Title: Exploring the Viscoelastic Properties of PAA Phantoms

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Abstract: A gel that has similar thermodynamic properties to human tissue is necessary for determining the safety of implanted medical devices during magnetic resonance imaging (MRI). One particular gel recommended by the ASTM standard (F218209) is the polyacrylic acid (PAA) phantom. In this work, PAA mixtures were characterized by measuring viscosity (as a function of shear rate), electrical conductivity, thermal conductivity, and elastic and viscous moduli (as a function of frequency). Experiments compared samples with blend times between 30 seconds and 9 minutes, and measurements were taken over a period of weeks to document the aging process in the phantoms. Results suggest that 3 minutes or more of blending 500 mL quantities causes the sample to transform from a gel (which has a well-defined yield stress) into a viscous liquid. The same transformation was observed in a single sample over a period of two weeks. These results are important because the current ASTM standard does not specify blending time in detail. It is therefore possible that variability in the gel preparation methods could affect the results of experiments to determine the safety of implanted medical devices. These results will help to strengthen the ASTM standard procedure in future revisions.

Exploring the viscoelastic properties of PAA phantoms

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MRI implant heating experiments

- Complications from implant
- Implant reacts to magnetic field: heating
- Determine temperature rise induced by MRI

Polyacrylic acid (PAA) phantom

- Widely used for MRI implant heating experiments
- Instructions for fabrication in ASTM standard

ASTM Standard (F2182–09)

1.32 g/L NaCl and 10 g/L PAA in water

"Preparation of PAA gelled saline:
(1) Add NaCl to water and stir to dissolve completely.

(2) Add PAA, stir to suspend completely.

(3) After one hour, blend the suspension into a slurry. A kitchen grade immersion blender with a blade has been found to be satisfactory. The blender is turned on intermittently for at least 20 min in order to remove all lumps of any discernable size.

(4) The slurry is ready to use after 24 h. Stir occasionally. The appearance of the slurry should be semi-transparent, free of bubbles, and free of lumps of any discernable size.

"The viscosity shall be great enough so that the phantom material does not allow bulk transport or convection currents. Generally, this is achieved by inclusion of a gelling agent."

"The gelled saline should have a shelf life of two months. However, a new batch of gelled saline is needed when there is a change in any property, such as volume, conductivity, color, or viscosity."

Very Brief Intro to Rheology

Difference between gel and viscous liquid?

Gel has yield stress, and
elastic modulus > viscous modulus

Thus below a certain stress, gel does not flow, i.e. no convection!

In a viscous liquid, convection will occur

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"The gelled saline should have a shelf life

Will the ambiguous variables in the standard affect the outcome of MRI implant heating experiments?

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Blend time

Sample aging

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andpaper)
ple
plate
aper)

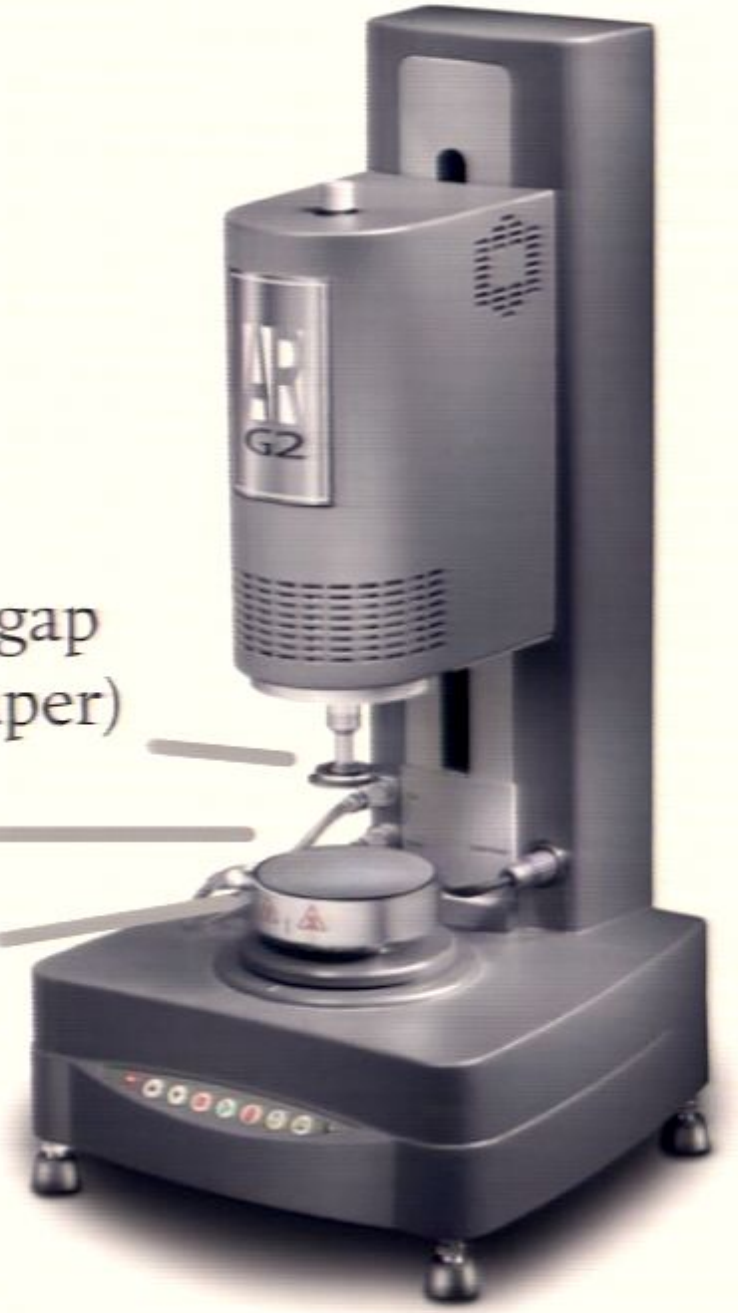
AR 1500ex rheometer

- stress-controlled

Rotating top cone with geometry gap
(with sandpaper)

Fluid Sample

Stationary bottom plate
(with sandpaper)



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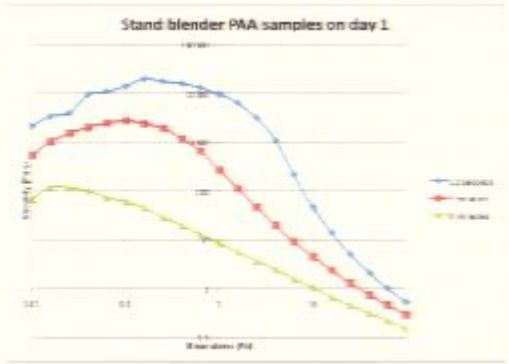
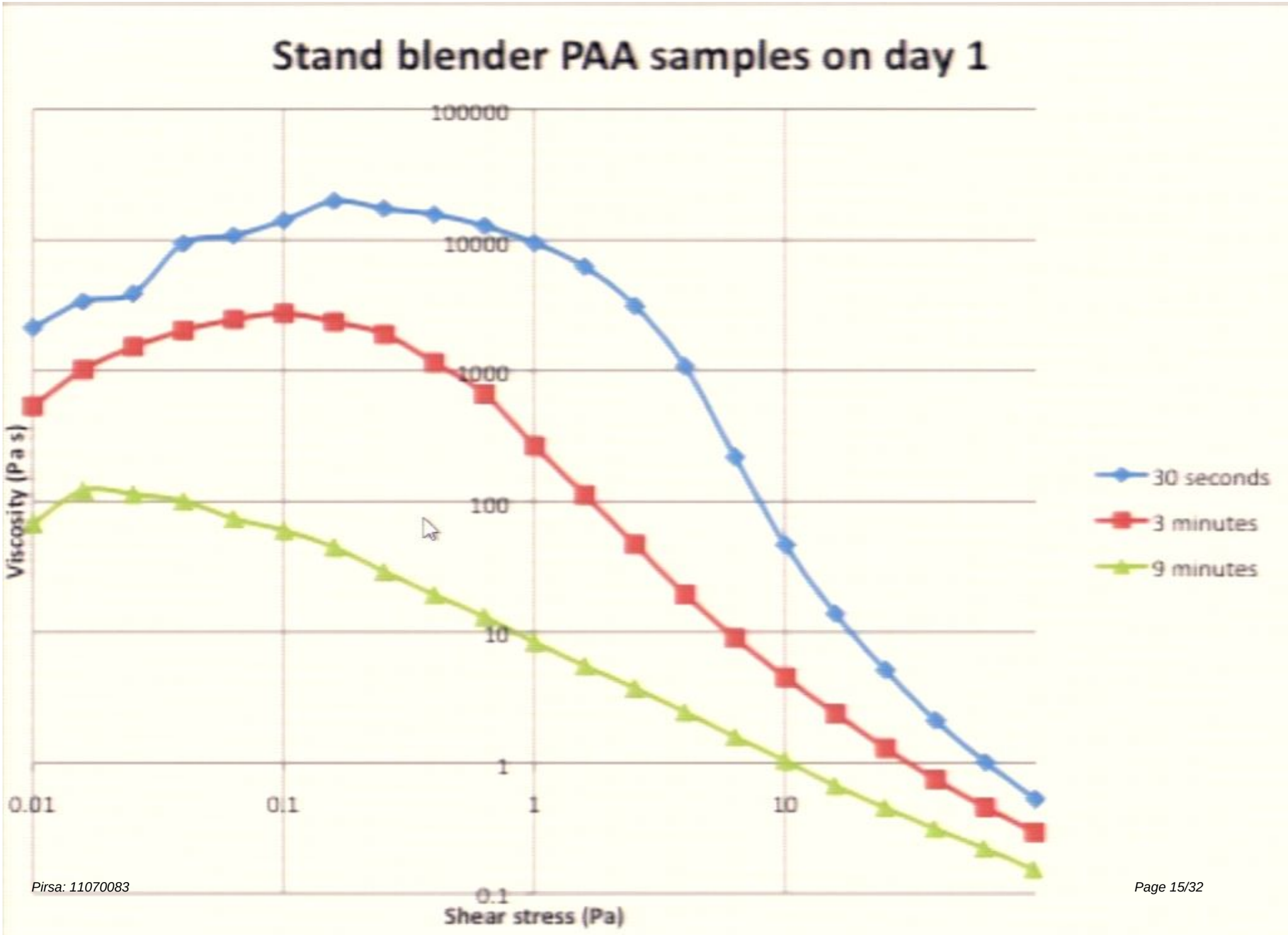
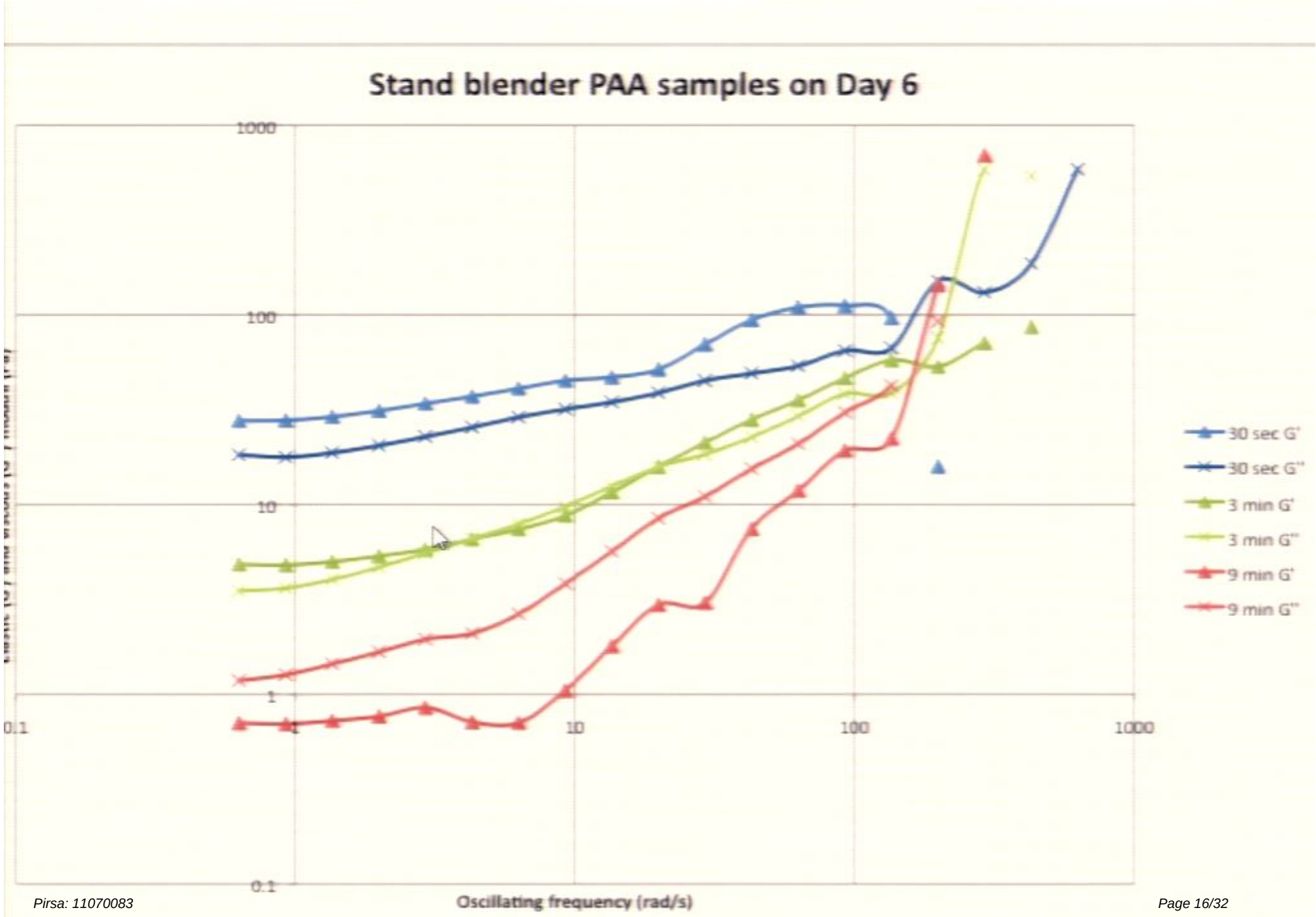
Parameters

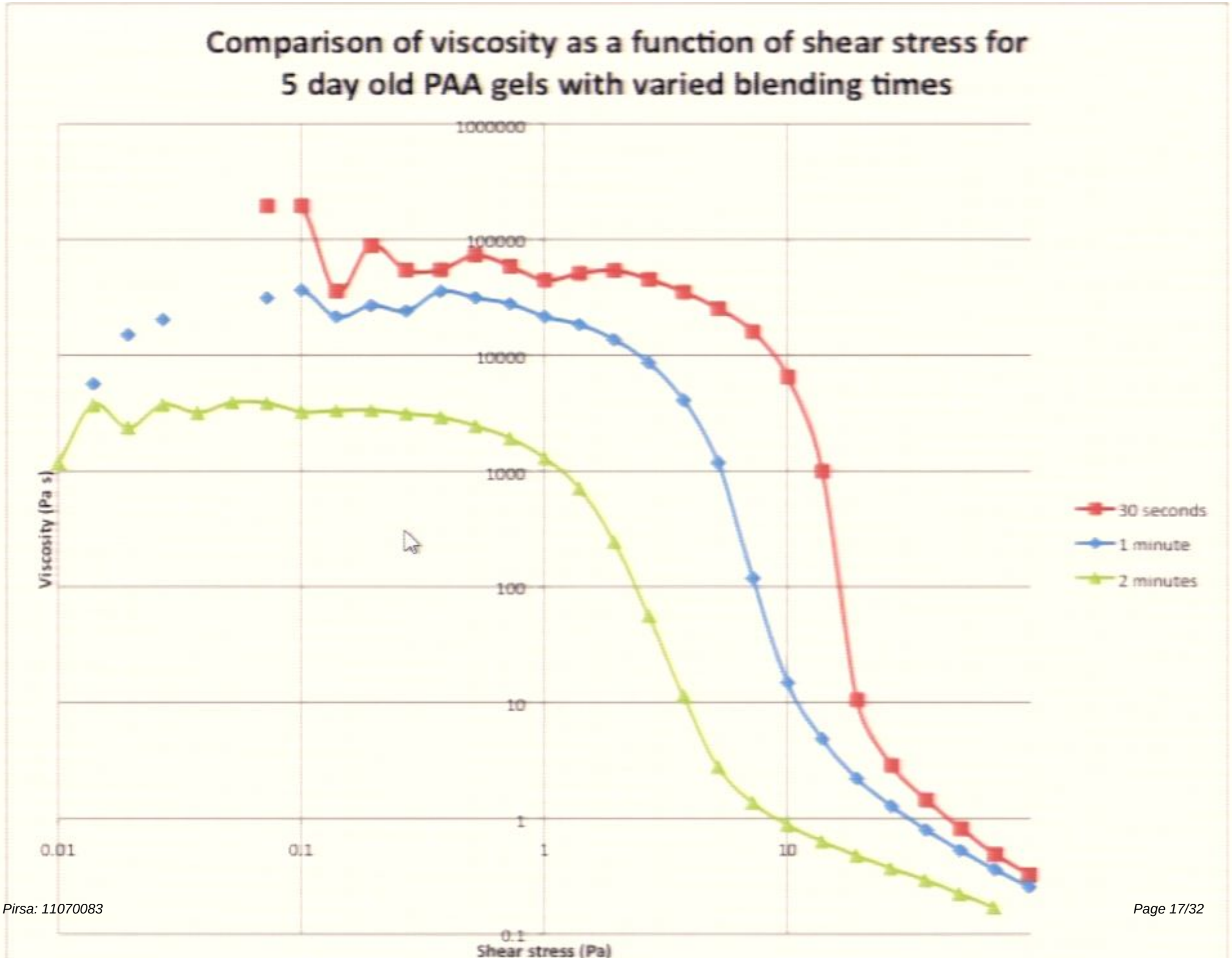
- viscosity
- elastic and viscous moduli

Blend time experiments

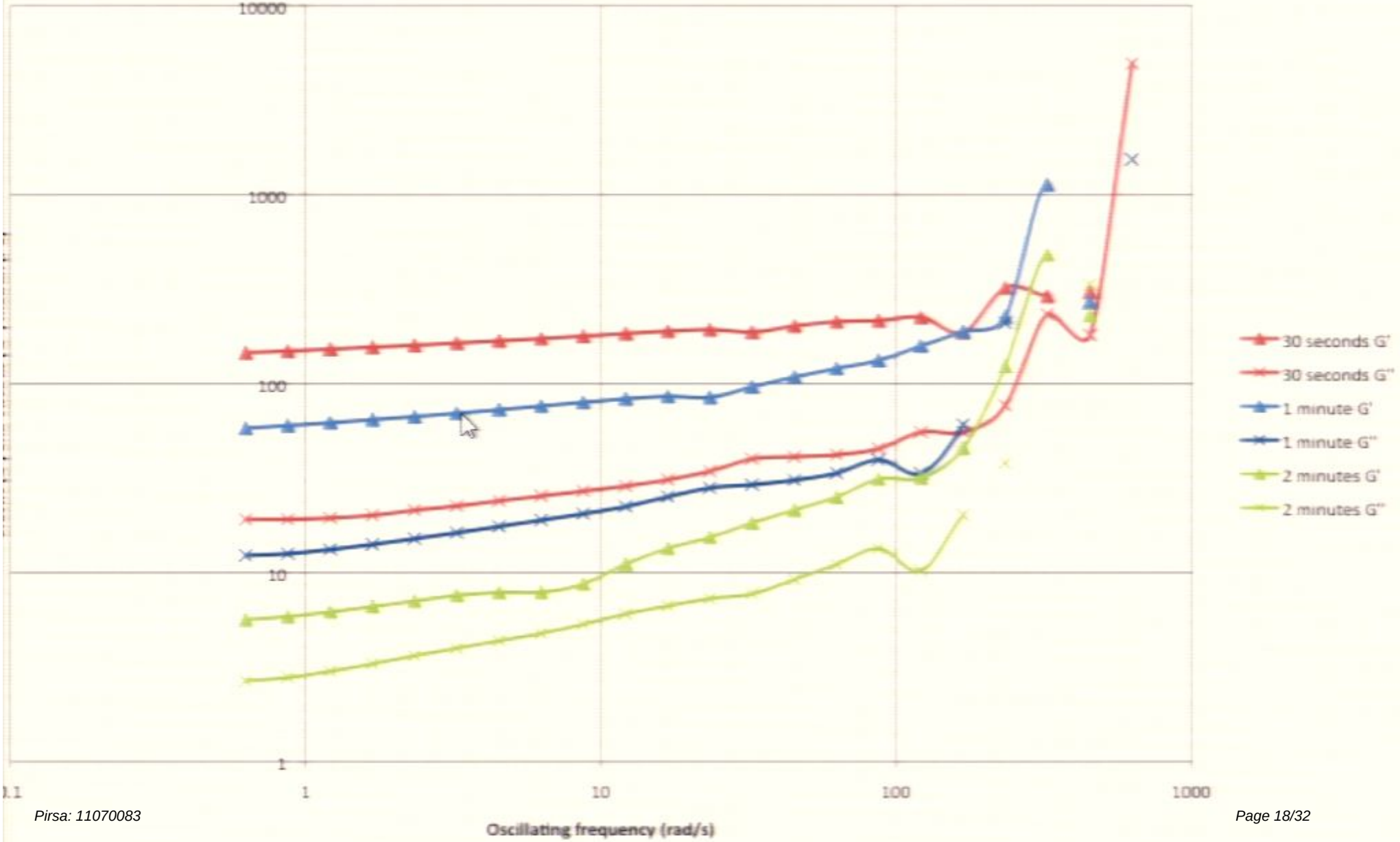



Stand blender PAA samples on day 1
100000
10000
1000
100
10
1
0.1
0.01
0.1
1
10
Viscosity (Pa s)
Shear stress (Pa)
30 seconds
3 minutes
9 minutes

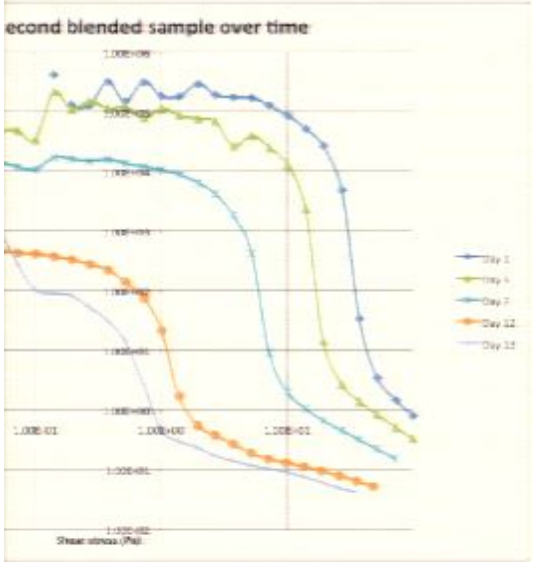

Stand blender PAA samples on Day 6
1000
100
10
1
0.1
0.1
1
10
100
1000
Oscillating frequency (rad/s)
30 sec G'
30 sec G''
3 min G'
3 min G''
9 min G'
9 min G''

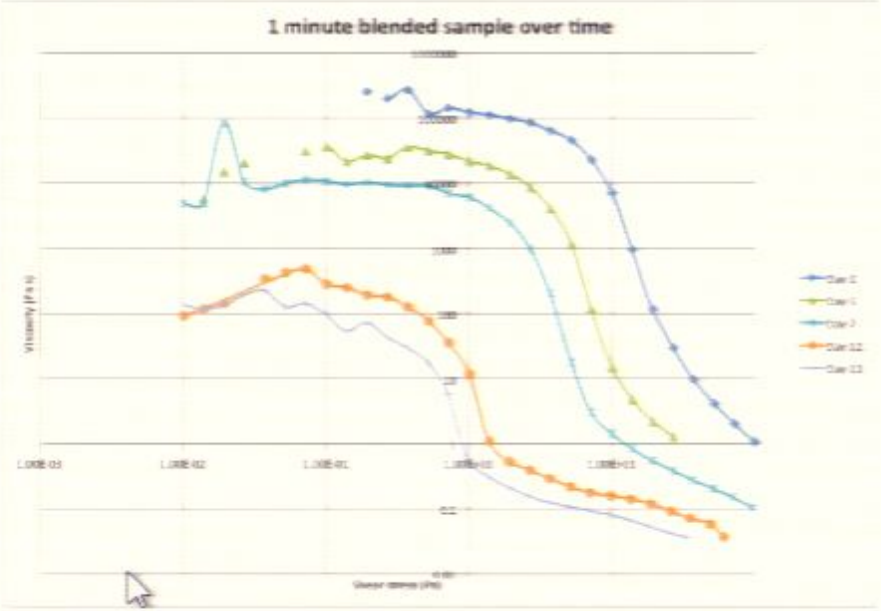

Comparison of viscosity as a function of shear stress for 5 day old PAA gels with varied blending times
Viscosity (Pa s)
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.1
1
10
Shear stress (Pa)
30 seconds
1 minute
2 minutes

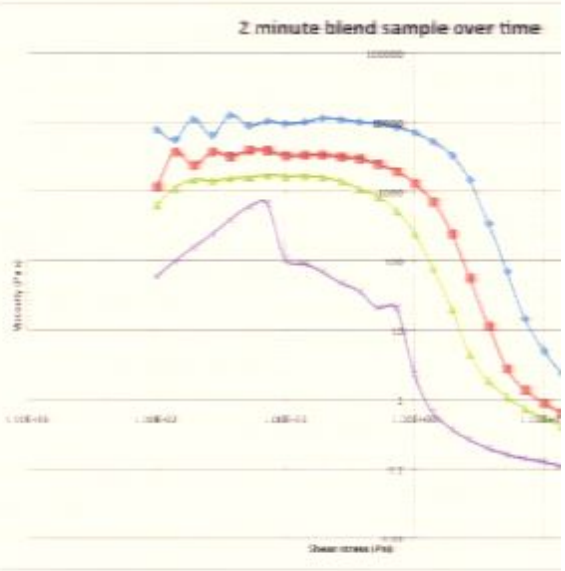
Comparison of elastic and viscous moduli as a function of oscillating frequency for 5 day old PAA gels with varied blending times

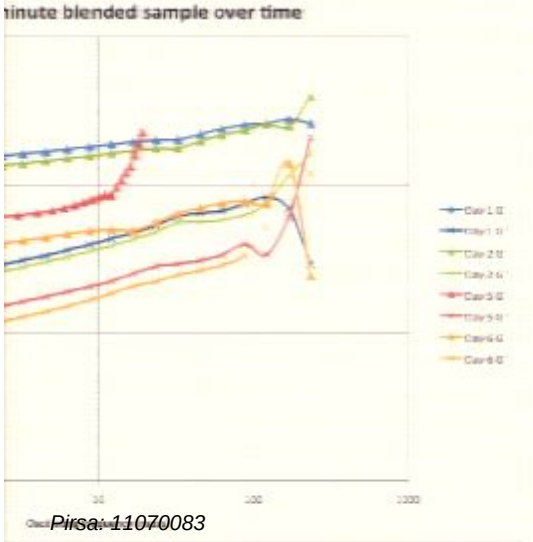


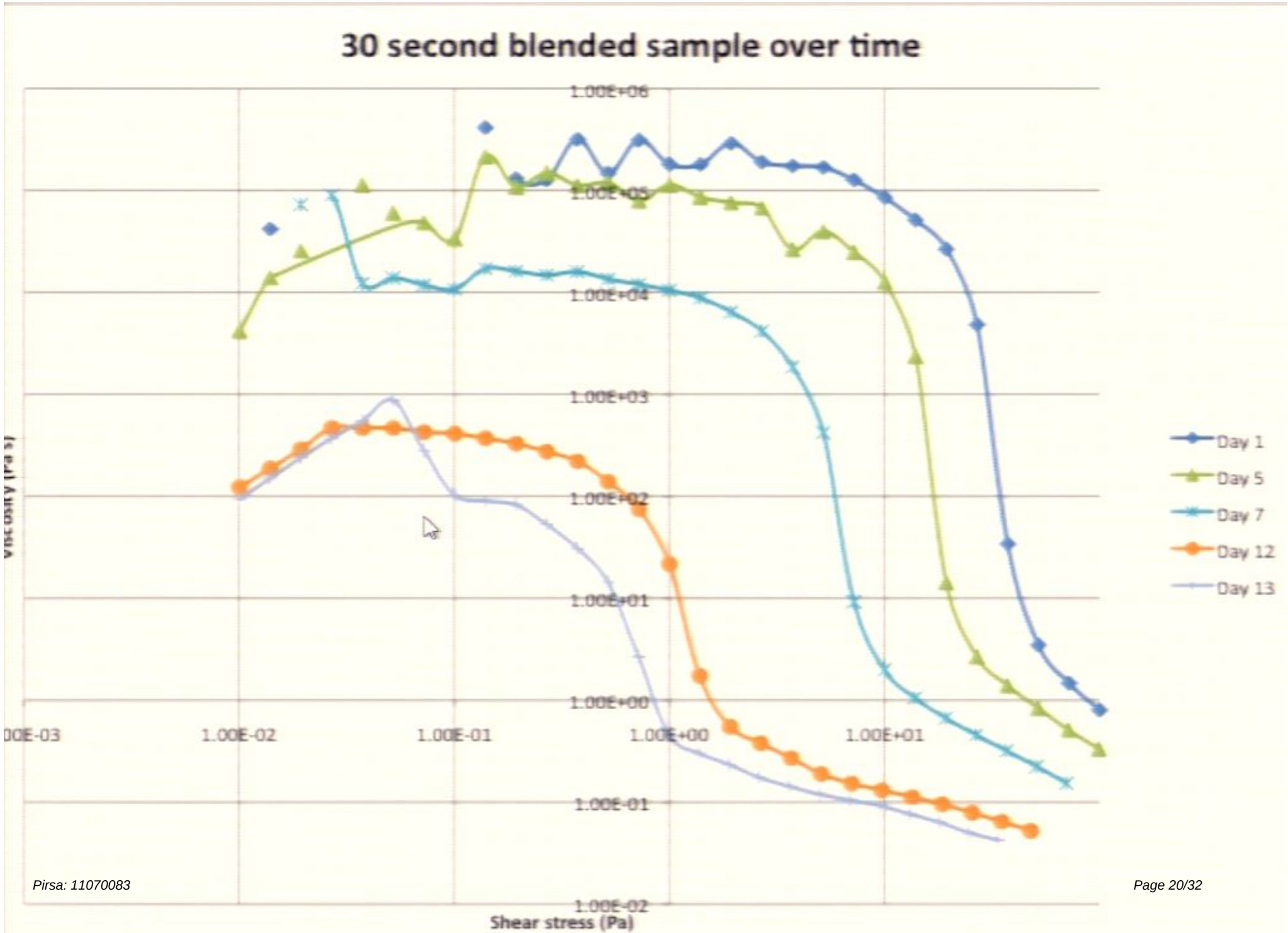
Aging experiments

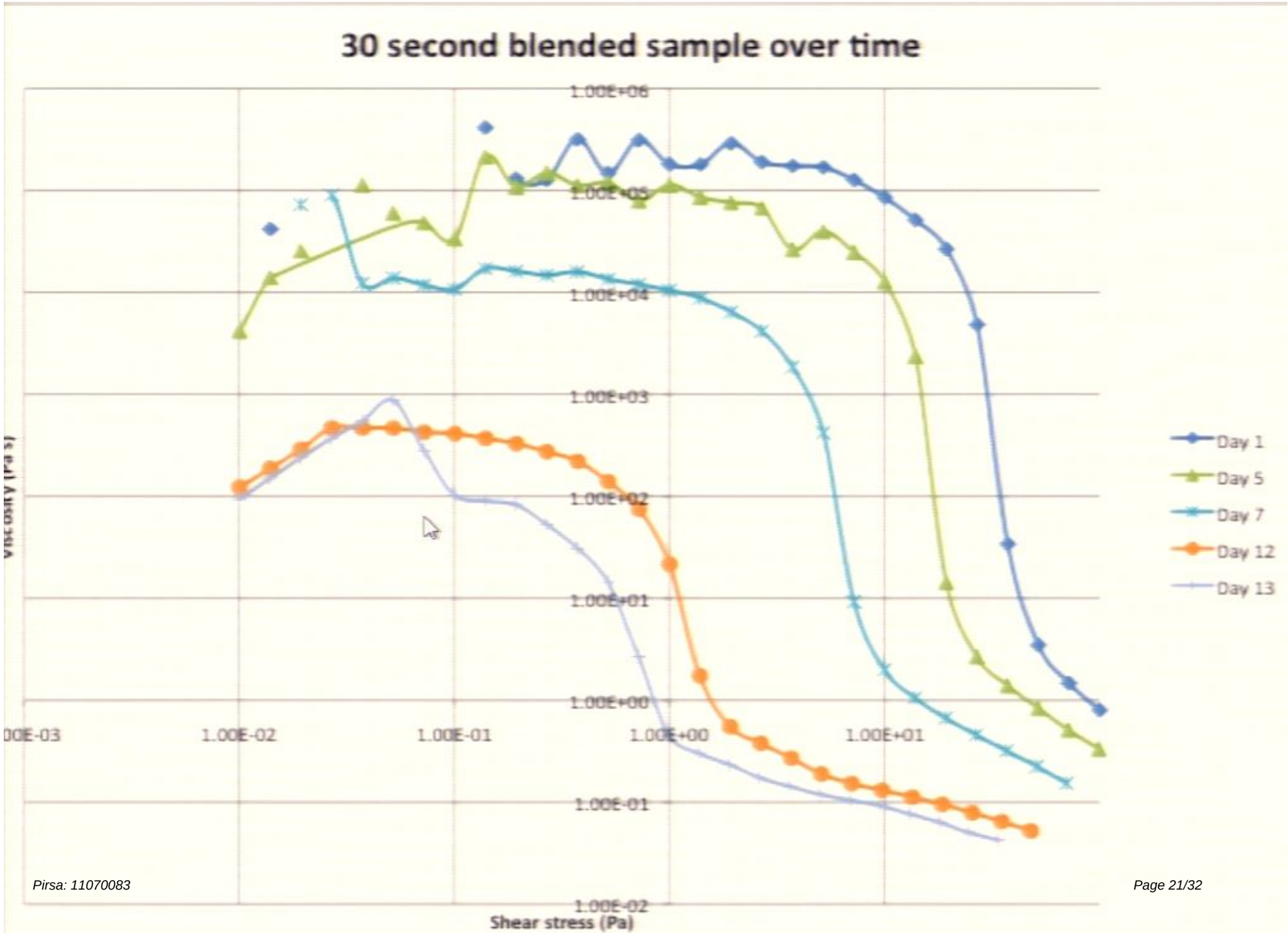









30 second blended sample over time
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
Shear stress (Pa)
Day 1
Day 5
Day 7
Day 12
Day 13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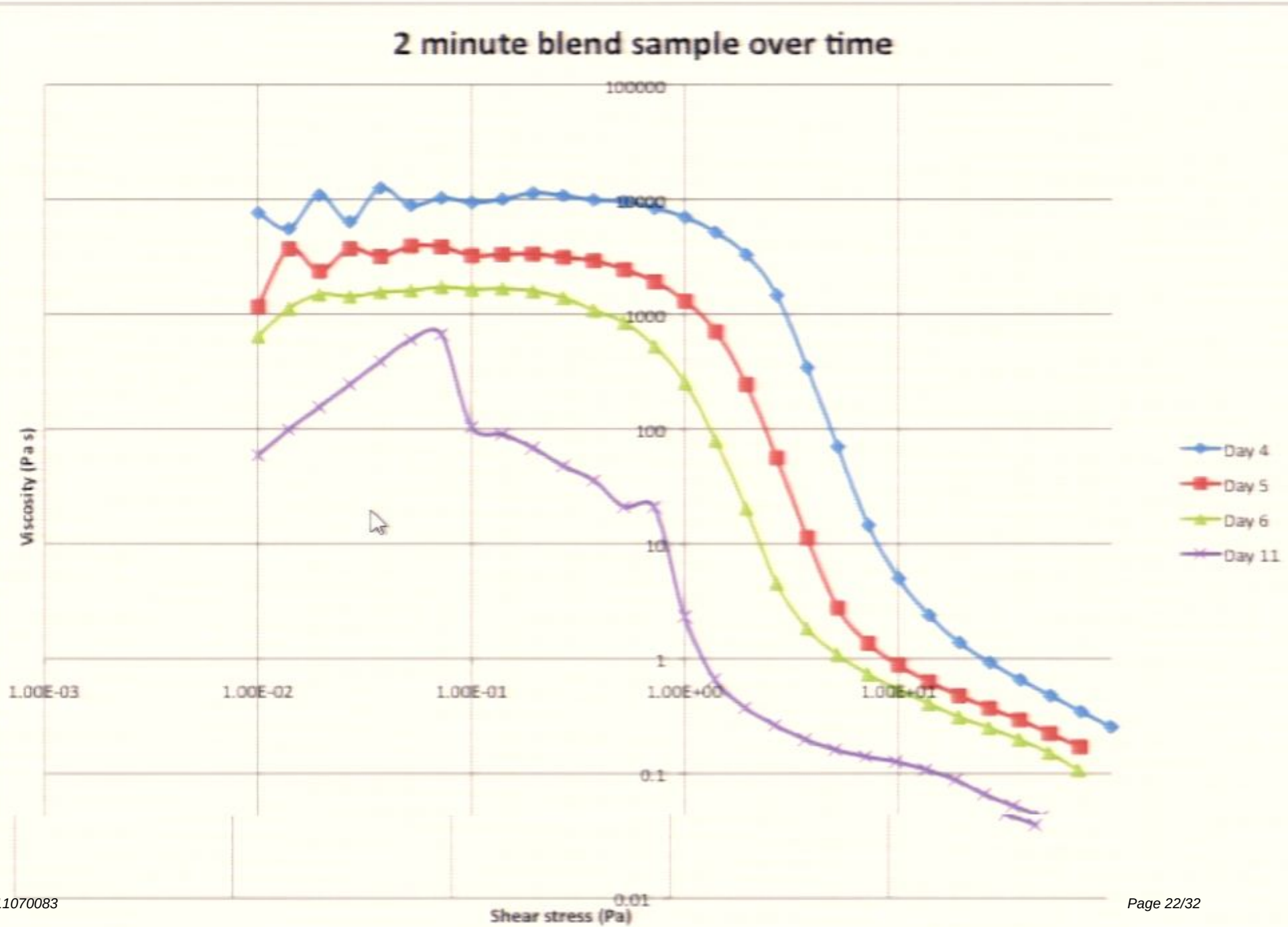
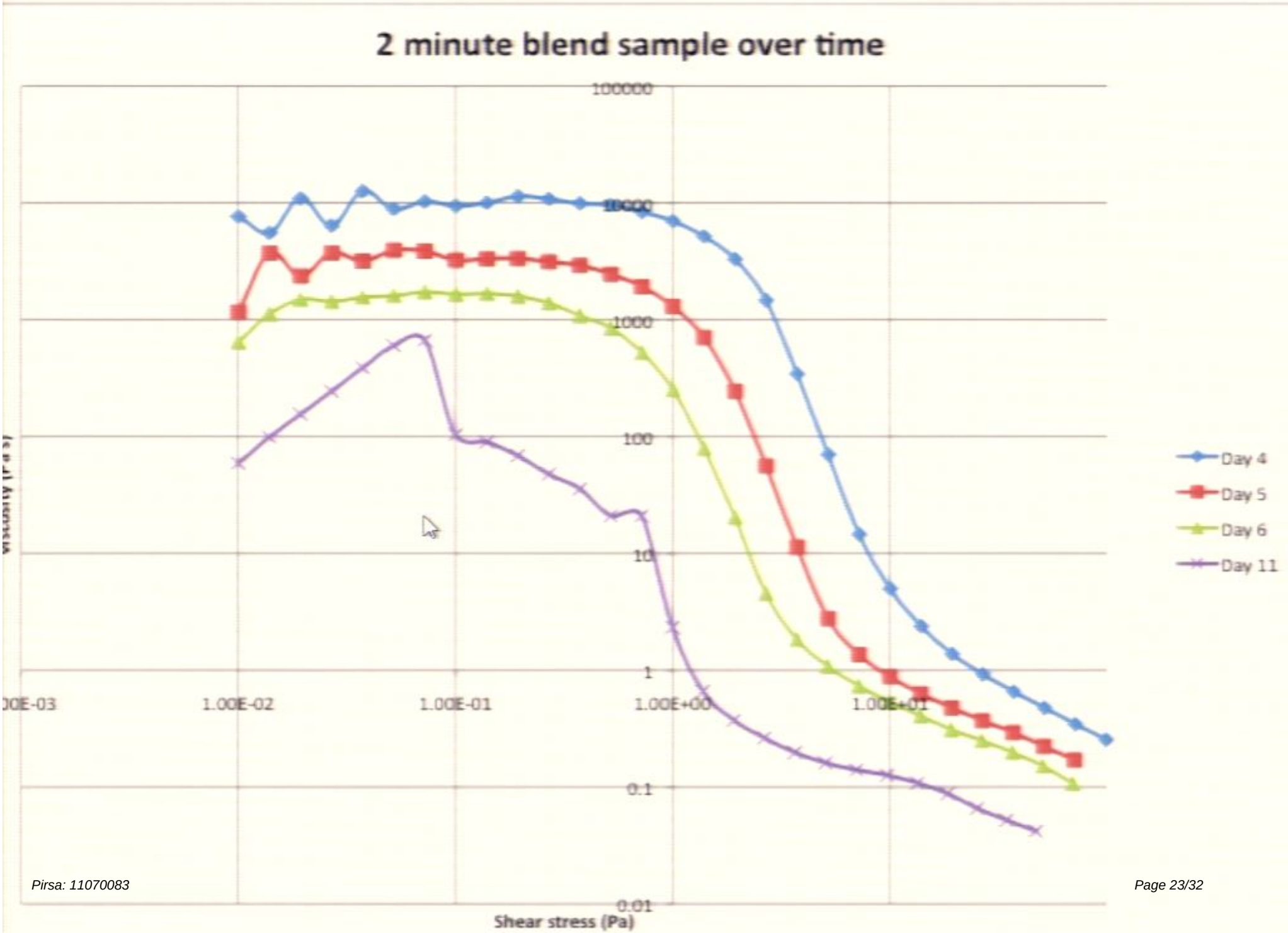
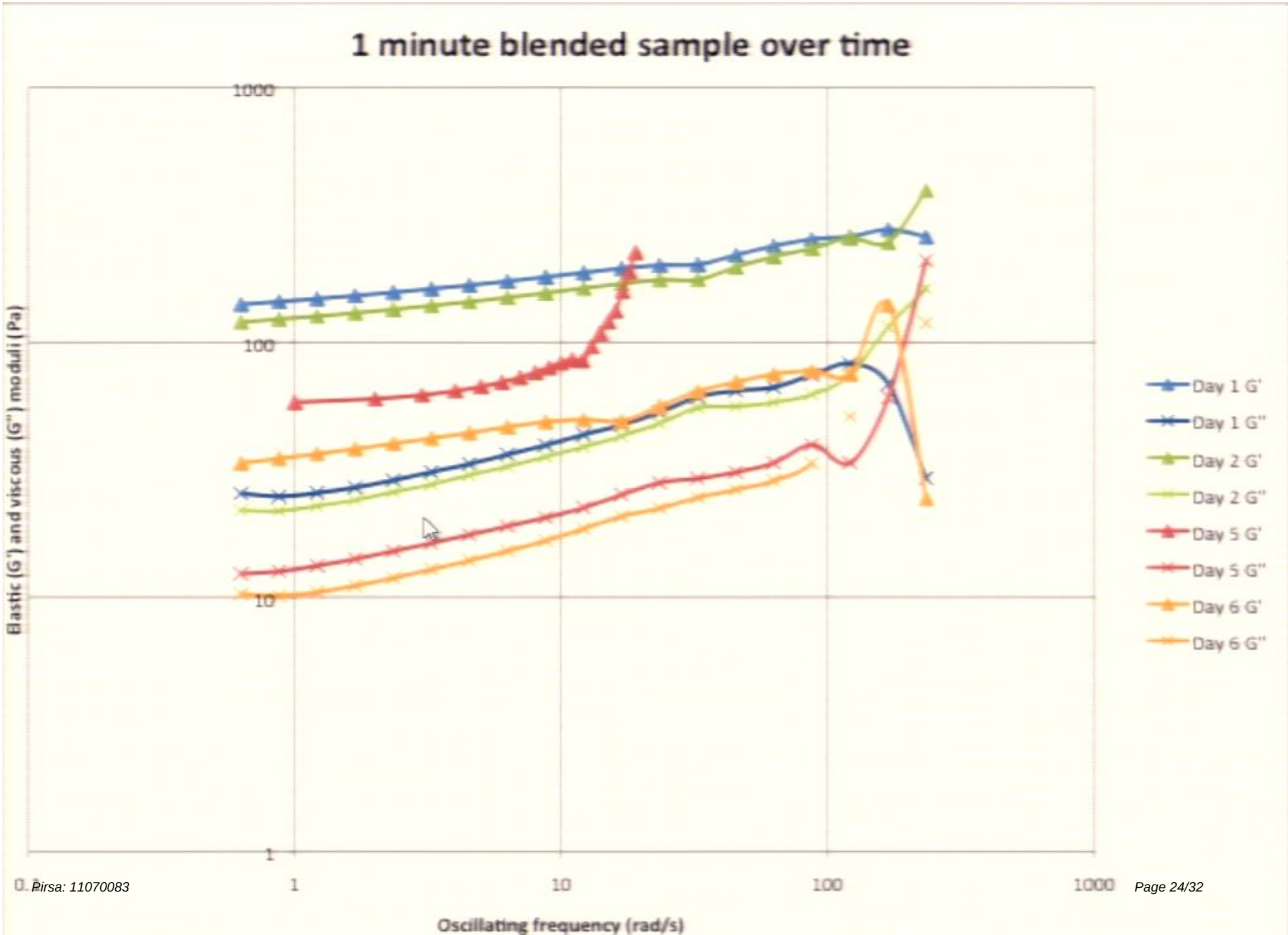
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
Shear stress (Pa)
Day 1
Day 5
Day 7
Day 12
Day 13


2 minute blend sample over time
Viscosity (Pa s)
100000
10000
1000
100
10
1
0.1
0.01
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
Shear stress (Pa)
Day 4
Day 5
Day 6
Day 11


2 minute blend sample over time
100000
10000
1000
100
10
1
0.1
0.01
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
Shear stress (Pa)
Day 4
Day 5
Day 6
Day 11


1 minute blended sample over time
Elastic (G') and viscous (G") moduli (Pa)
1000
100
10
1
0.1
1
10
100
1000
Oscillating frequency (rad/s)
Day 1 G'
Day 1 G"
Day 2 G'
Day 2 G"
Day 5 G'
Day 5 G"
Day 6 G'
Day 6 G"

Conclusions

Blend time drastically affects viscoelastic properties

- Too much blending ruins the phantom
- Maximum blend time should be added to standard

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Phantom changes significantly after only 2 weeks

- Change expiration date in standard

Next steps

- Make standard sized sample
- Perform MRI experiments

Hopefully, paper will induce changes in standard

Questions?

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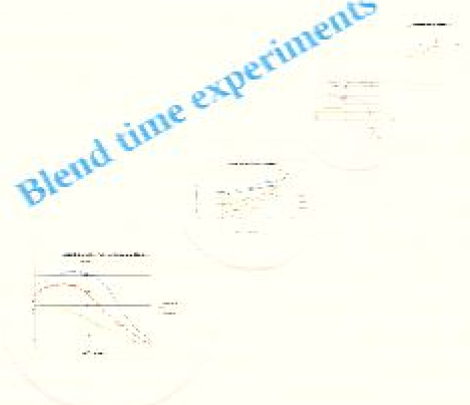
Very Brief Intro to Rheology

Blend time experiments



Parameters

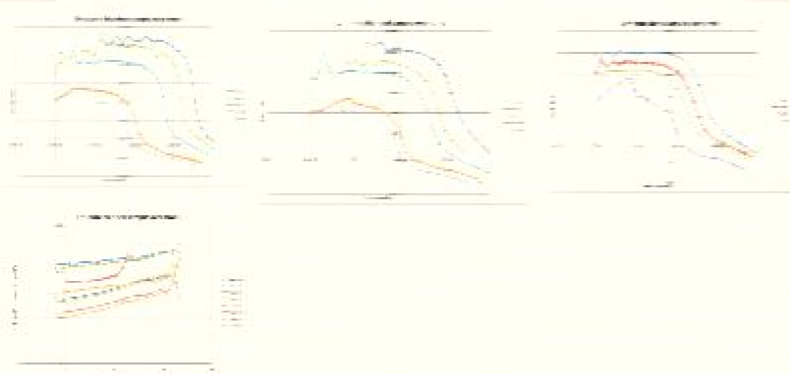
- viscosity
- elastic and viscous moduli

AR 1500ex rheometer
- stress-controlled

Blend time

Sample aging

Aging experiments



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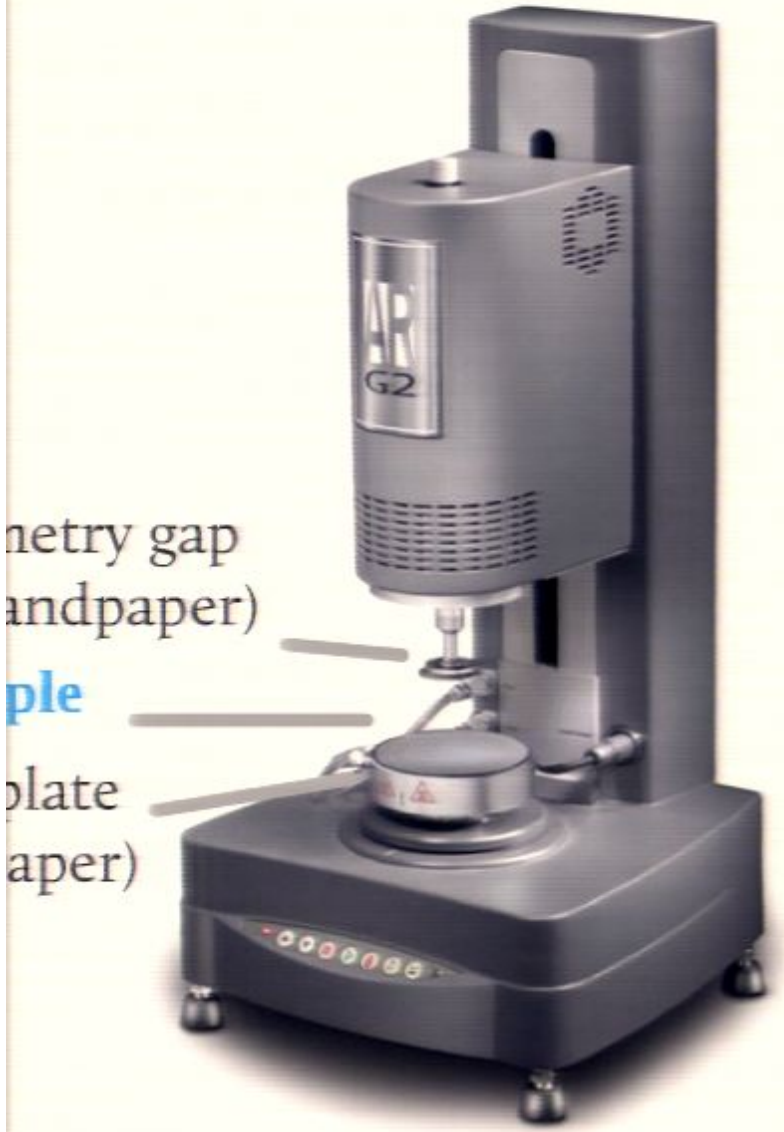

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plate
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AR 1500ex rheometer

- stress-controlled

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AR 1500ex rheometer

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