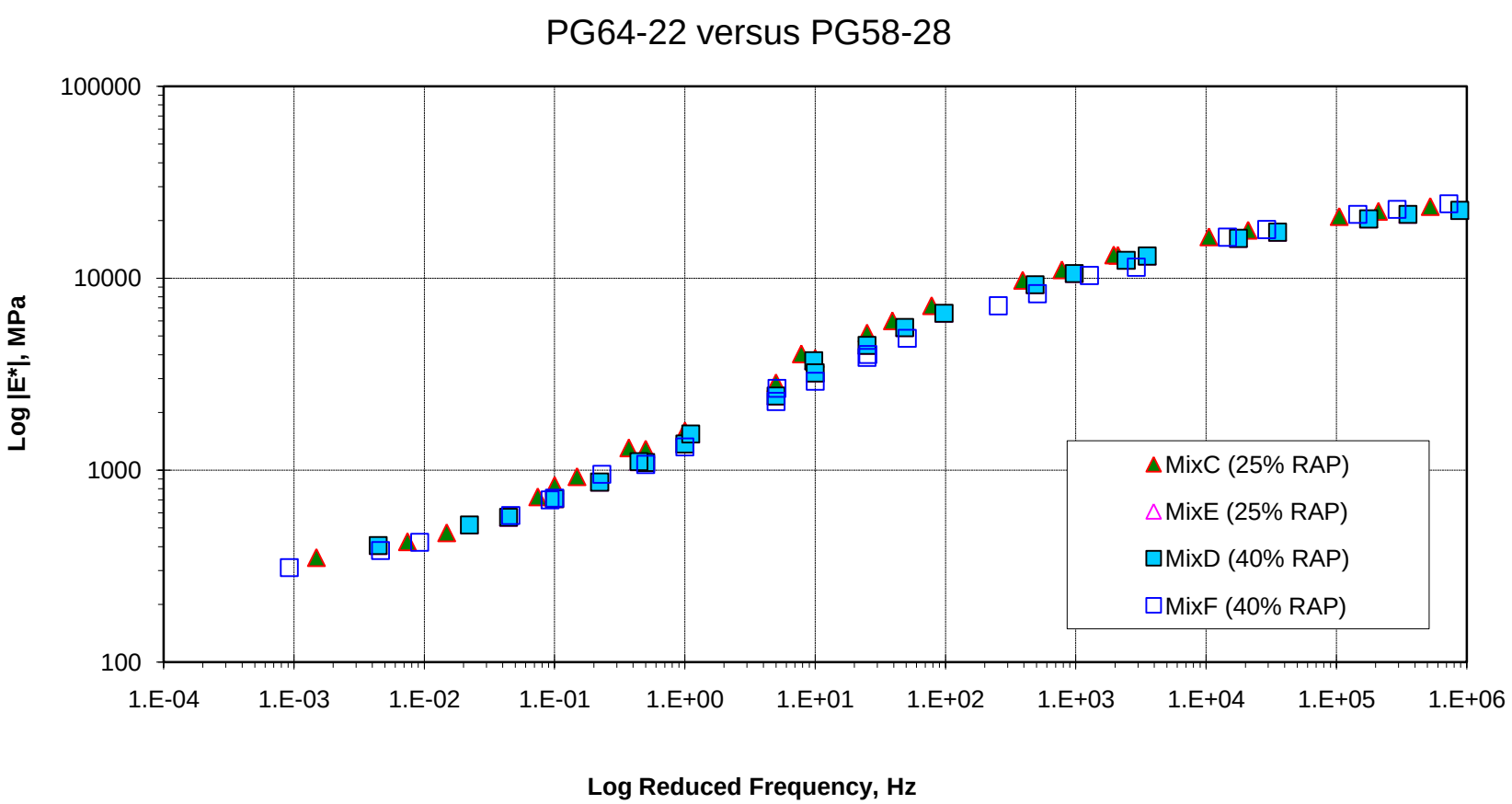
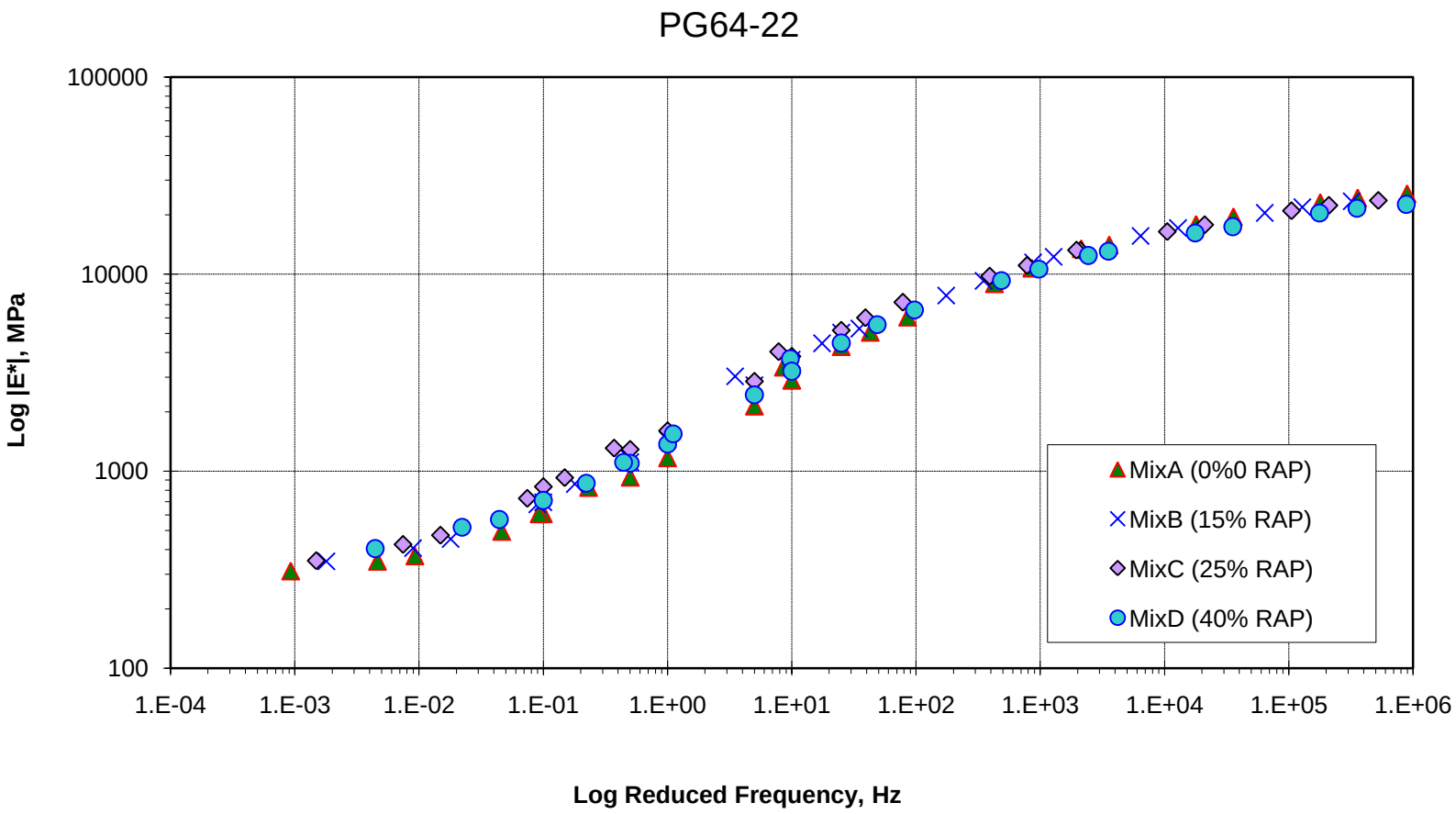
10000
1000
100
Log |E*|, MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Log Reduced Frequency, Hz
MixA (0% RAP)
MixE (25% RAP)
MixF (40% RAP)

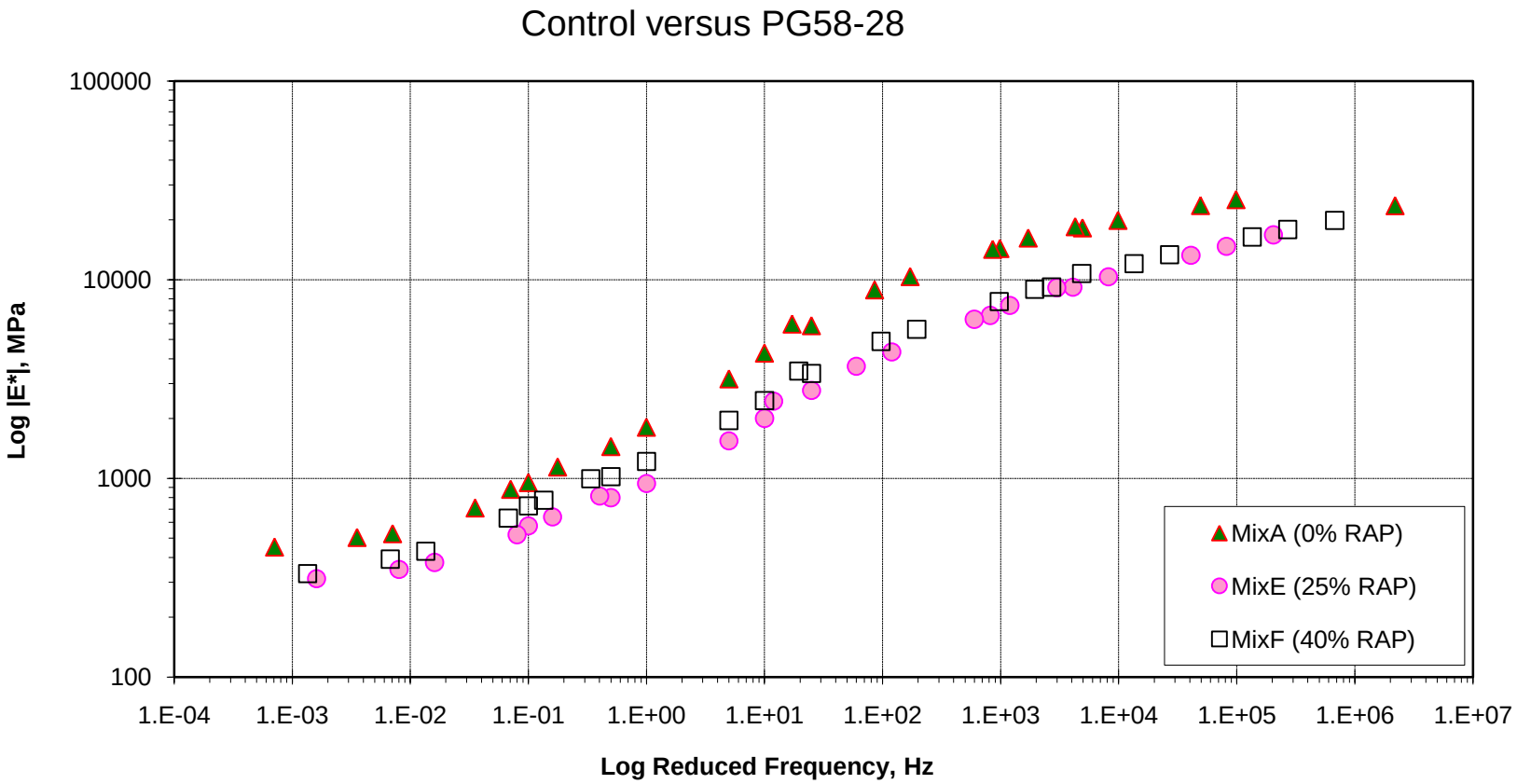
# P&B Mix |E*|


PG64-22 versus PG58-28
100000
10000
1000
100
Log |E*|, MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Log Reduced Frequency, Hz
MixC (25% RAP)
MixE (25% RAP)
MixD (40% RAP)
MixF (40% RAP)

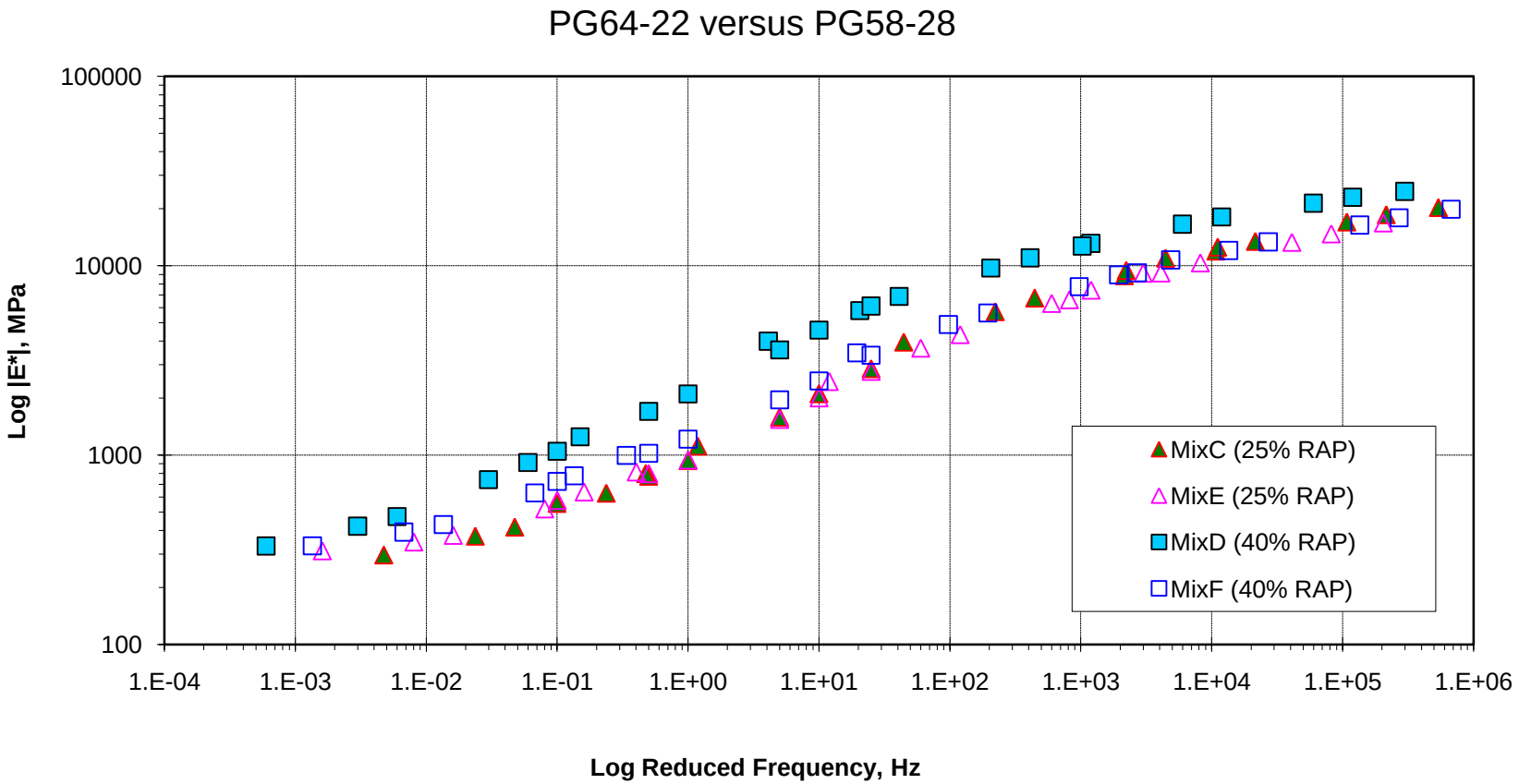
# P&B Mix |E*|


PG64-22
100000
10000
1000
100
Log |E*|, MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Log Reduced Frequency, Hz
MixA (0%0 RAP)
MixB (15% RAP)
MixC (25% RAP)
MixD (40% RAP)

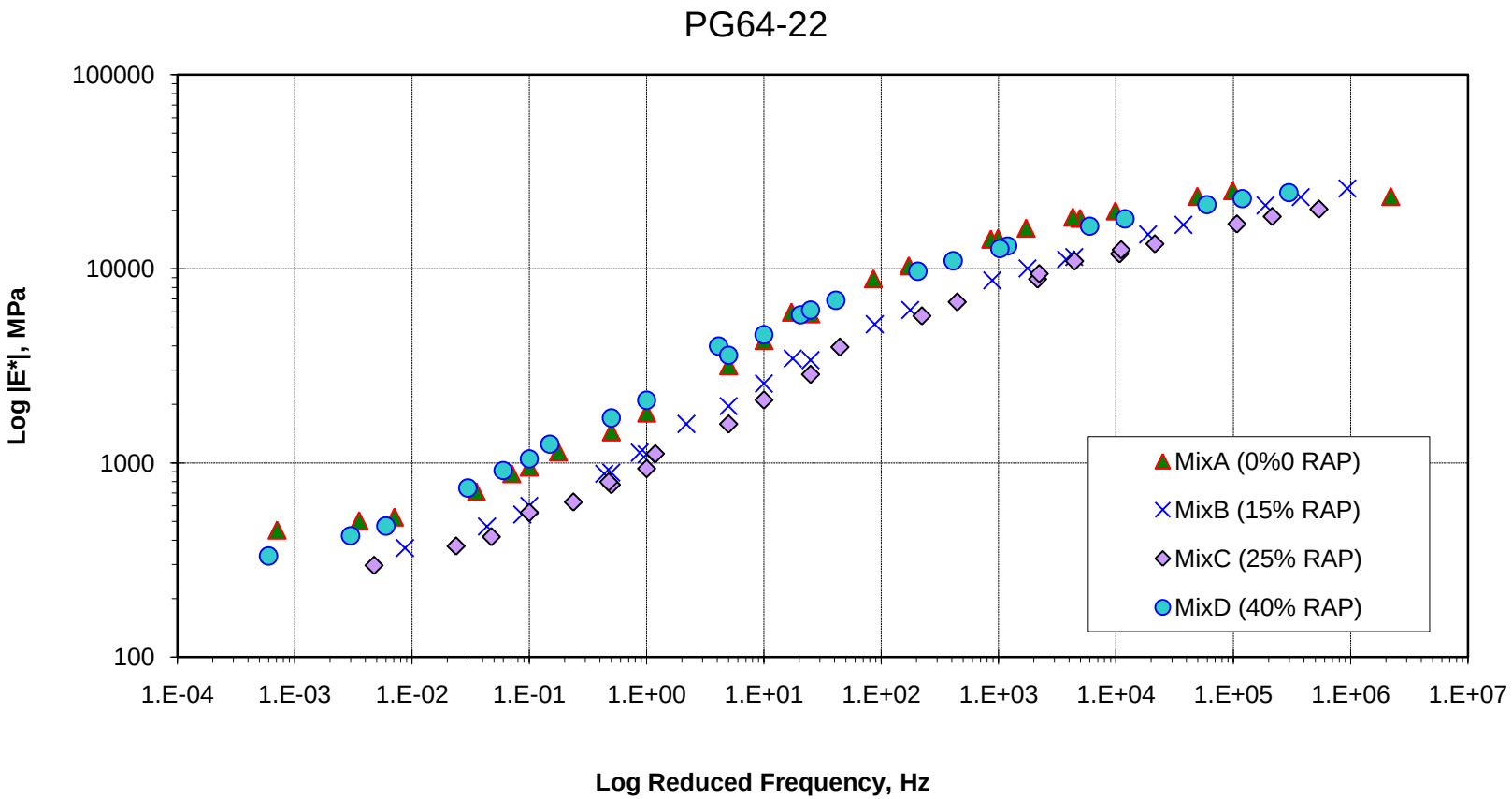
# RR Mix |E*|


Control versus PG58-28
100000
10000
1000
100
Log |E*|, MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Log Reduced Frequency, Hz
MixA (0% RAP)
MixE (25% RAP)
MixF (40% RAP)

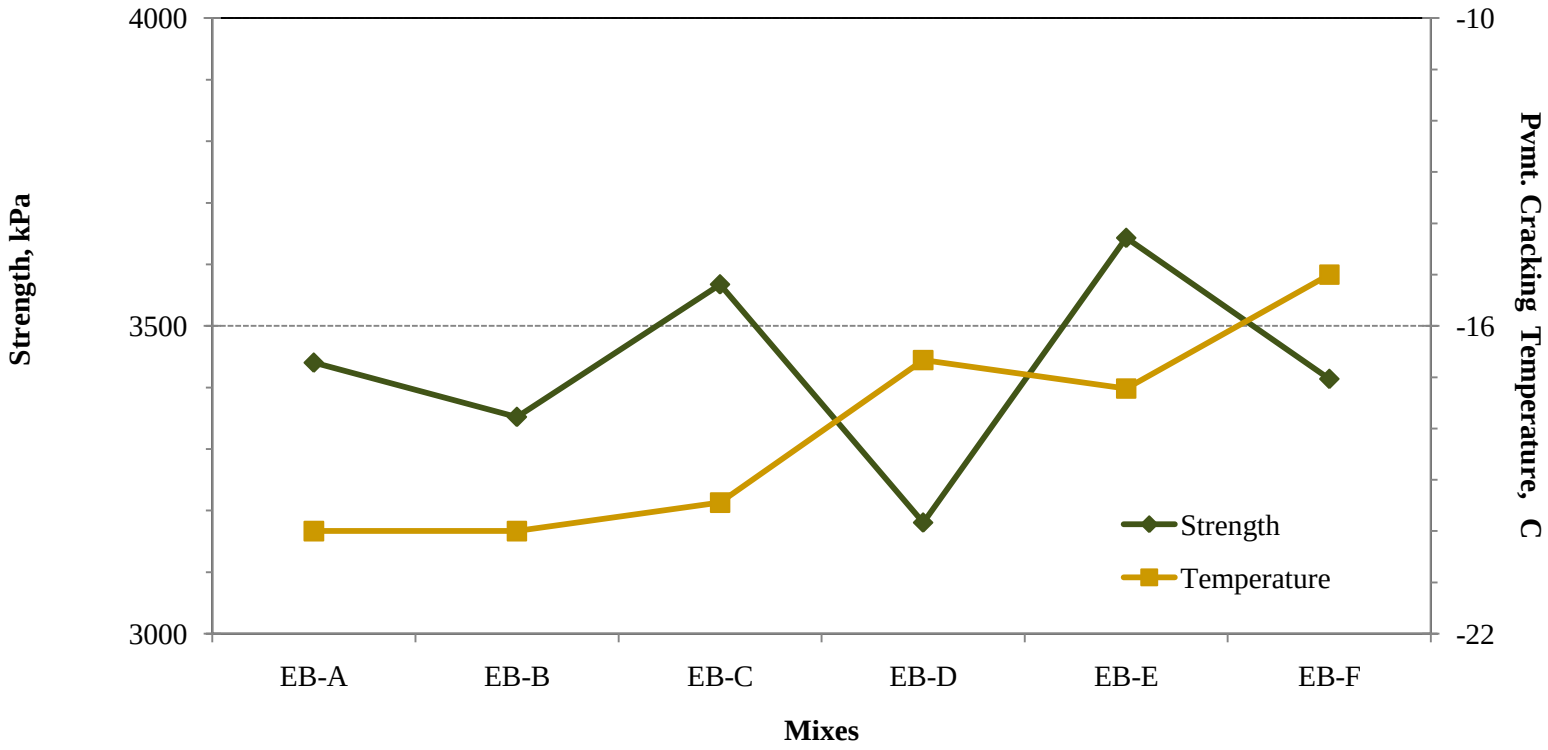
# RR Mix |E*|


PG64-22 versus PG58-28
Log |E*|, MPa
100000
10000
1000
100
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Log Reduced Frequency, Hz
MixC (25% RAP)
MixE (25% RAP)
MixD (40% RAP)
MixF (40% RAP)

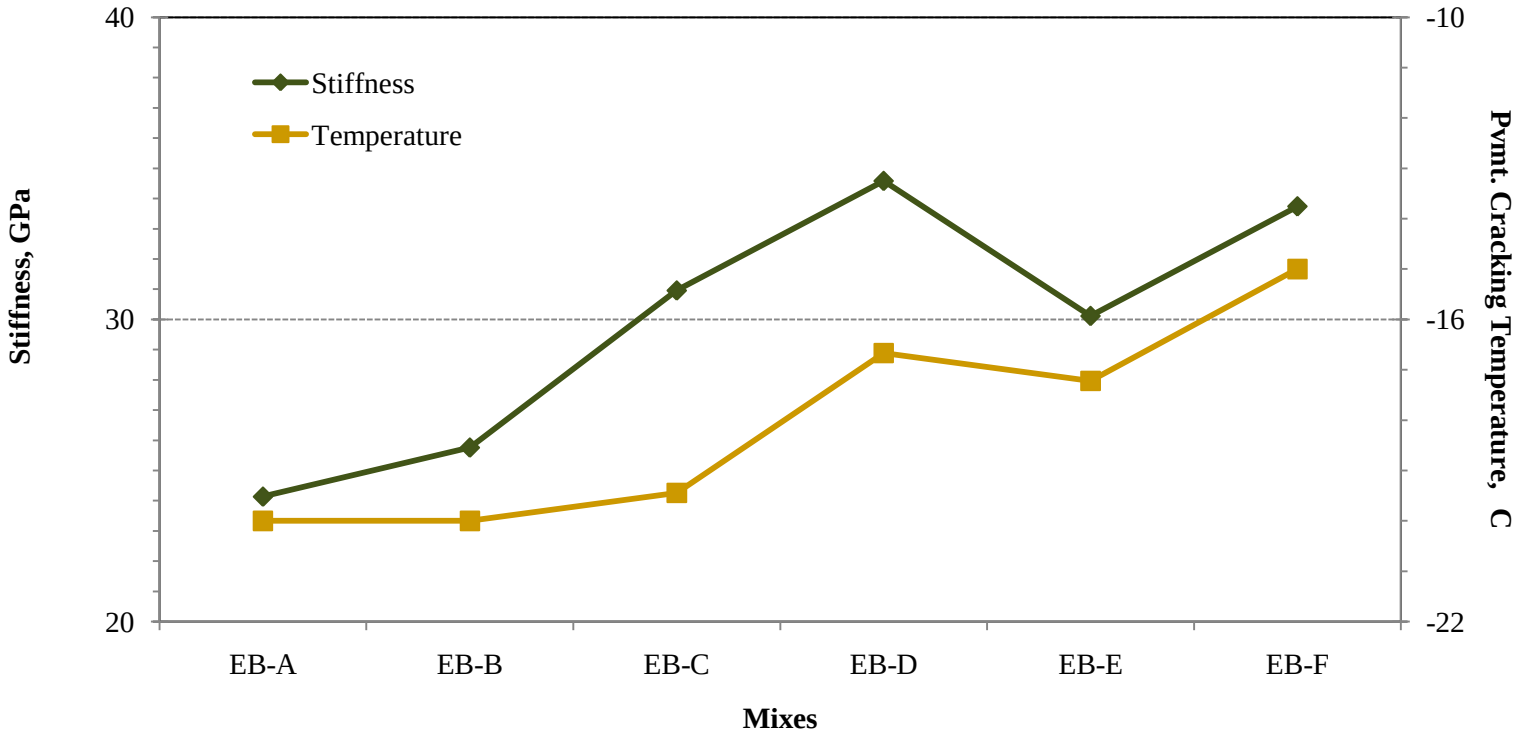
# RR Mix |E*|


PG64-22
100000
10000
1000
100
Log |E*|, MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Log Reduced Frequency, Hz
MixA (0%0 RAP)
MixB (15% RAP)
MixC (25% RAP)
MixD (40% RAP)

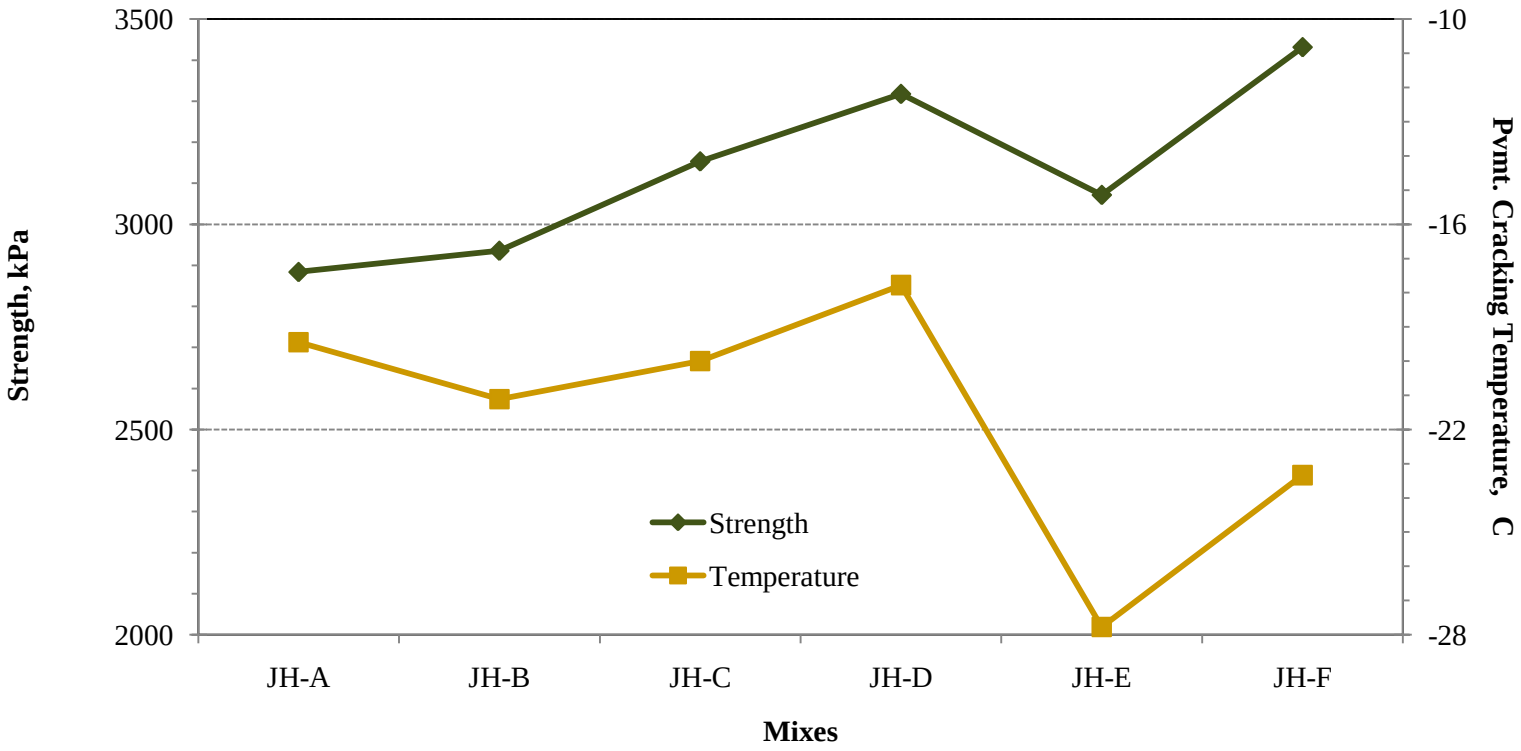
# E&B IDT Strength



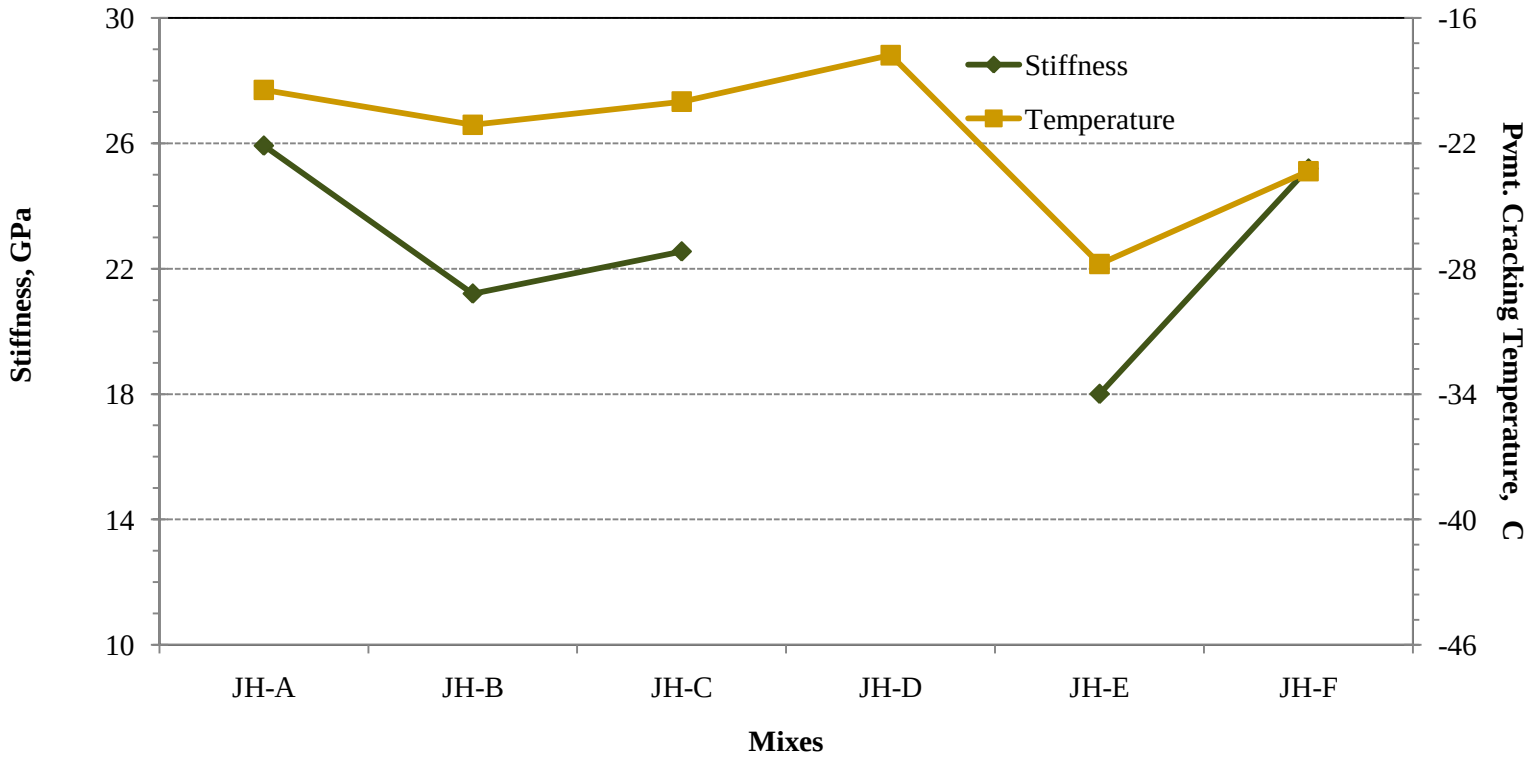
# E&B IDT Stiffness



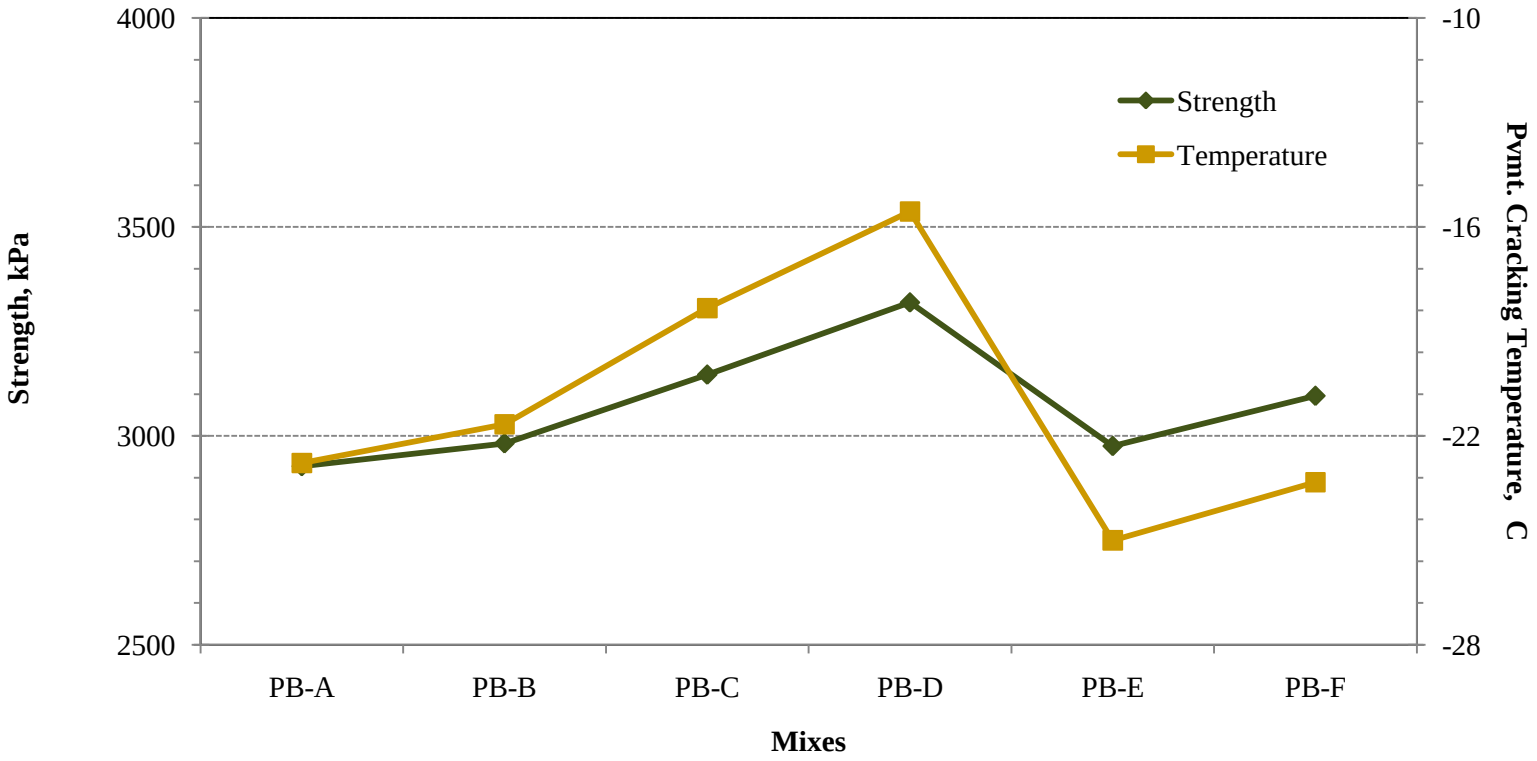
# JHR IDT Strength



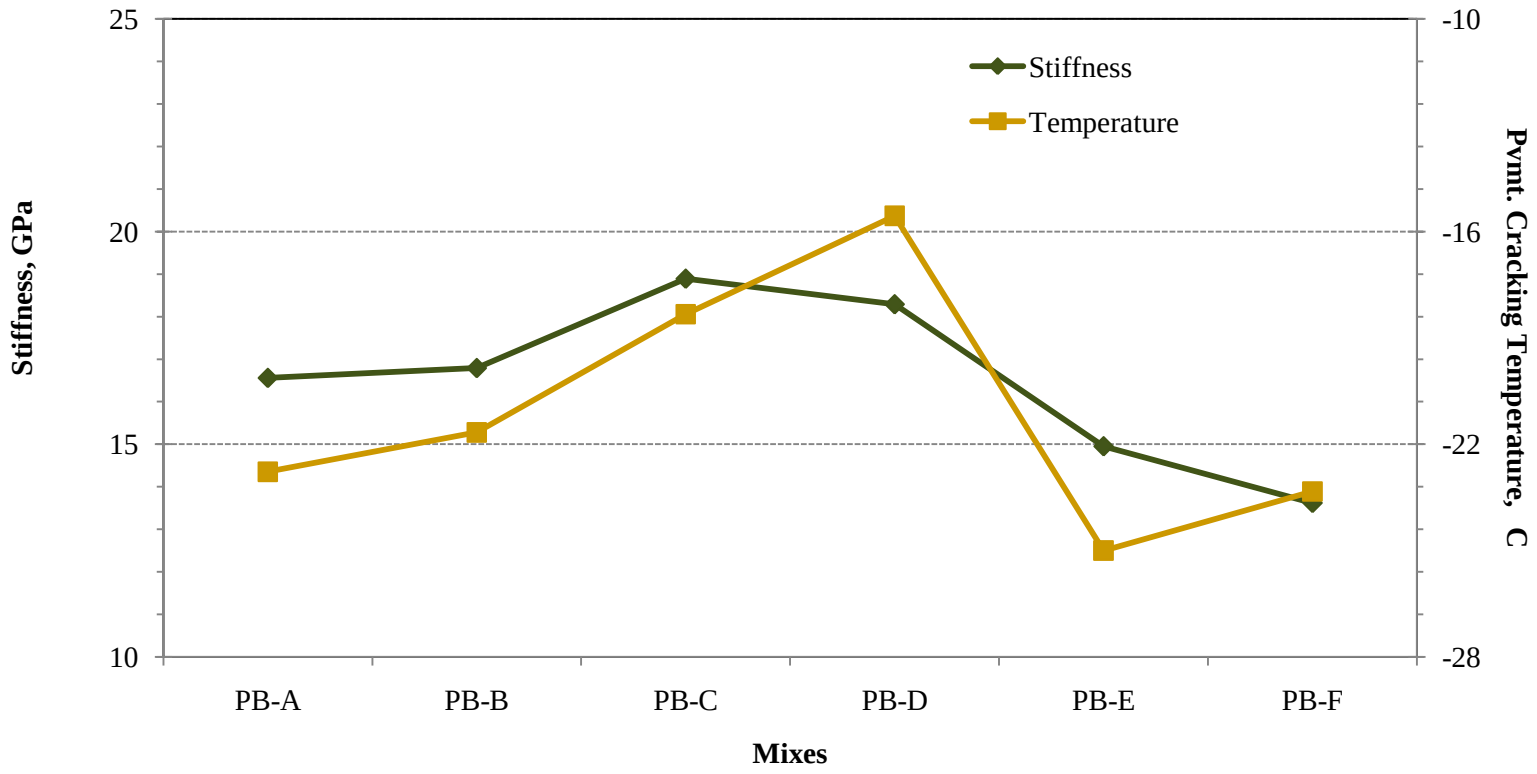
# JHR IDT Stiffness



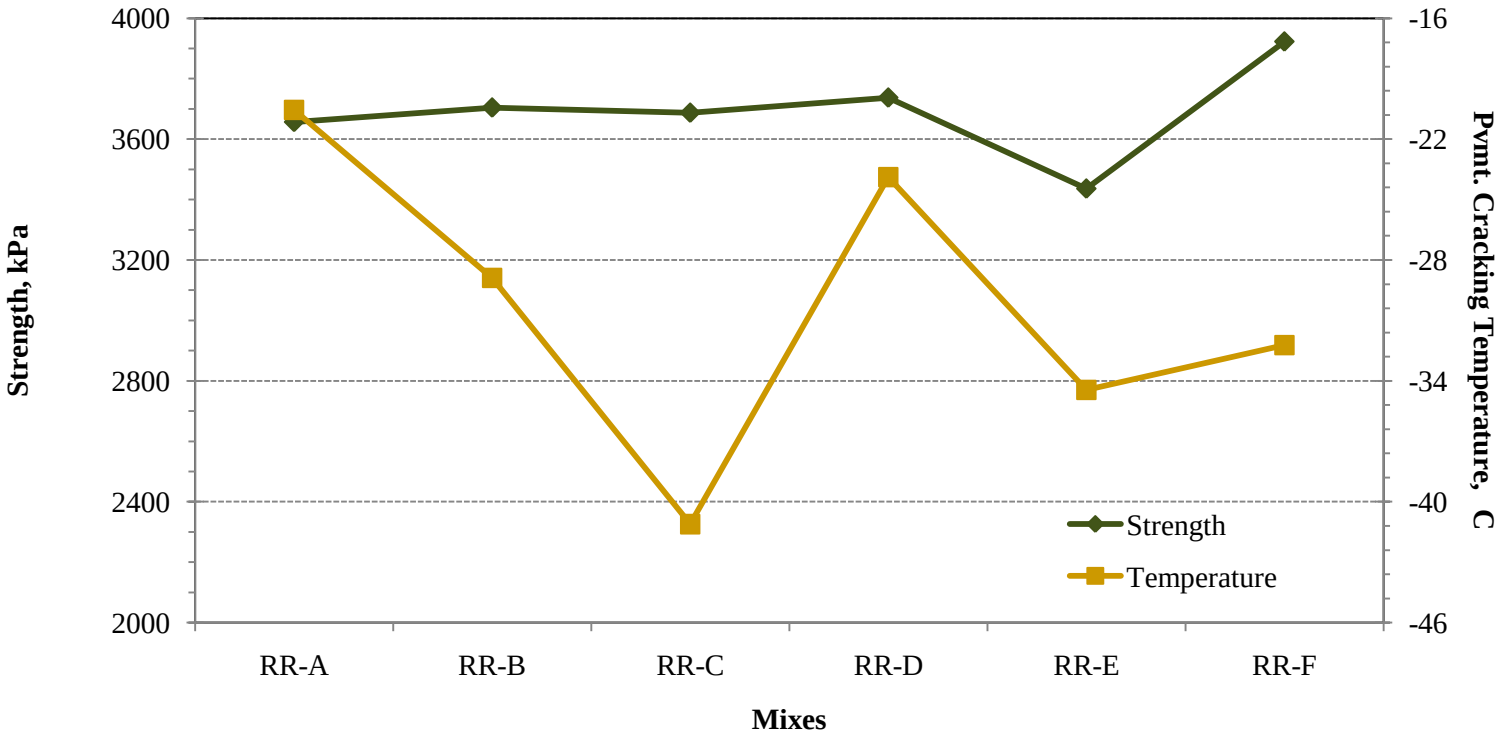
# P&B IDT Strength



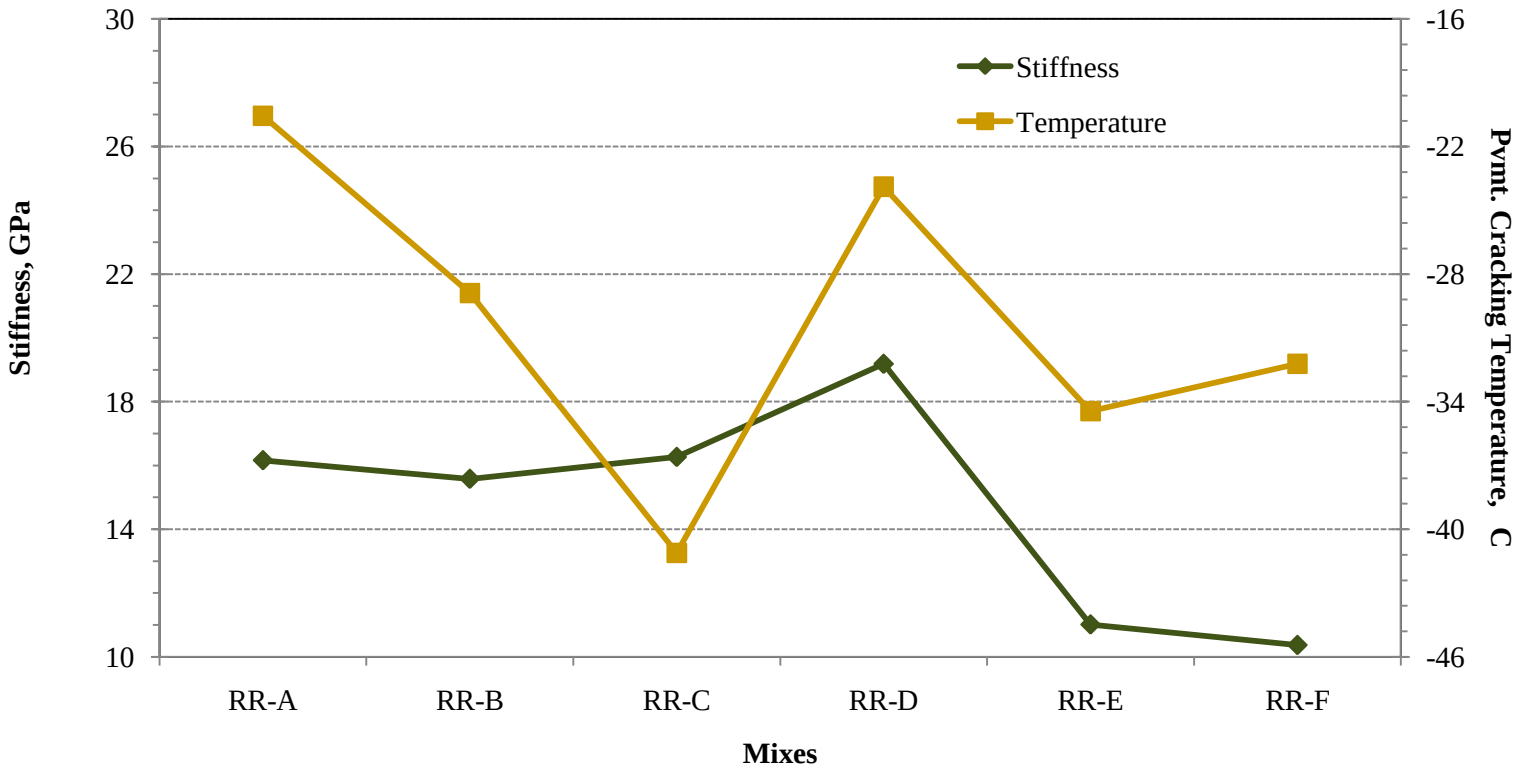
# P&B IDT Stiffness



# RR IDT Strength



# RR IDT Stiffness



# What does this mean?

- In some cases, it appears binder grade does not affect IDT (E&B)
- In some cases, similar temperature and modulus/ stiffness/strength through 15%, others through 25%
- PG58 usually but not always softer than PG64

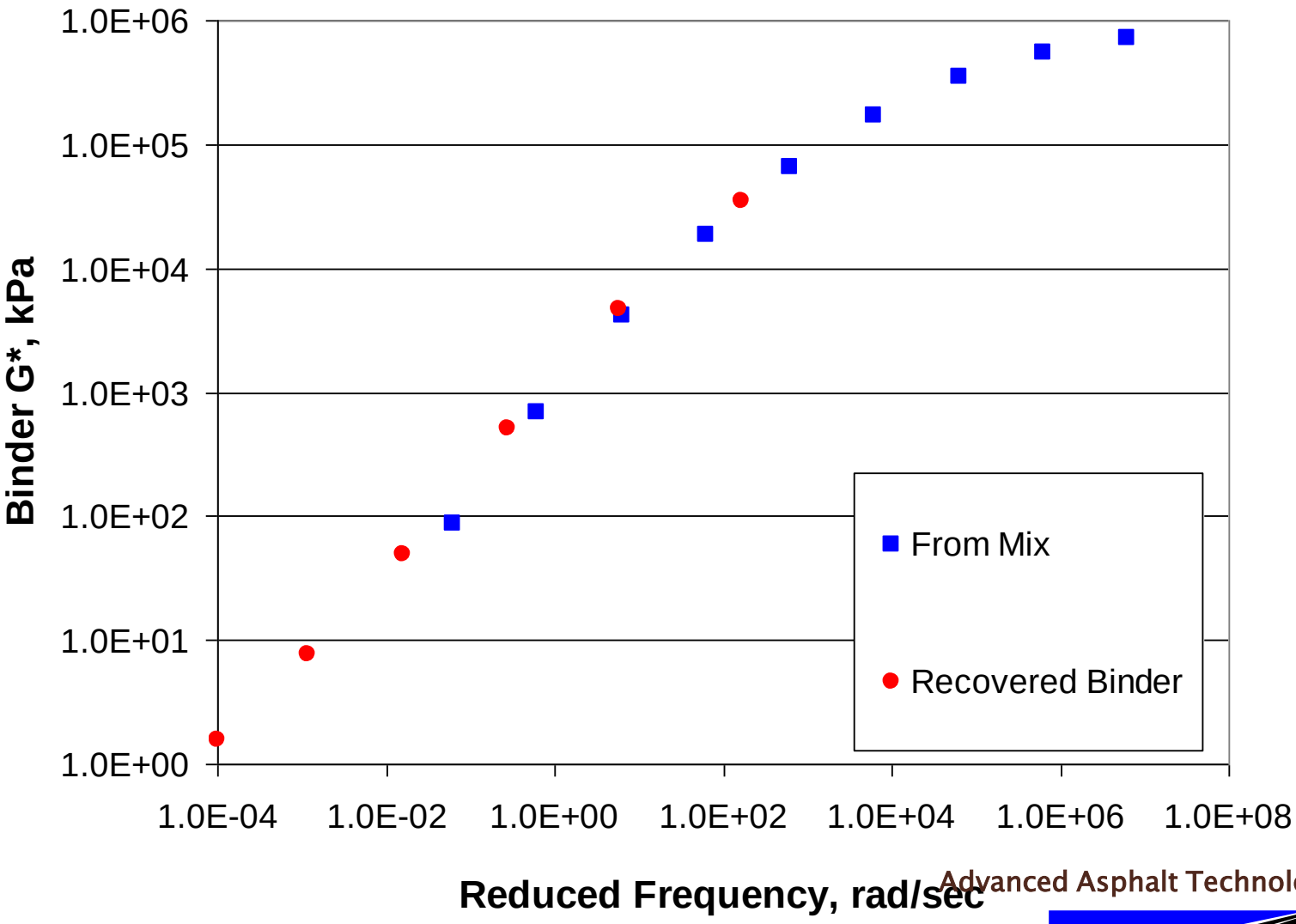
# Blending - Bonaquist approach

- Measure mix dynamic modulus
- Develop master curve
  - Stiffness over range of temps and loading rates
- Extract/ recover binder (total blending)
- Measure binder shear modulus

# Blending - Bonaquist approach

- Estimate mix modulus for that binder (if totally blended)
  - Hirsch model uses binder shear modulus and mix volumetrics to estimate mix stiffness
- Compare estimated(from binder) and measured mix moduli
  - Overlap indicates good mixing

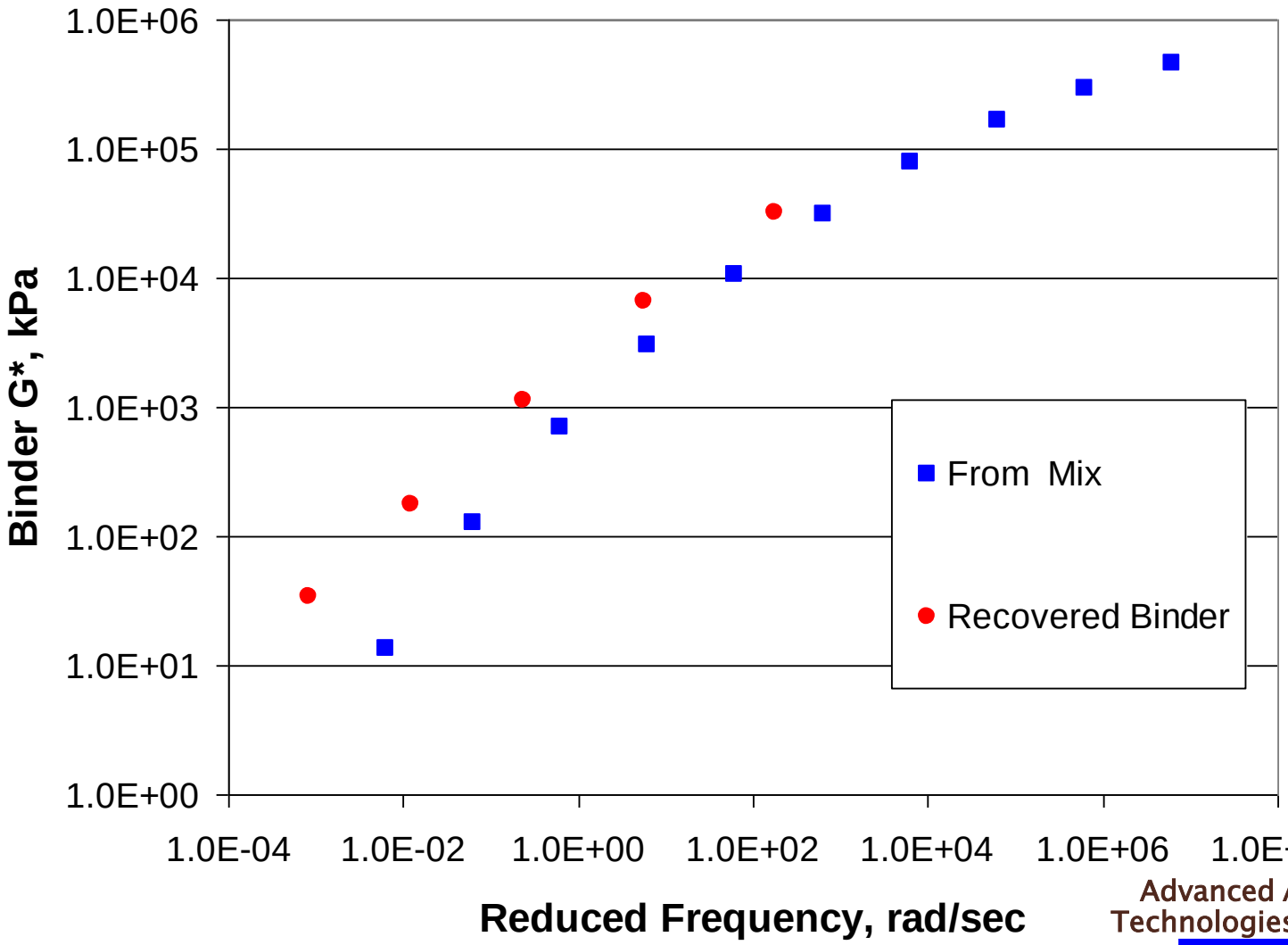
# 9.5 mm with PG 64-22, Batch Plant




Advanced Asphalt Technologies, LLC

"Engineering Services for the Asphalt Industry"

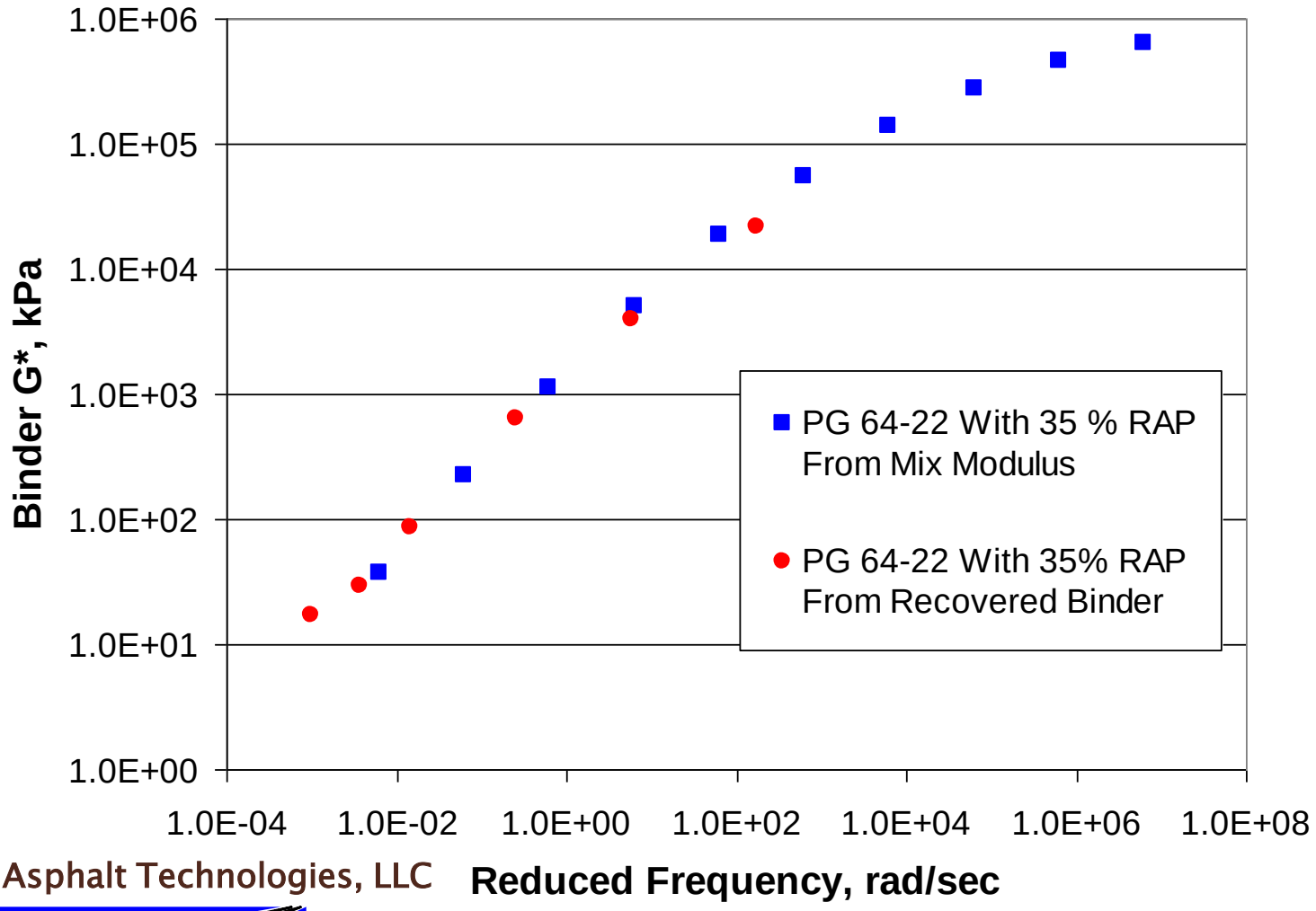
# 9.5 mm with PG 64-22 + 5% RAS, Batch Plant




Advanced Asphalt Technologies, LLC

"Engineering Services for the Asphalt Industry"

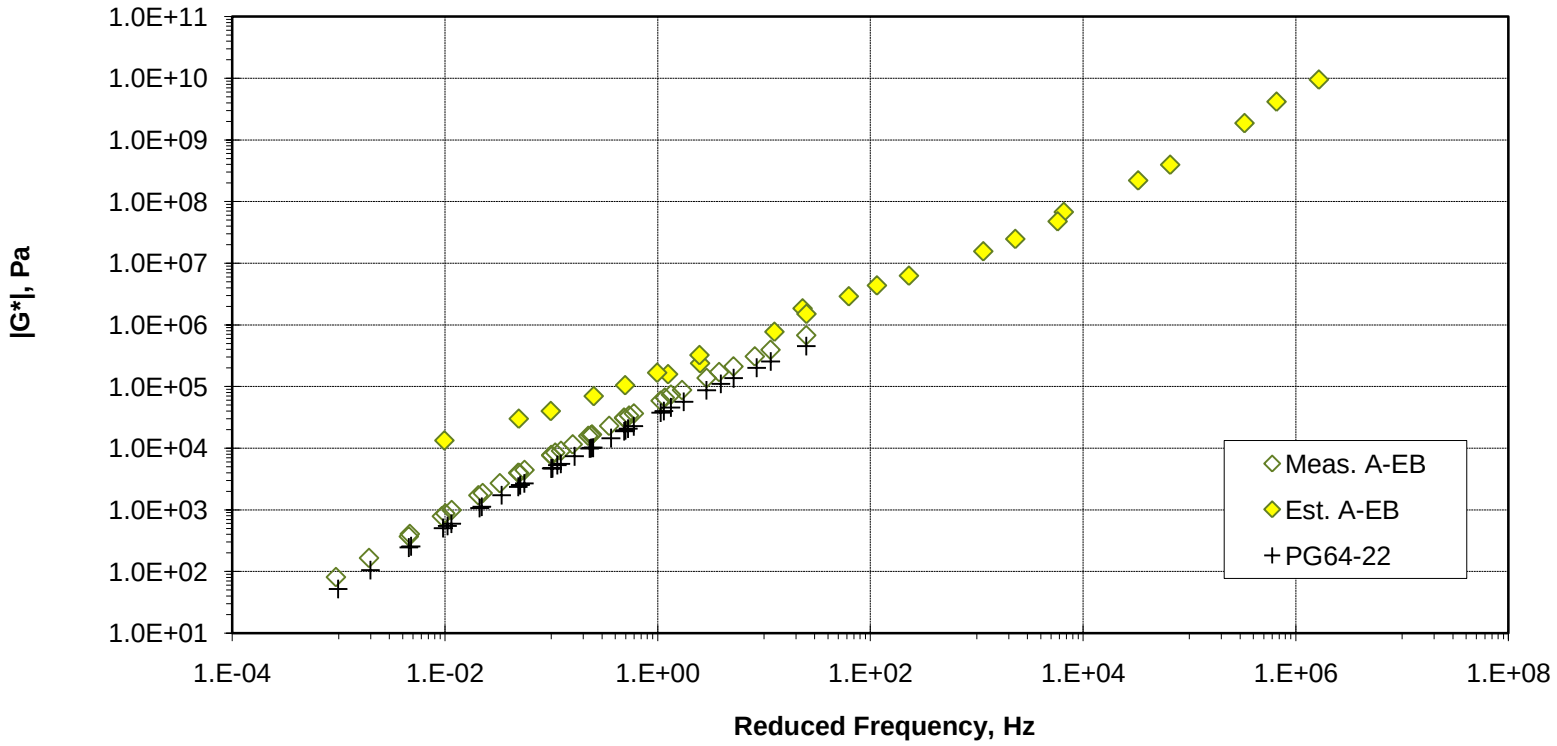
# 9.5 mm with PG 64-22 + 35 % FRAP, Double Barrel



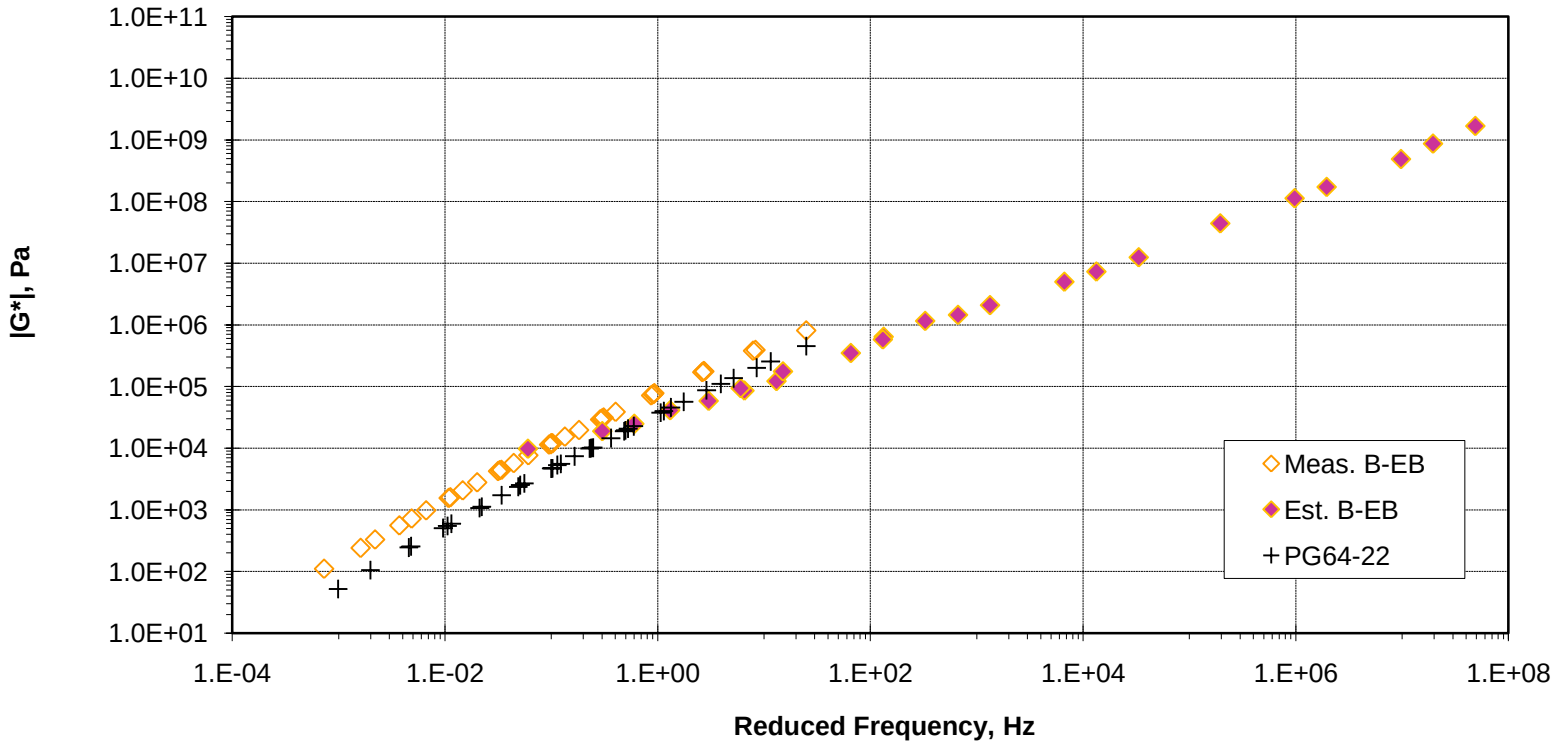

Advanced Asphalt Technologies, LLC

*"Engineering Services for the Asphalt Industry"*

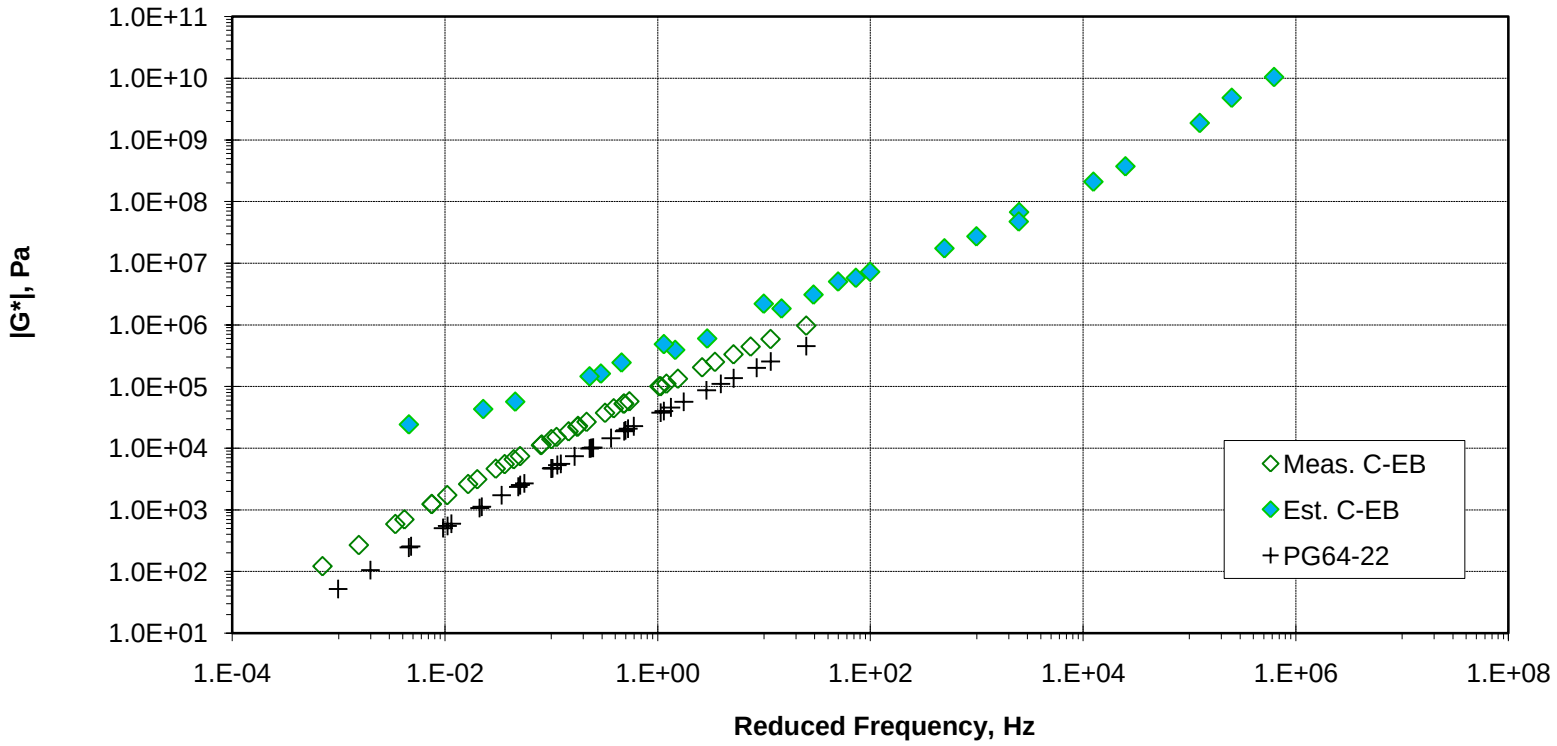
# E&B Mix A


1.0E+11
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. A-EB
Est. A-EB
PG64-22

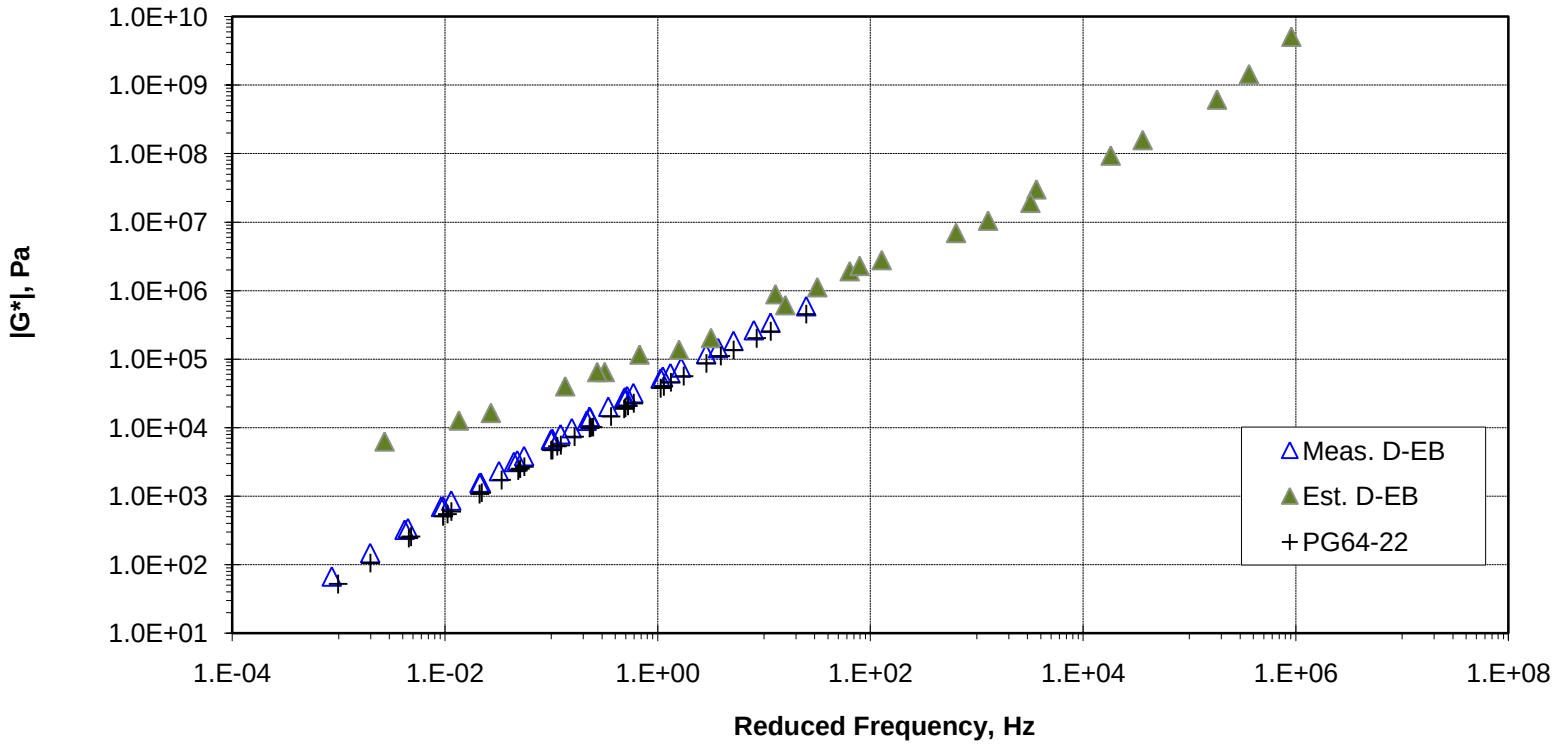
# E&B Mix B


1.0E+11
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. B-EB
Est. B-EB
PG64-22

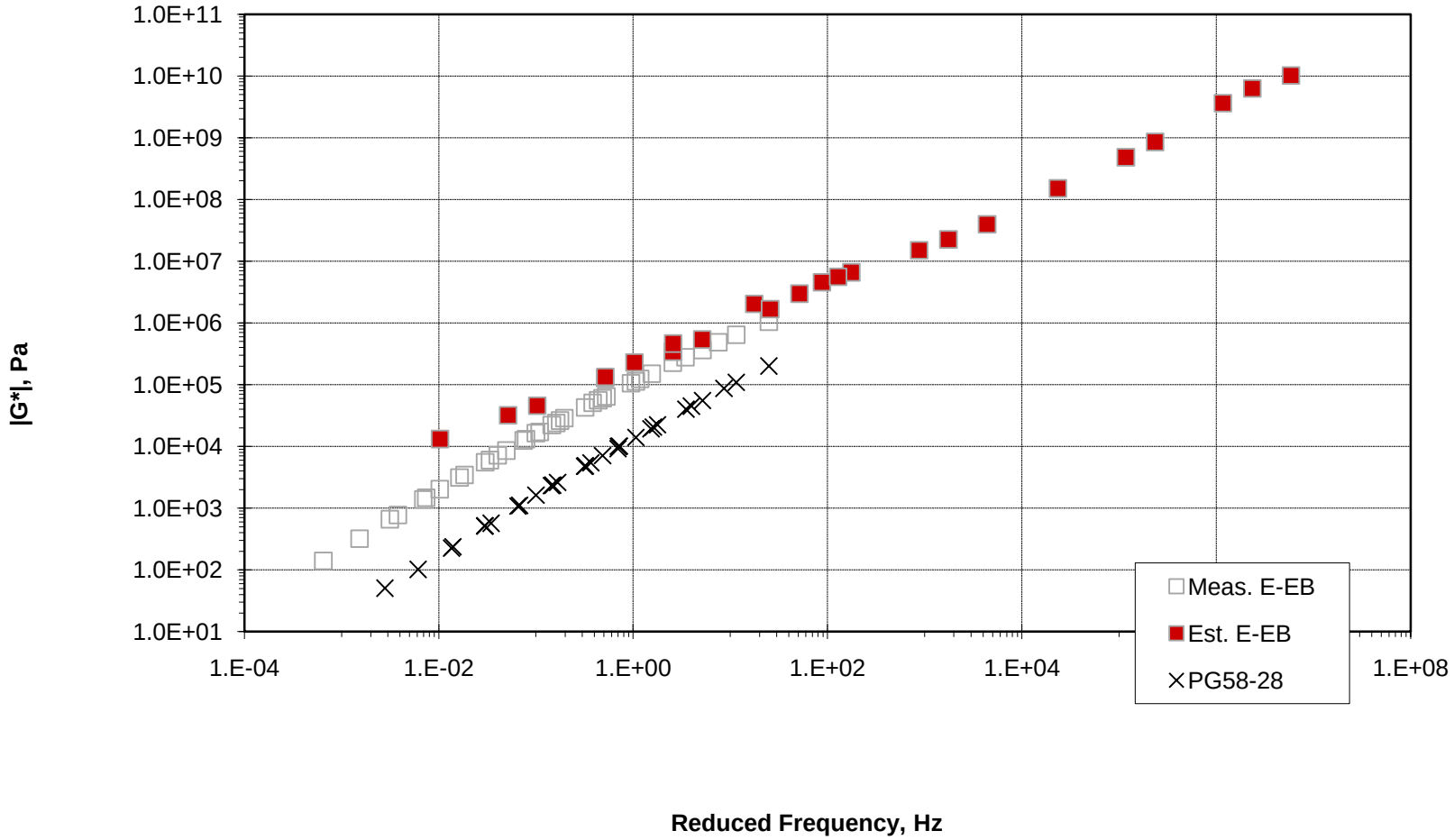
# E&B Mix C


1.0E+11
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. C-EB
Est. C-EB
PG64-22

# E&B Mix D


1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. D-EB
Est. D-EB
PG64-22

# E&B Mix E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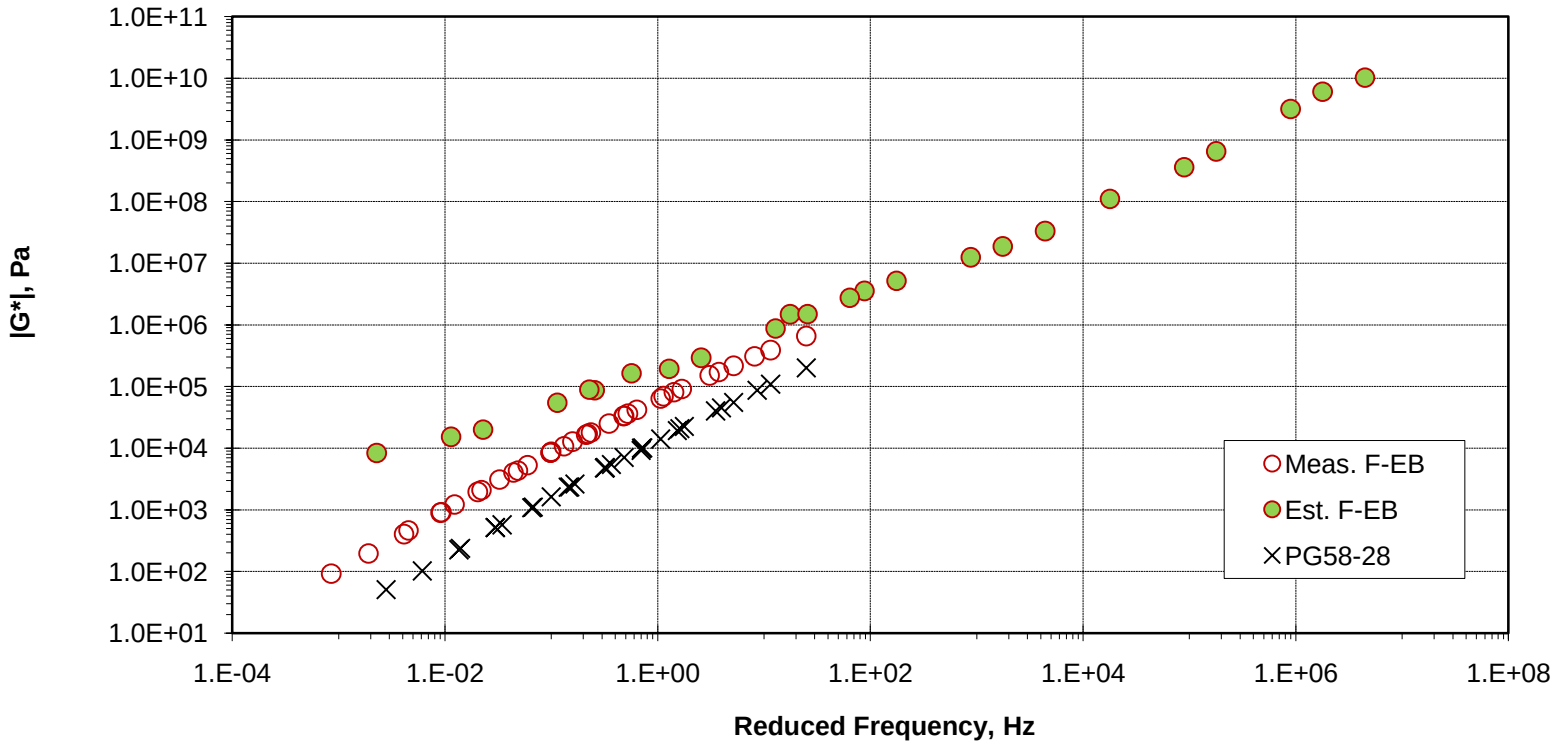
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+08
Reduced Frequency, Hz
Meas. E-EB
Est. E-EB
PG58-28

# E&B Mix F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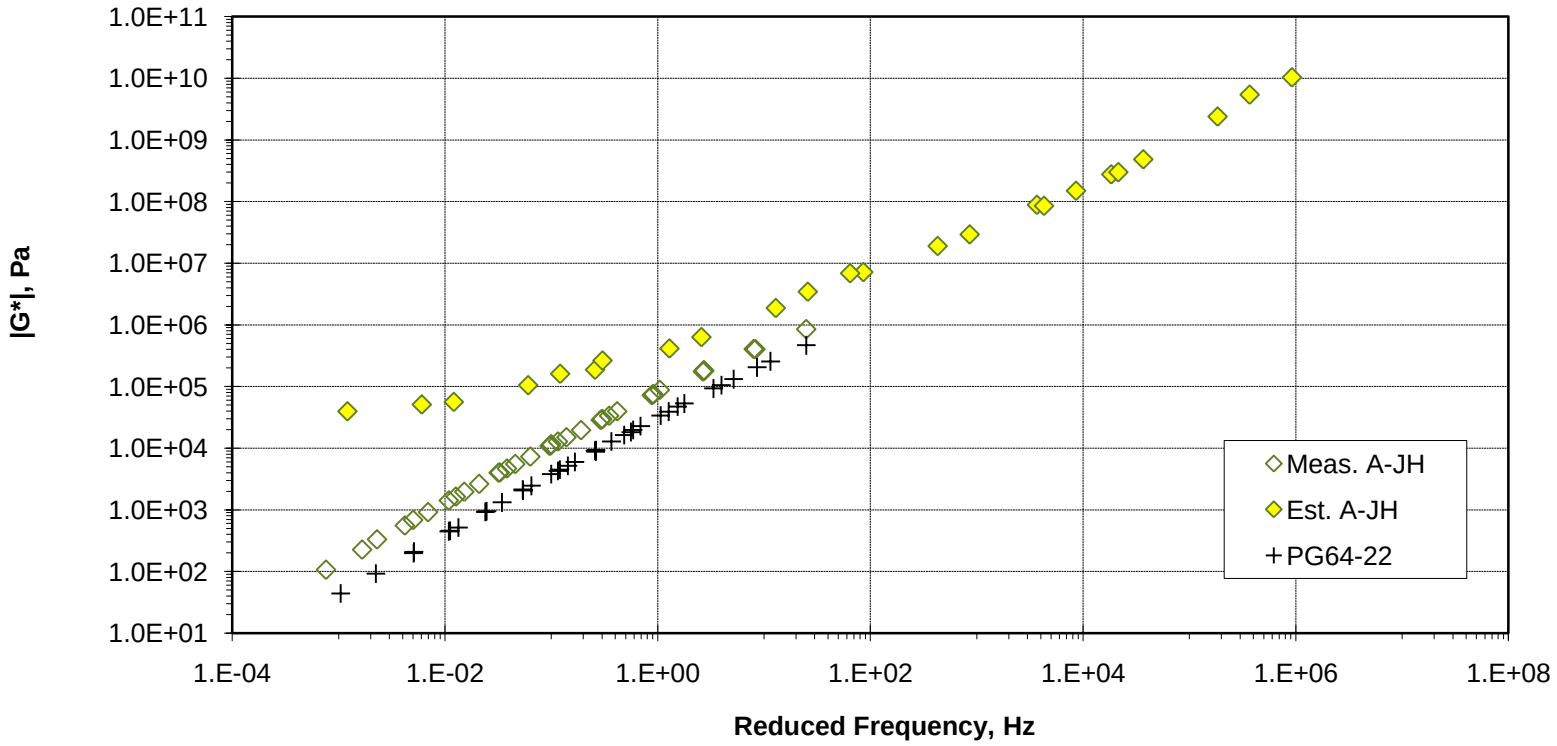
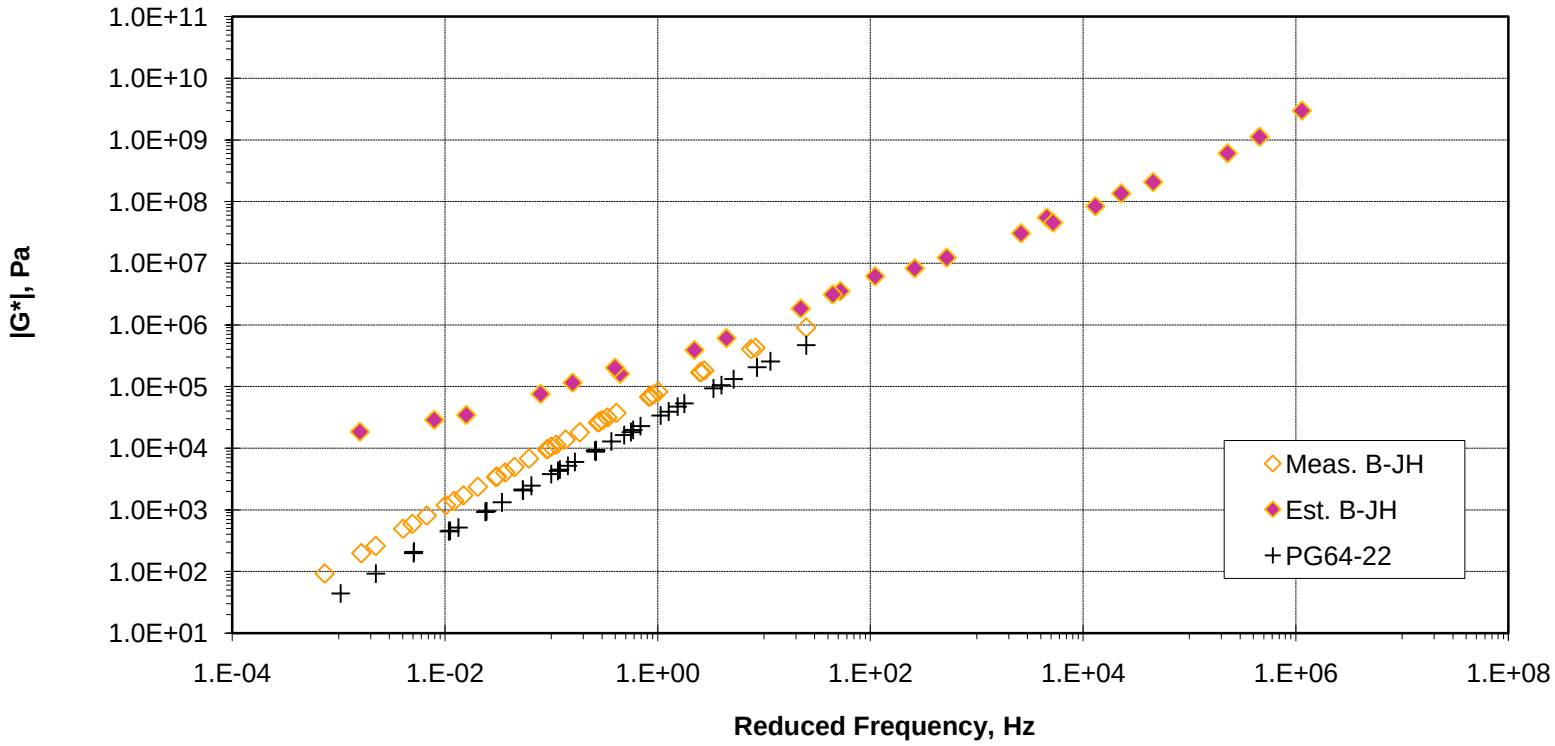
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. F-EB
Est. F-EB
PG58-28

# JHR Mix A


1.0E+11
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. A-JH
Est. A-JH
PG64-22

# JHR Mix B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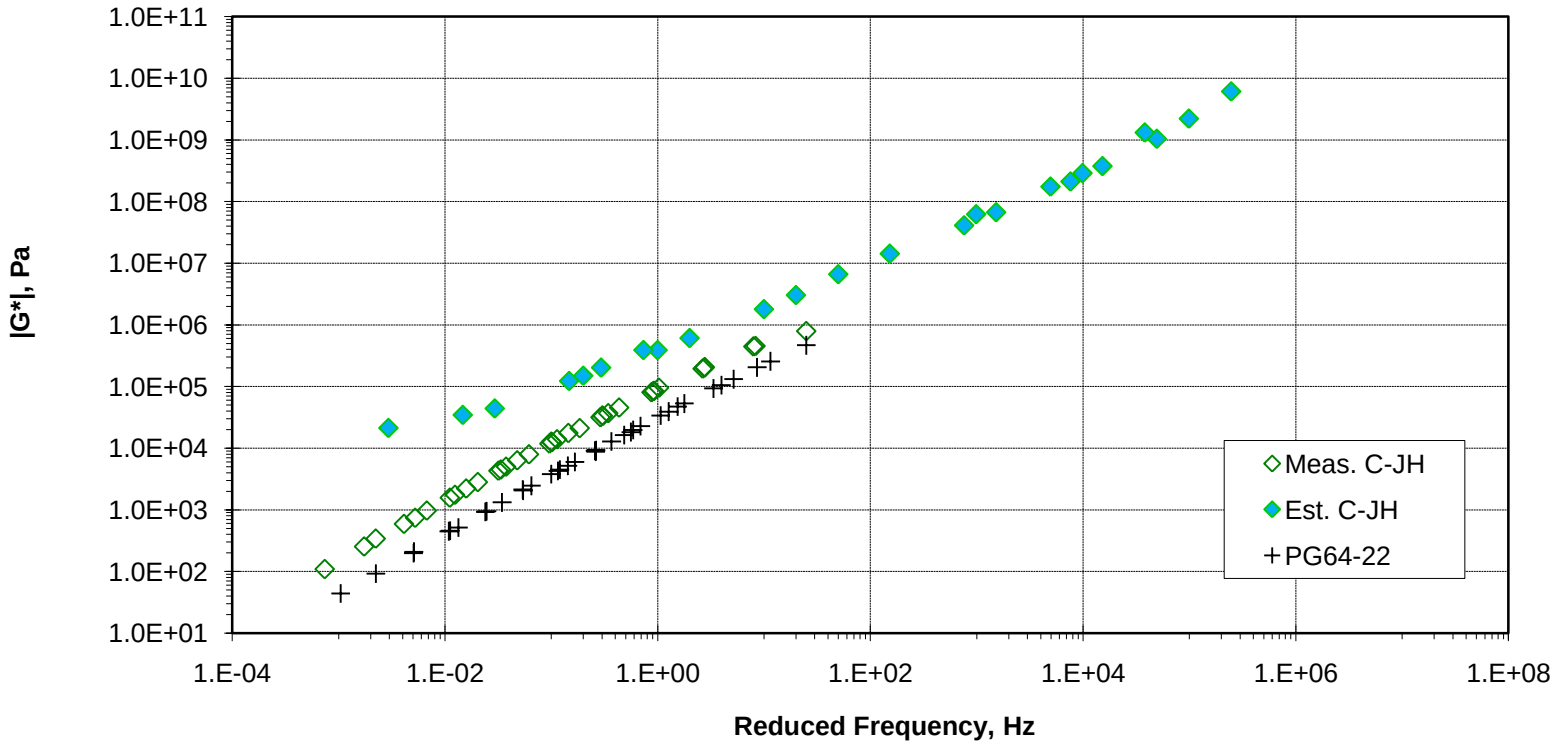
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. B-JH
Est. B-JH
PG64-22

# JHR Mix C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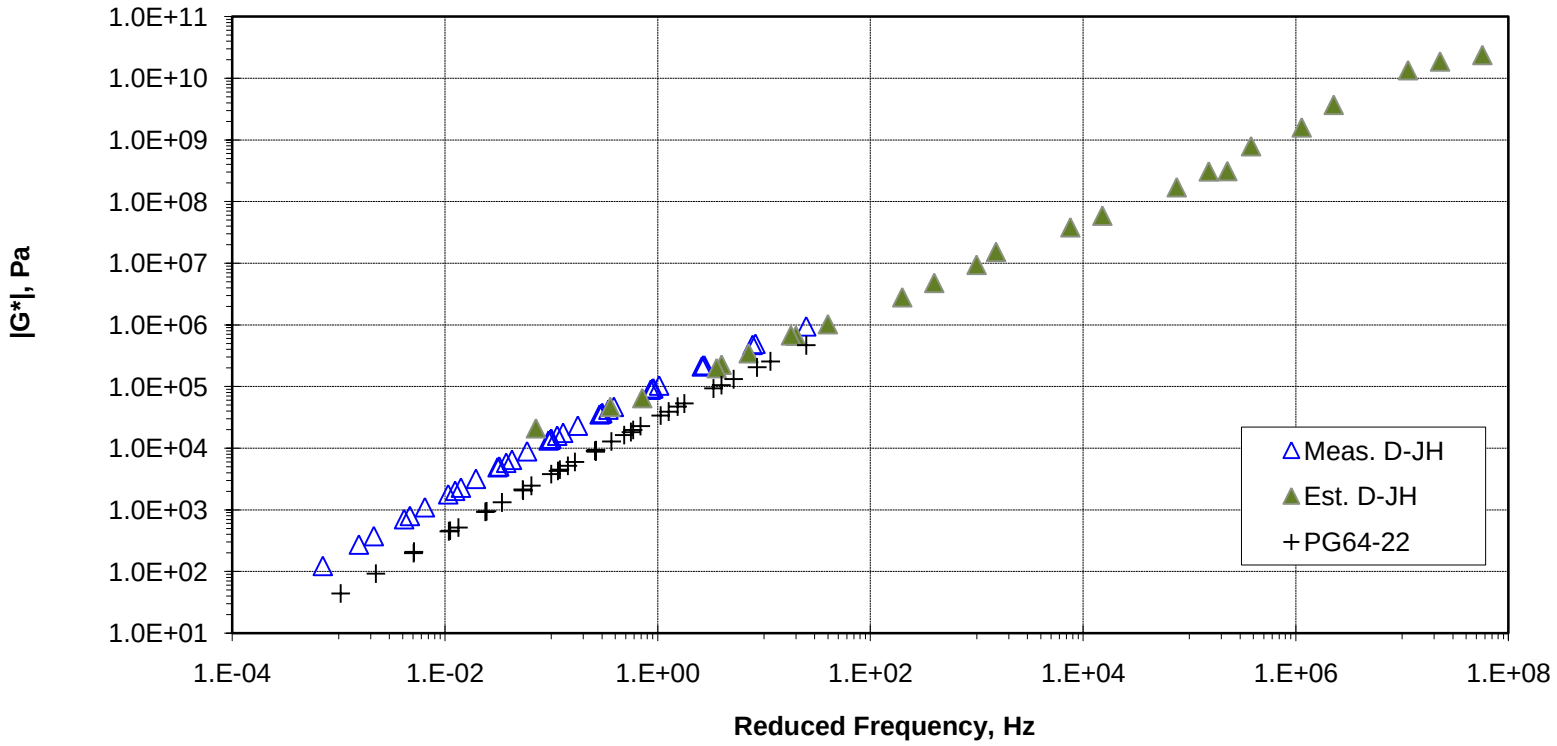
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. C-JH
Est. C-JH
PG64-22

# JHR Mix D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1.0E+05
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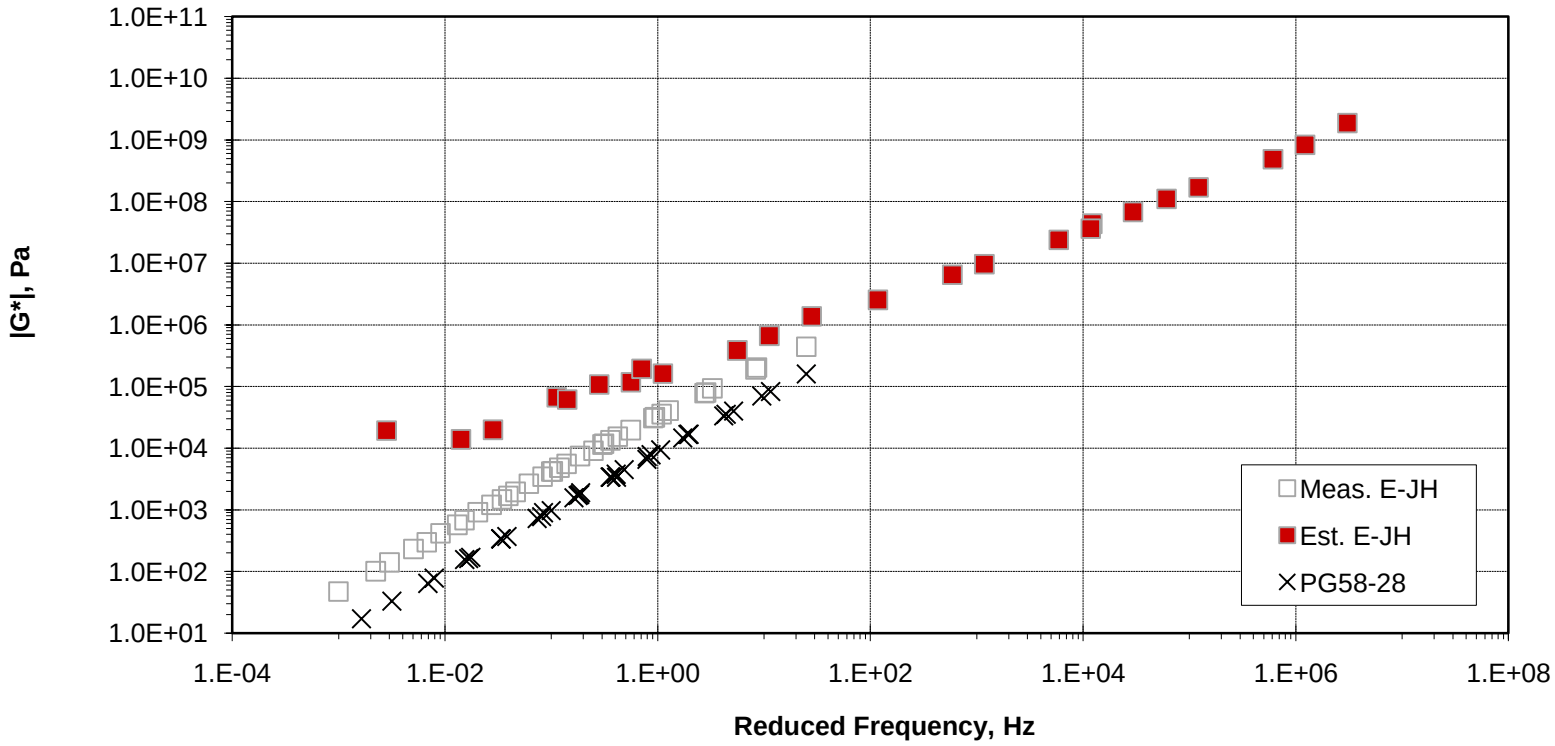
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. D-JH
Est. D-JH
PG64-22

# JHR Mix E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1.0E+05
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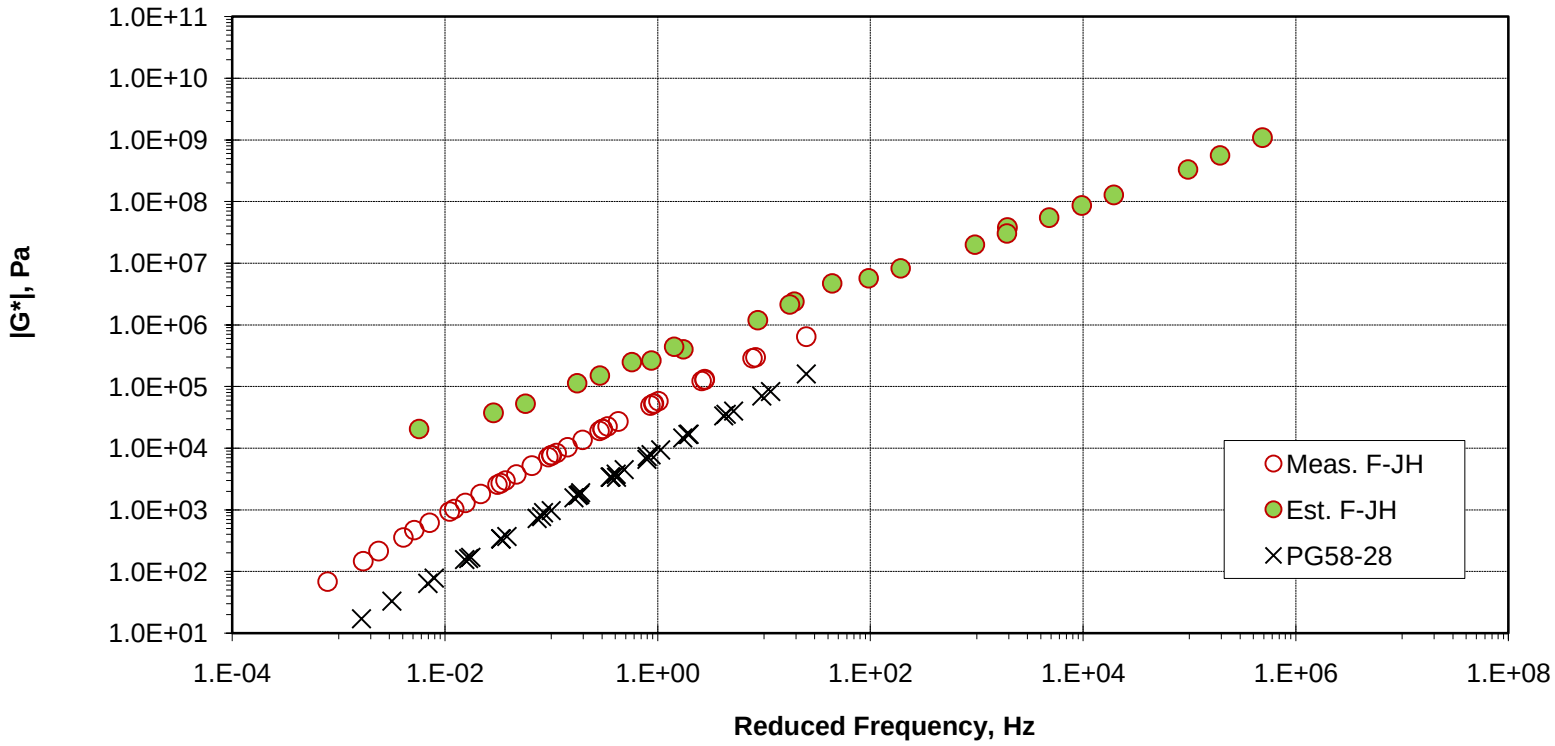
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. E-JH
Est. E-JH
PG58-28

# JHR Mix F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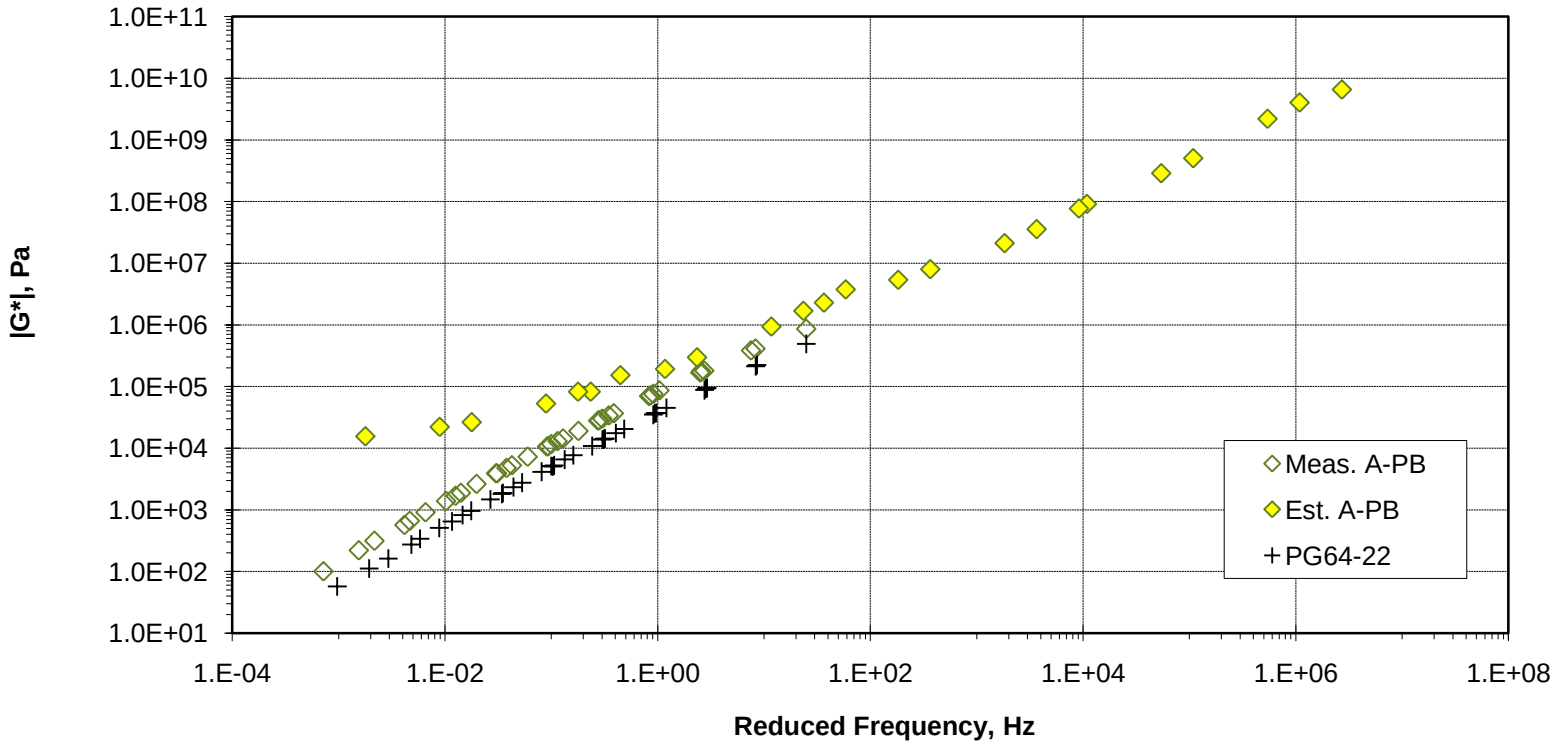
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. F-JH
Est. F-JH
PG58-28

# P&B Mix A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1.0E+06
1.0E+05
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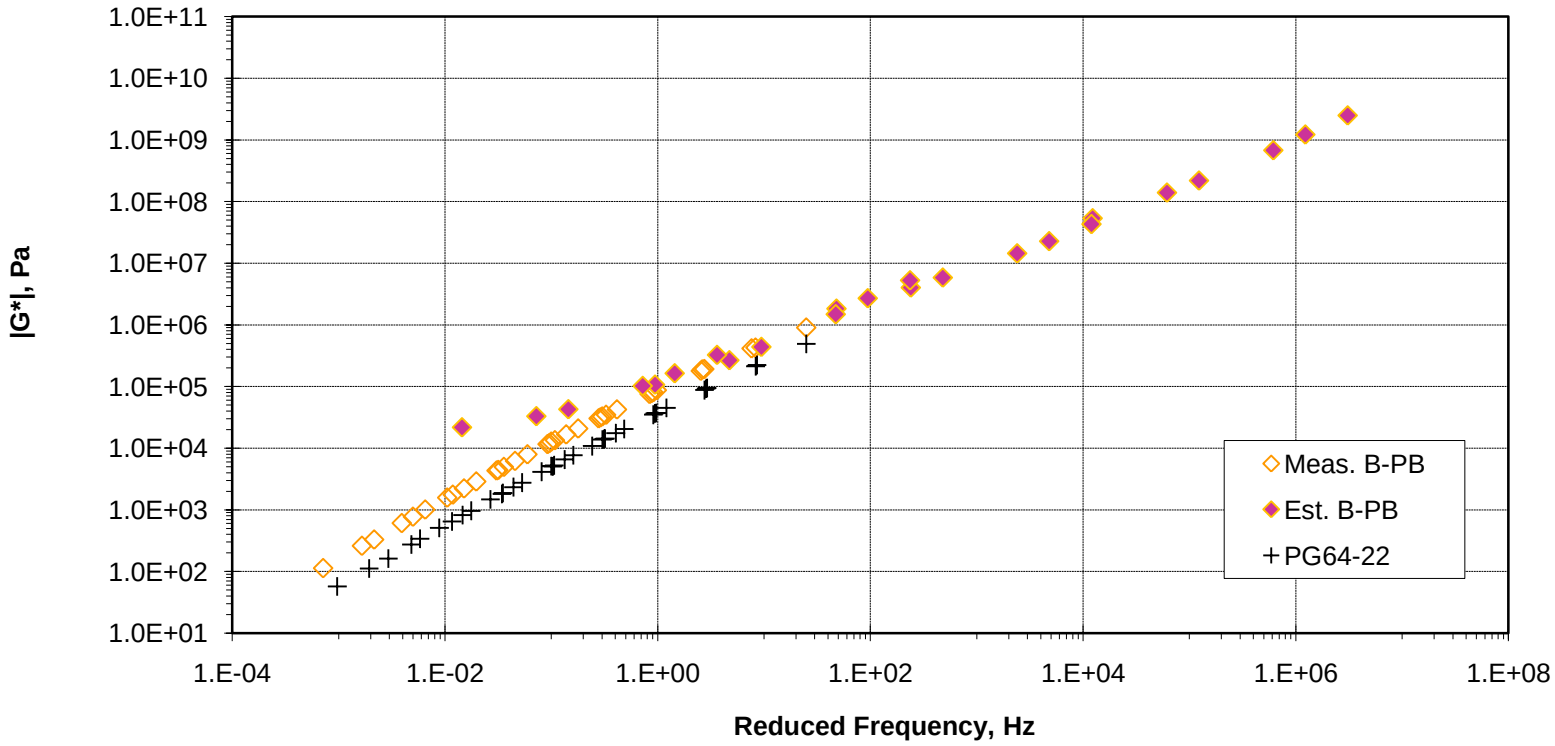
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. A-PB
Est. A-PB
PG64-22

# P&B Mix B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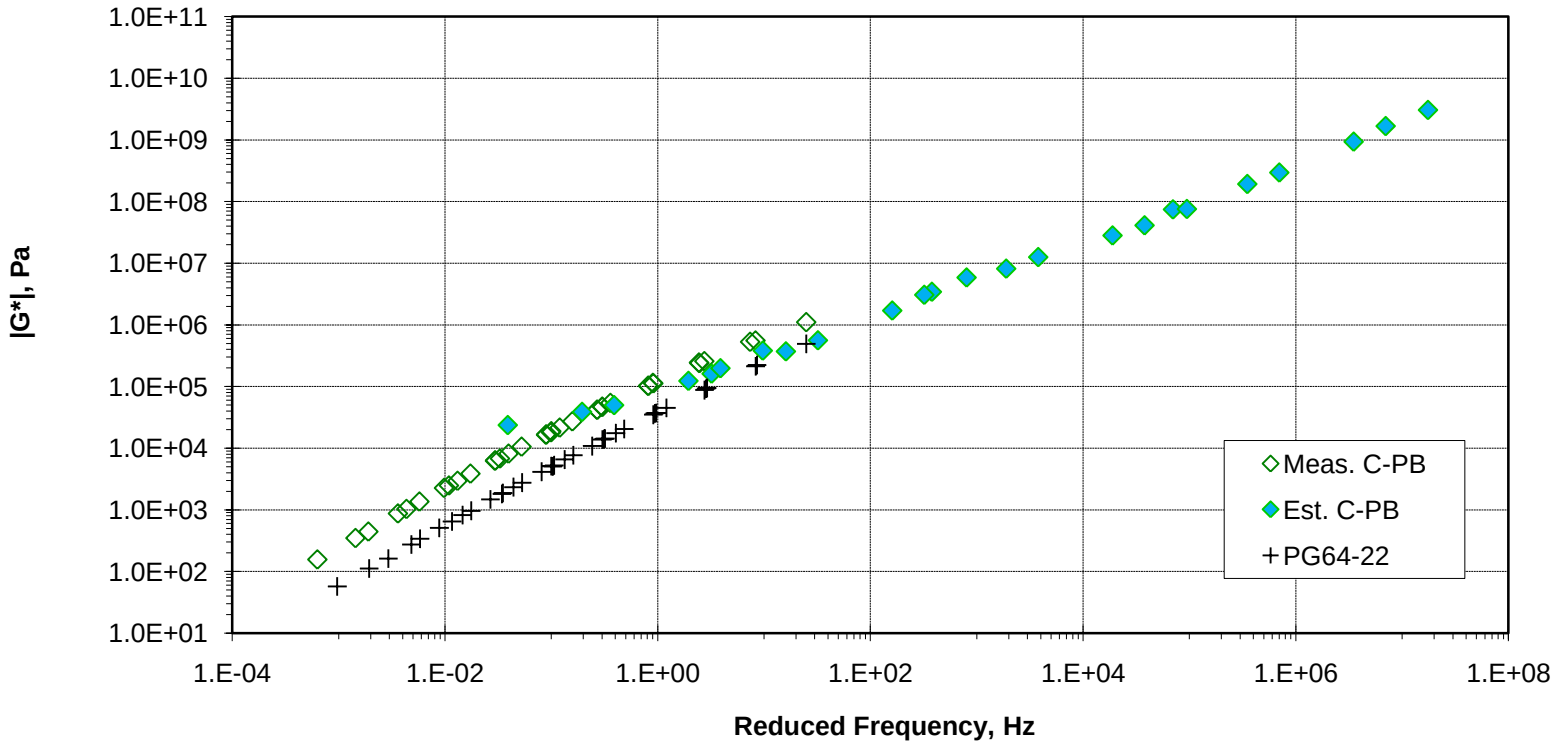
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. B-PB
Est. B-PB
PG64-22

# P&B Mix C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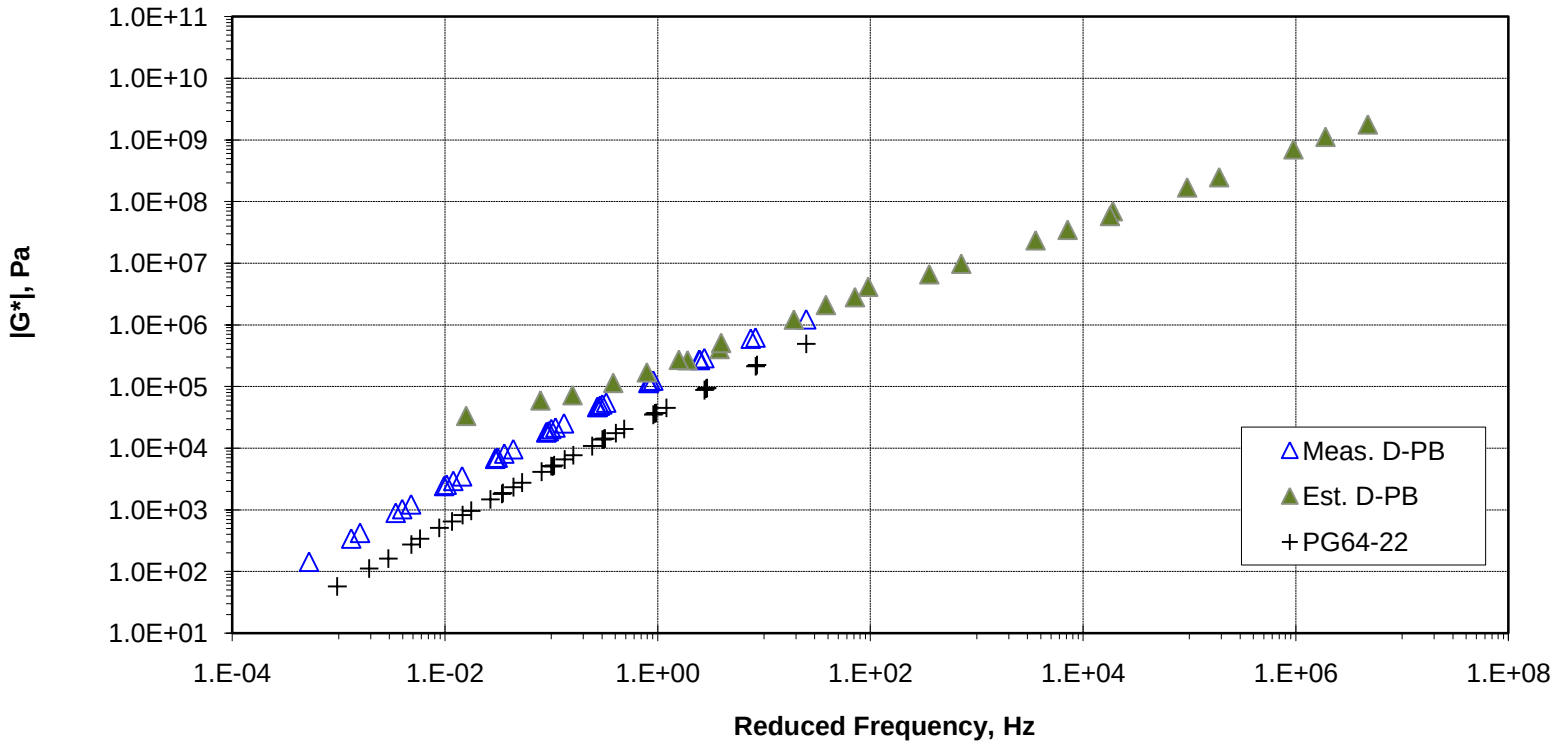
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. C-PB
Est. C-PB
PG64-22

# P&B Mix D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1.0E+07
1.0E+06
1.0E+05
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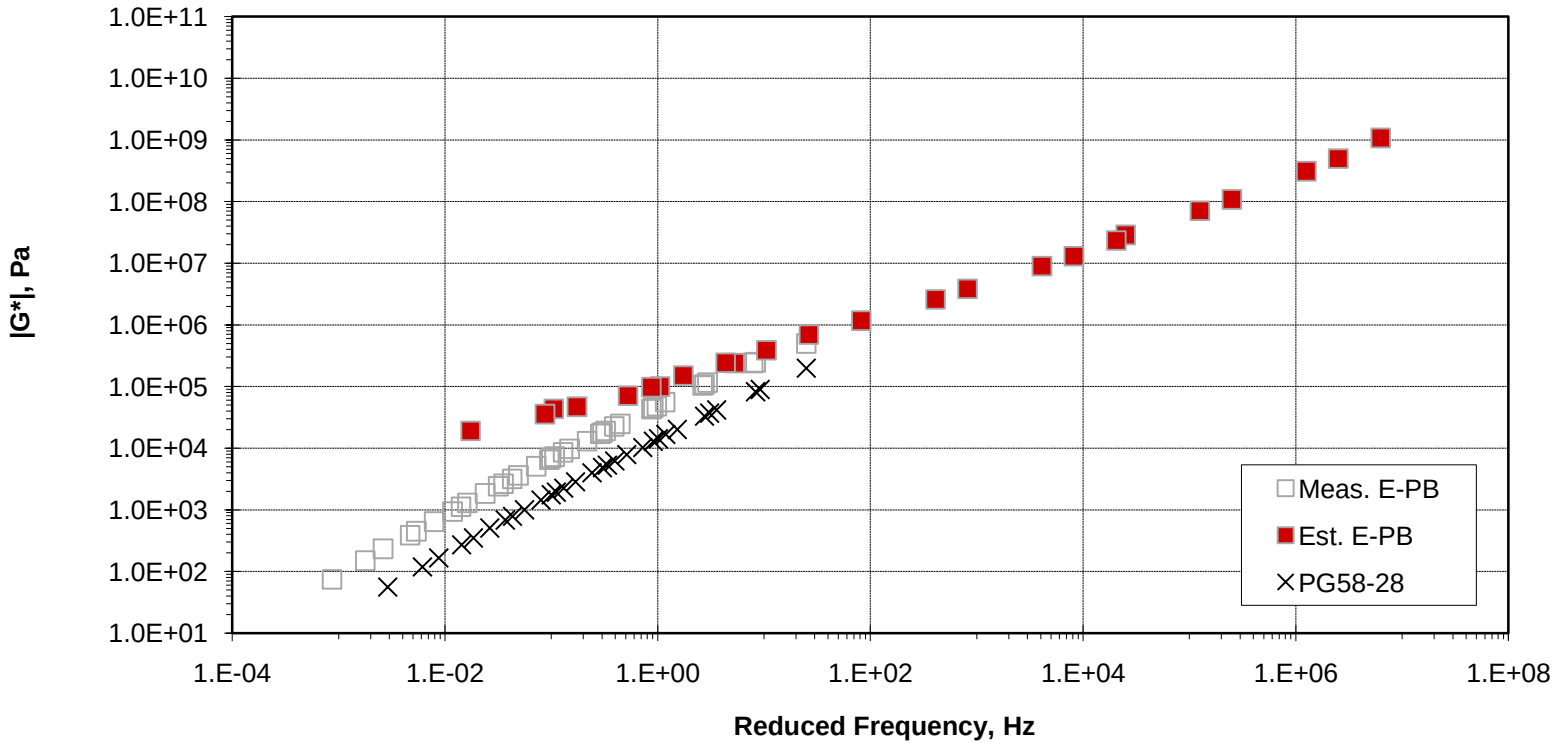
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. D-PB
Est. D-PB
PG64-22

# P&B Mix E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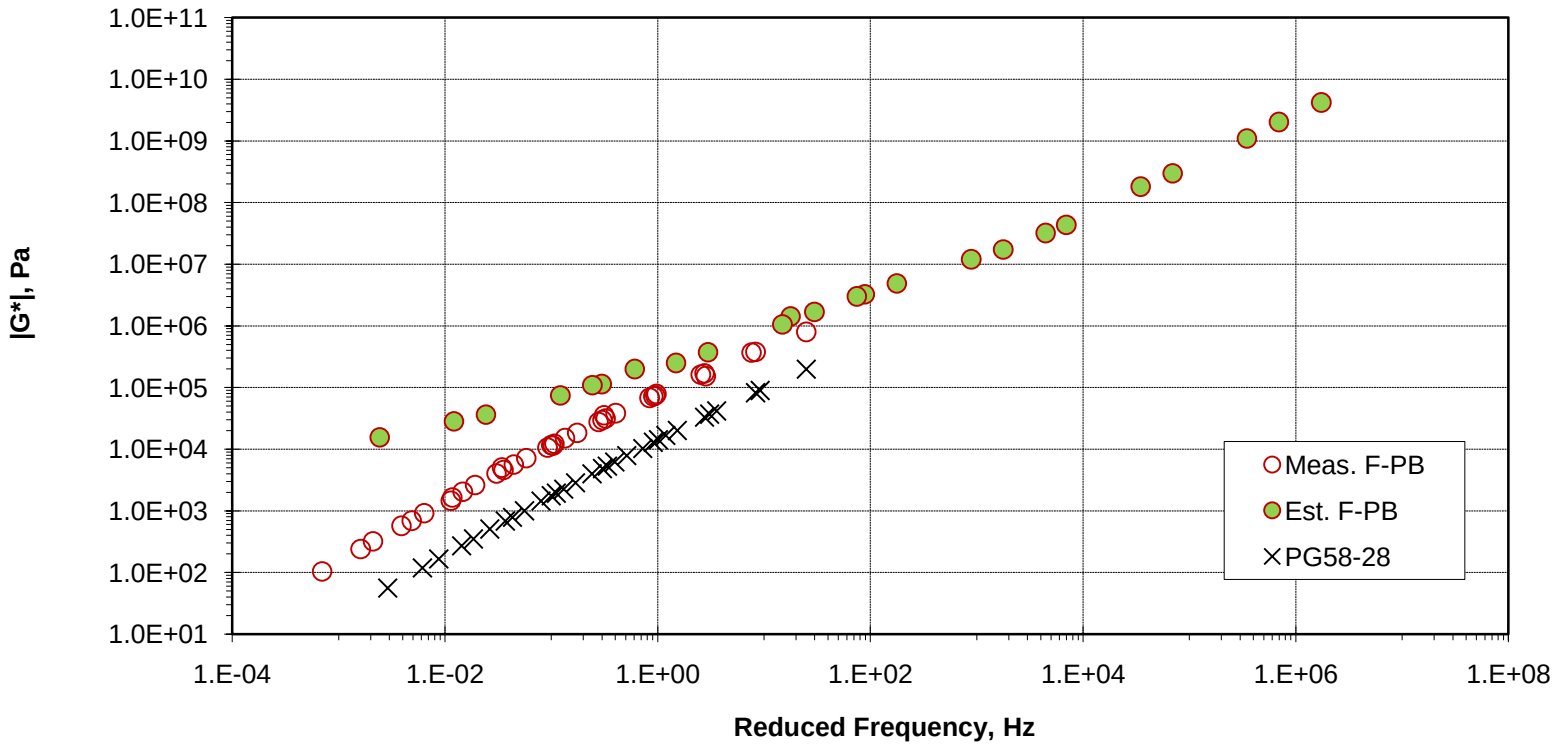
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. E-PB
Est. E-PB
PG58-28

# P&B Mix F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1.0E+07
1.0E+06
1.0E+05
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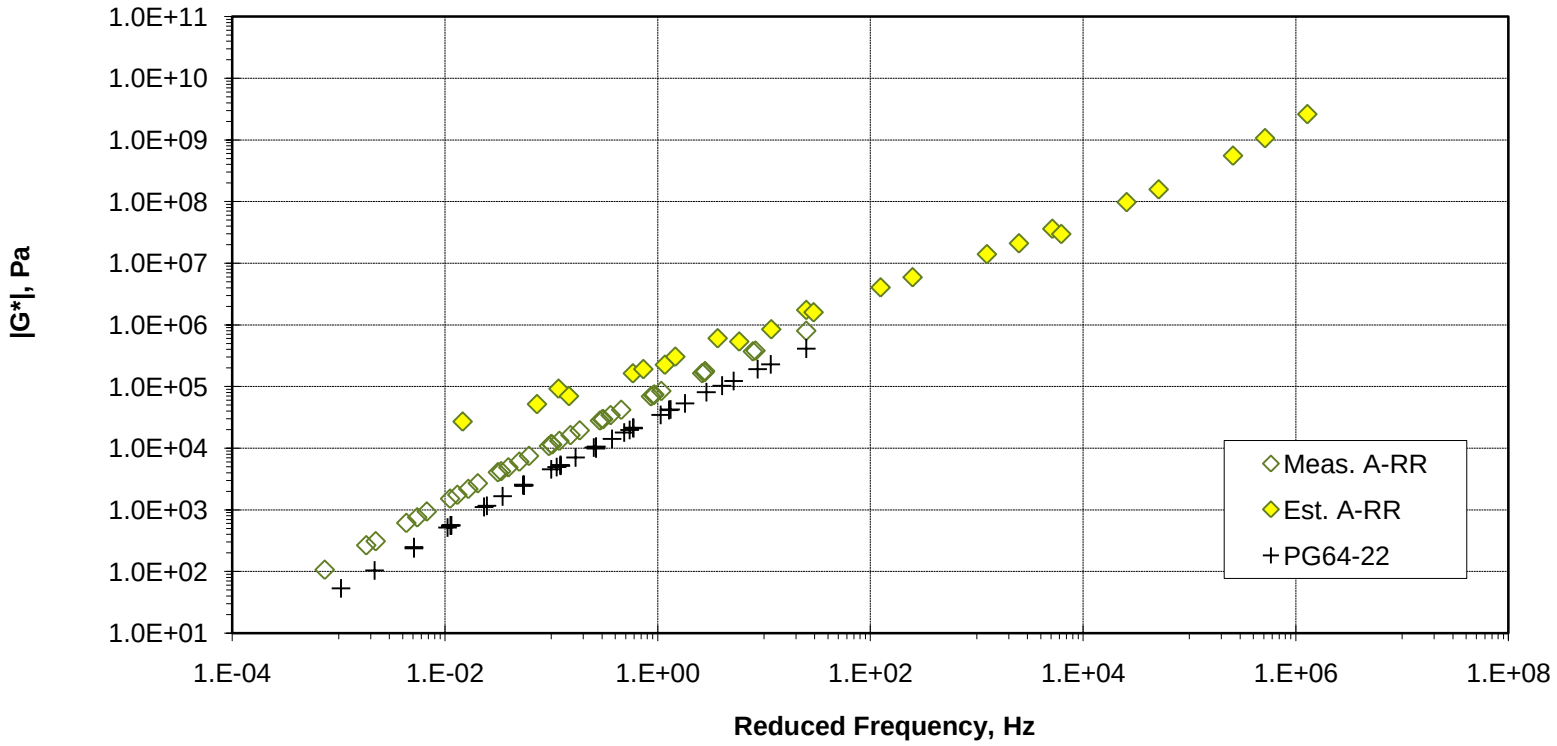
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. F-PB
Est. F-PB
PG58-28

# RR Mix A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1.0E+07
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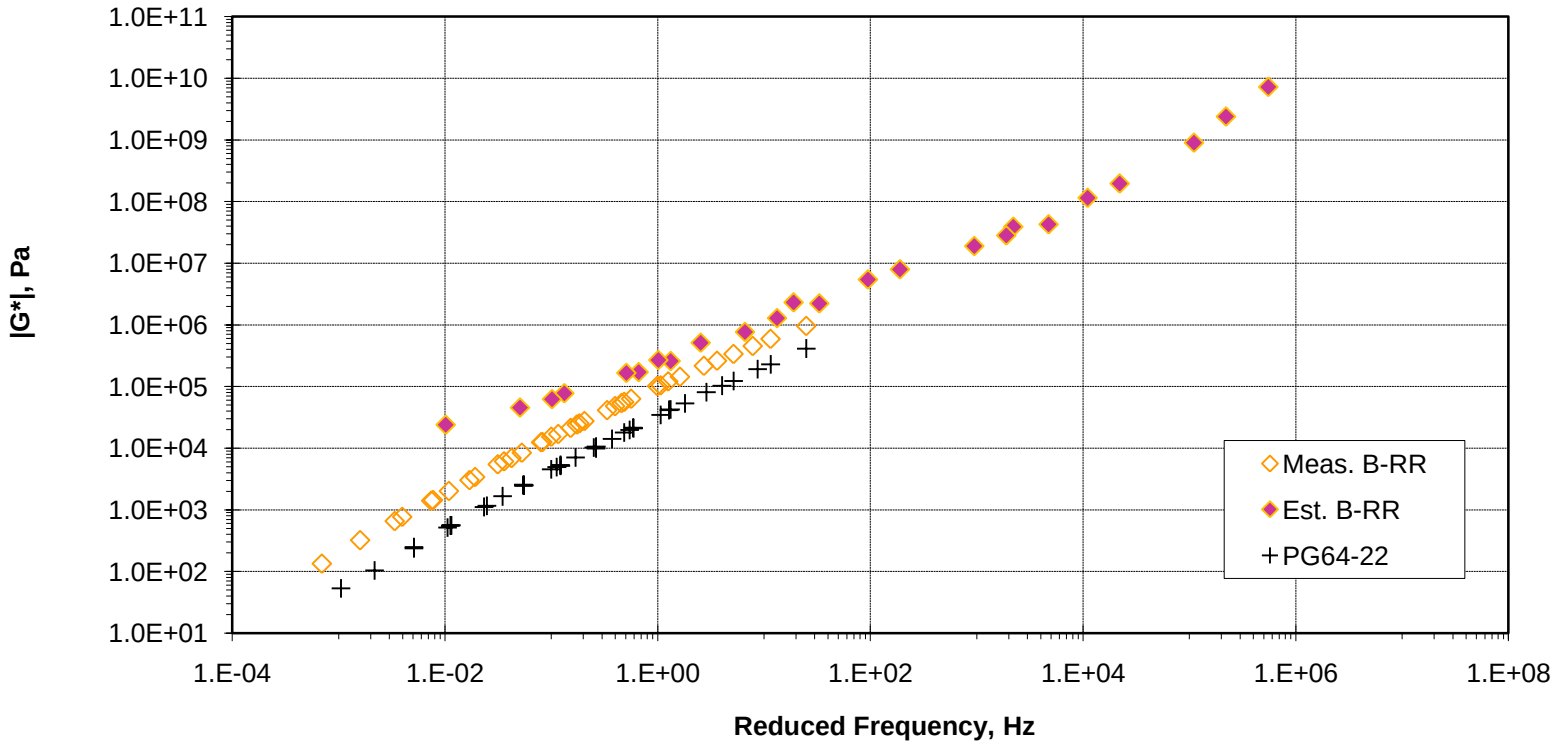
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. A-RR
Est. A-RR
PG64-22

# RR Mix B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1.0E+08
1.0E+07
1.0E+06
1.0E+05
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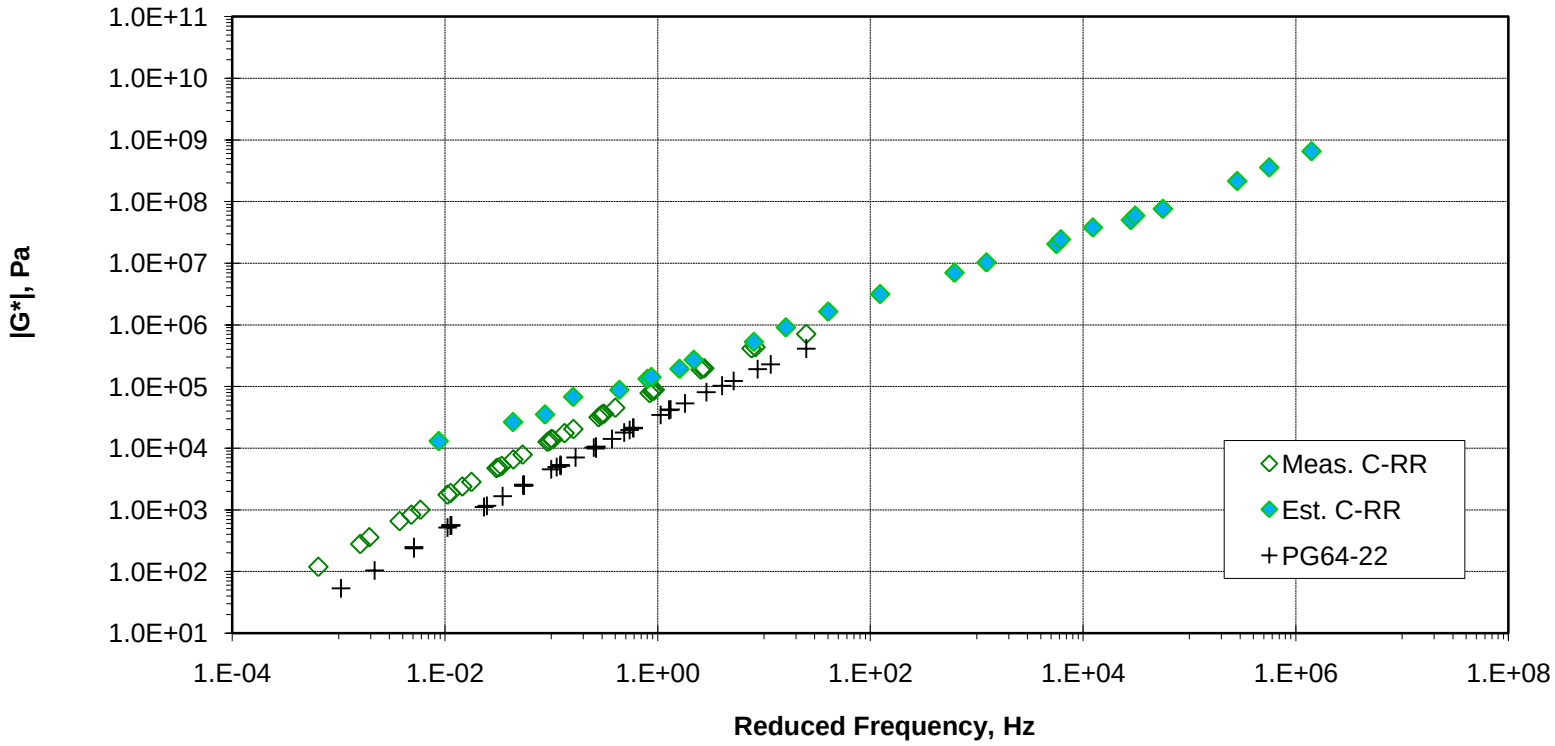
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. B-RR
Est. B-RR
PG64-22

# RR Mix C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1.0E+07
1.0E+06
1.0E+05
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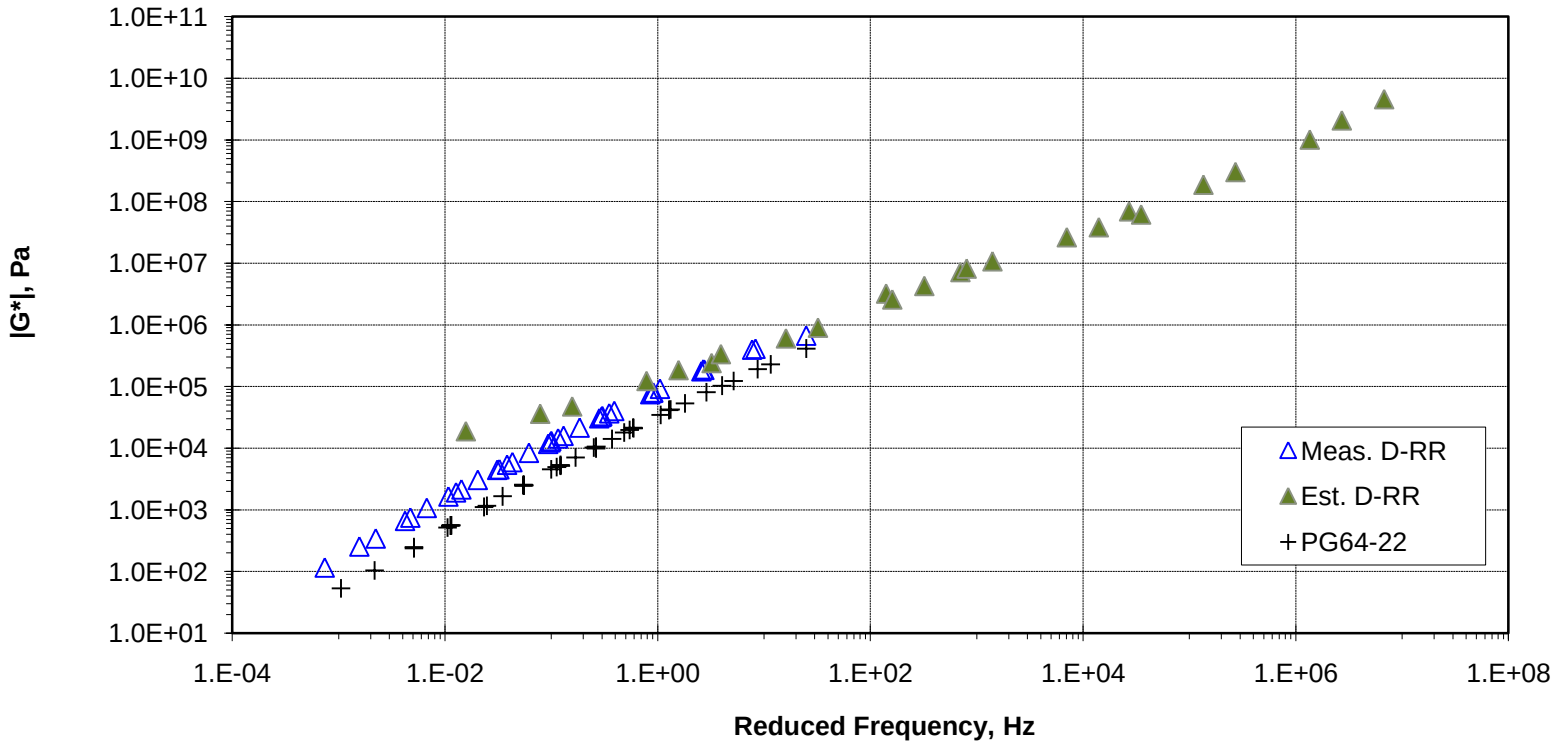
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. C-RR
Est. C-RR
PG64-22

# RR Mix D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1.0E+08
1.0E+07
1.0E+06
1.0E+05
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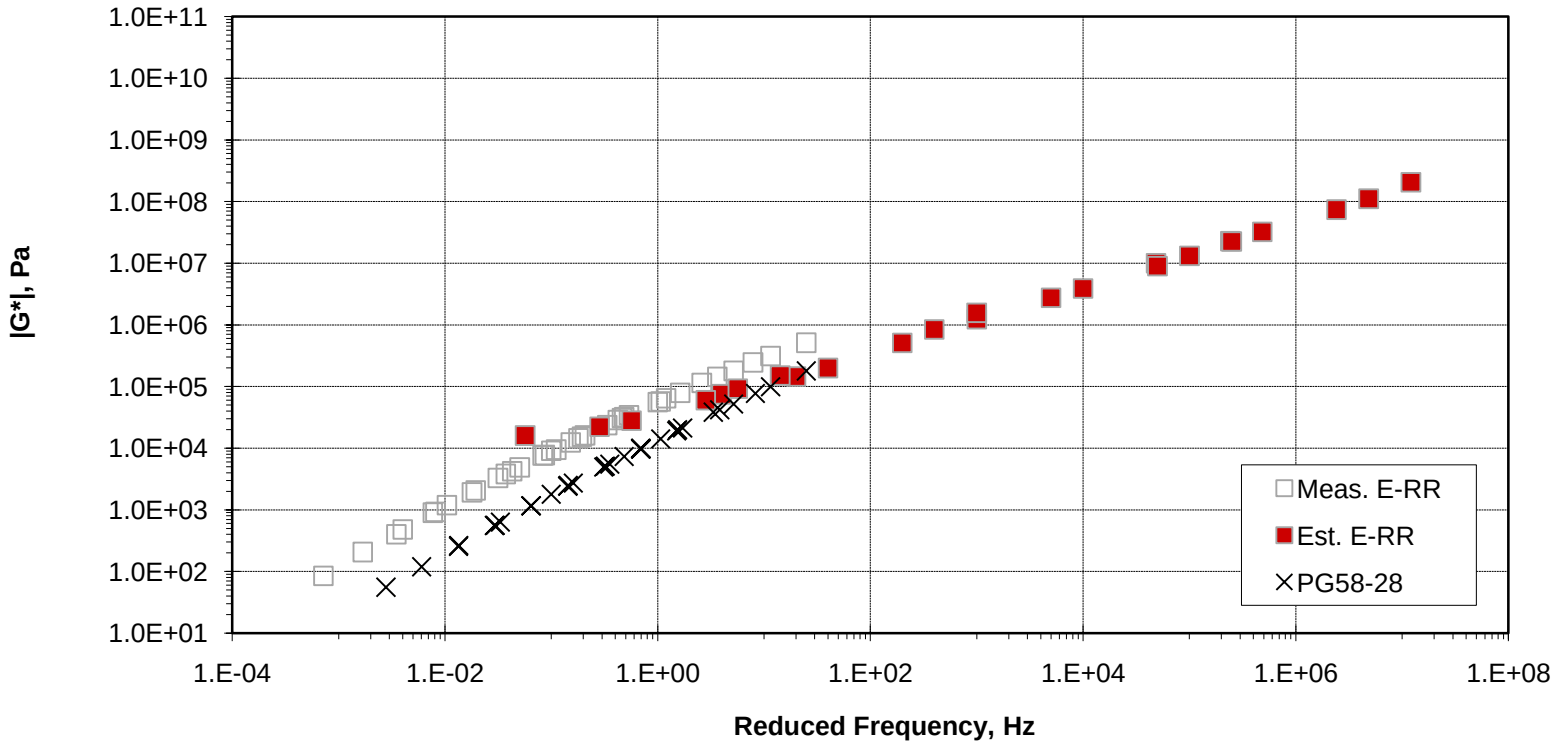
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. D-RR
Est. D-RR
PG64-22

# RR Mix E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1.0E+05
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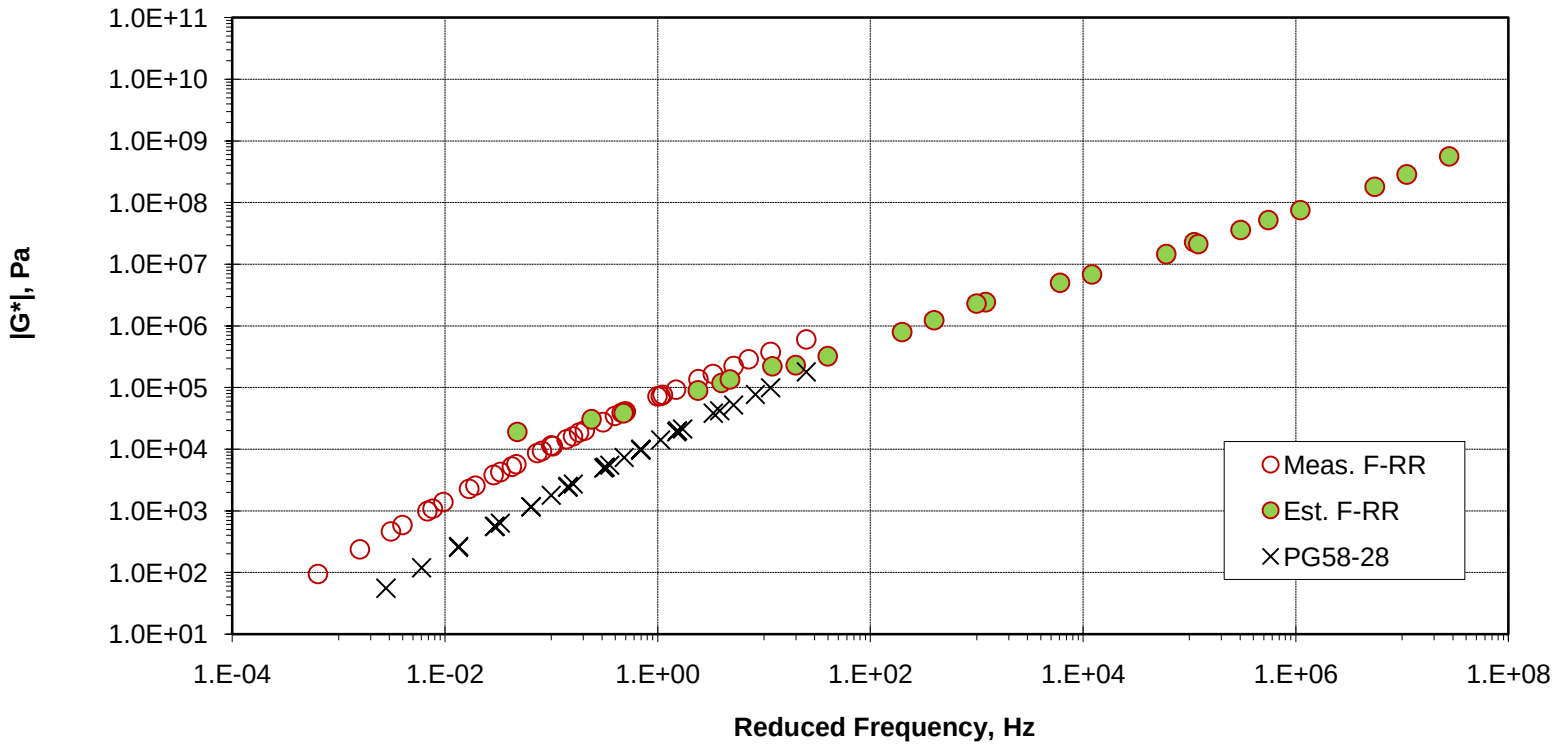
1.0E+03
1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. E-RR
Est. E-RR
PG58-28

# RR Mix F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1.0E+05
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1.0E+02
1.0E+01
|G*|, Pa
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
1.E+08
Reduced Frequency, Hz
Meas. F-RR
Est. F-RR
PG58-28

# What Does This Mean?

- Two cases indicated pretty good blending, two maybe questionable
- Relates to other comparisons
  - IDT indicated little effect of binder grade in the cases with questionable blending

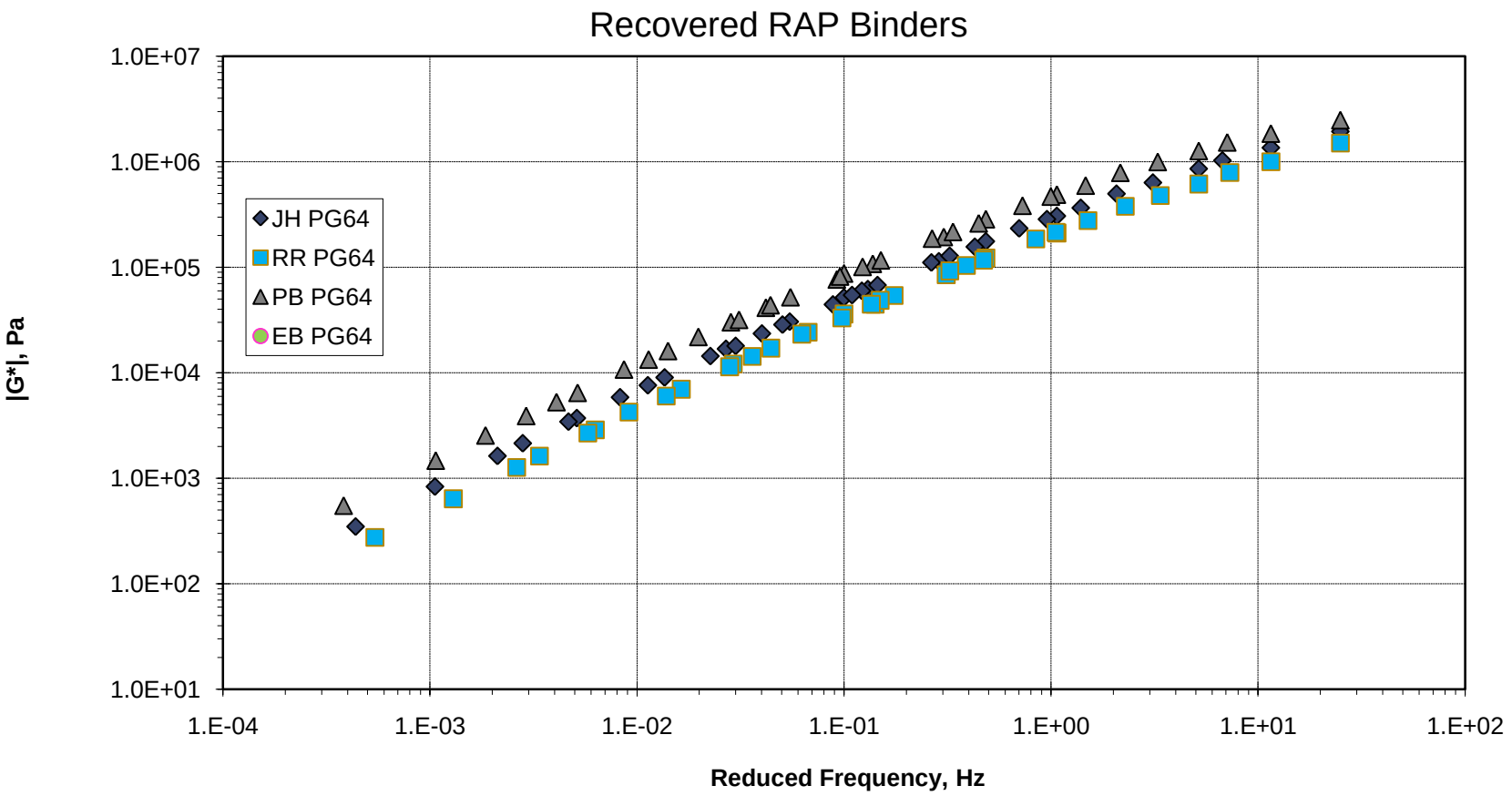
# Impacts of Blending on Performance

- If we assume there is blending and there isn't, virgin binder grade may be softer than desired.
  - Increased chance for rutting
  - Decreased chance for cracking
- If we assume there is no blending and there is, effective binder grade may be stiffer than desired.
  - Decreased chance for rutting
  - Increased chance for cracking

# Risks of False Assumptions

- Assuming there is blending may be more conservative.
  - Shouldn’t rely on binder to control rutting
  - Increased cracking can have performance and economic impacts
- But, if the RAP binder does not blend and act like binder, mix could be under-asphalted.

# Recovered RAP Binder Comparison



# Percent of Mix or Binder?

- Compared three different RAPs from P&B
  - Surface Millings 5.4% binder
  - Full Depth Millings 4.2%
  - Crushed and Screened 3.7%
- As binder content decreases, could use more RAP on % binder replacement basis

# DISCUSSION