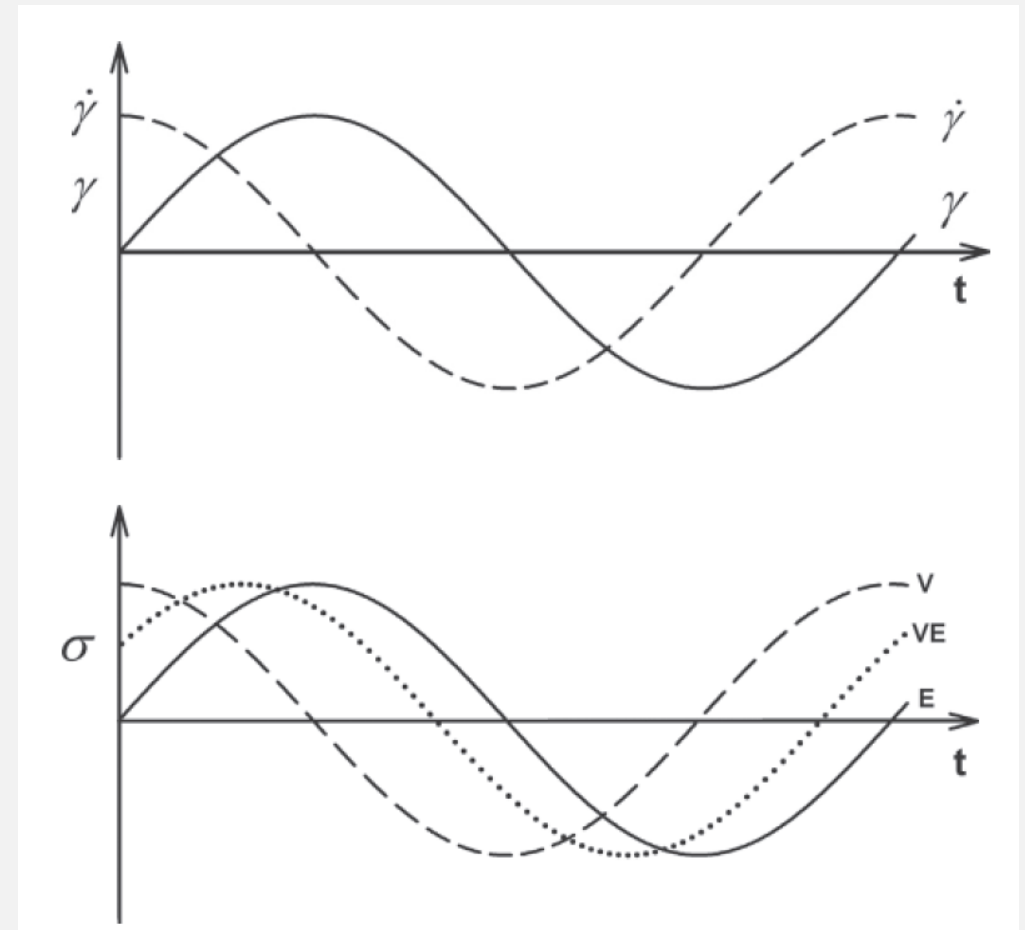
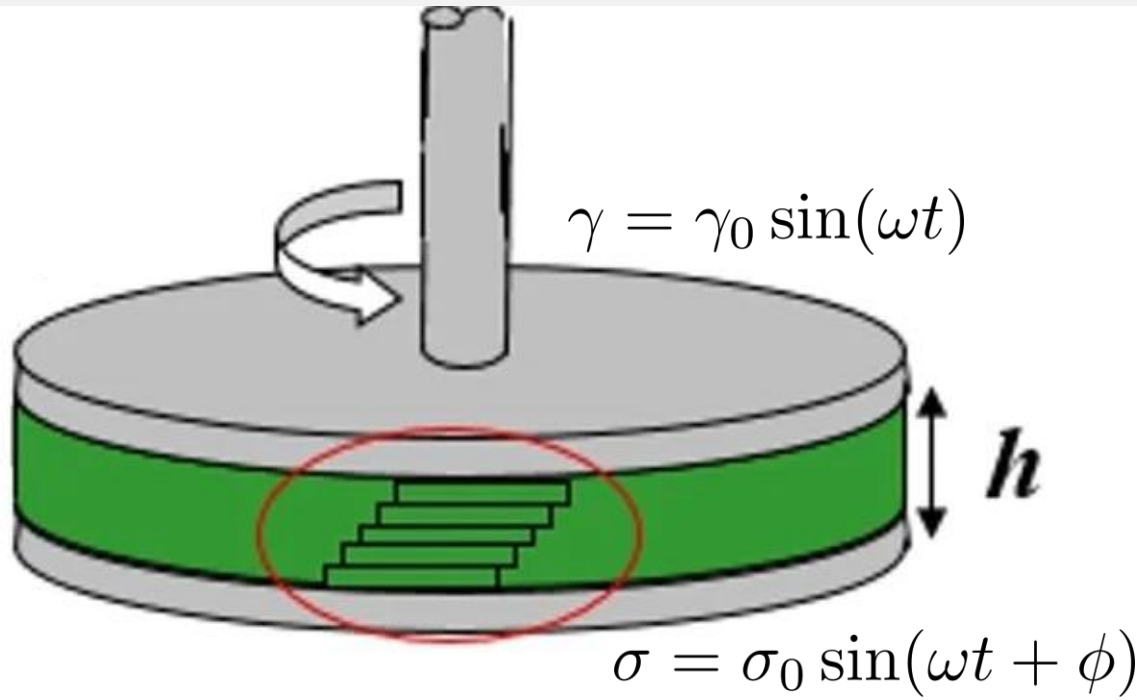


# On the measurement of linear viscoelastic moduli. A comparison between oscillatory tests

F. J. Rubio-Hernández<sup>1</sup>, M. Rodríguez-Lara<sup>1</sup>, J. F. Velázquez-Navarro<sup>2</sup>, and J. Sánchez-Rodríguez<sup>1</sup>

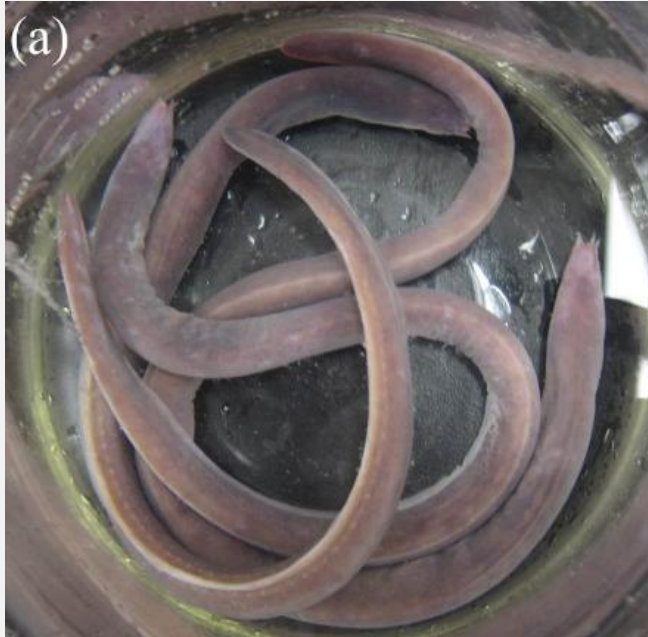
<sup>1</sup> Department of Applied Physics II, University of Málaga  
Department of Mechanics, Thermal, and Fluids Engineering, University of Málaga

- Powerful tool to investigate rheological properties



$$\sigma = (G' + iG'')\gamma$$
$$G' = \frac{\sigma_0}{\gamma_0} \cos \phi$$
$$G'' = \frac{\sigma_0}{\gamma_0} \sin \phi$$

- Some samples may exhibit problems during shear measures



Soft biological tissues

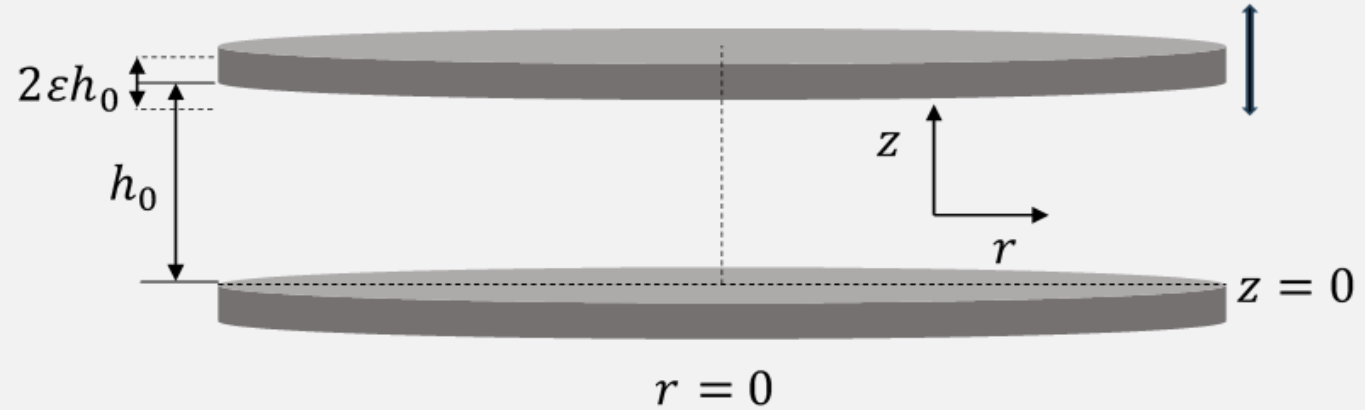


Highly viscous non-newtonian pastes

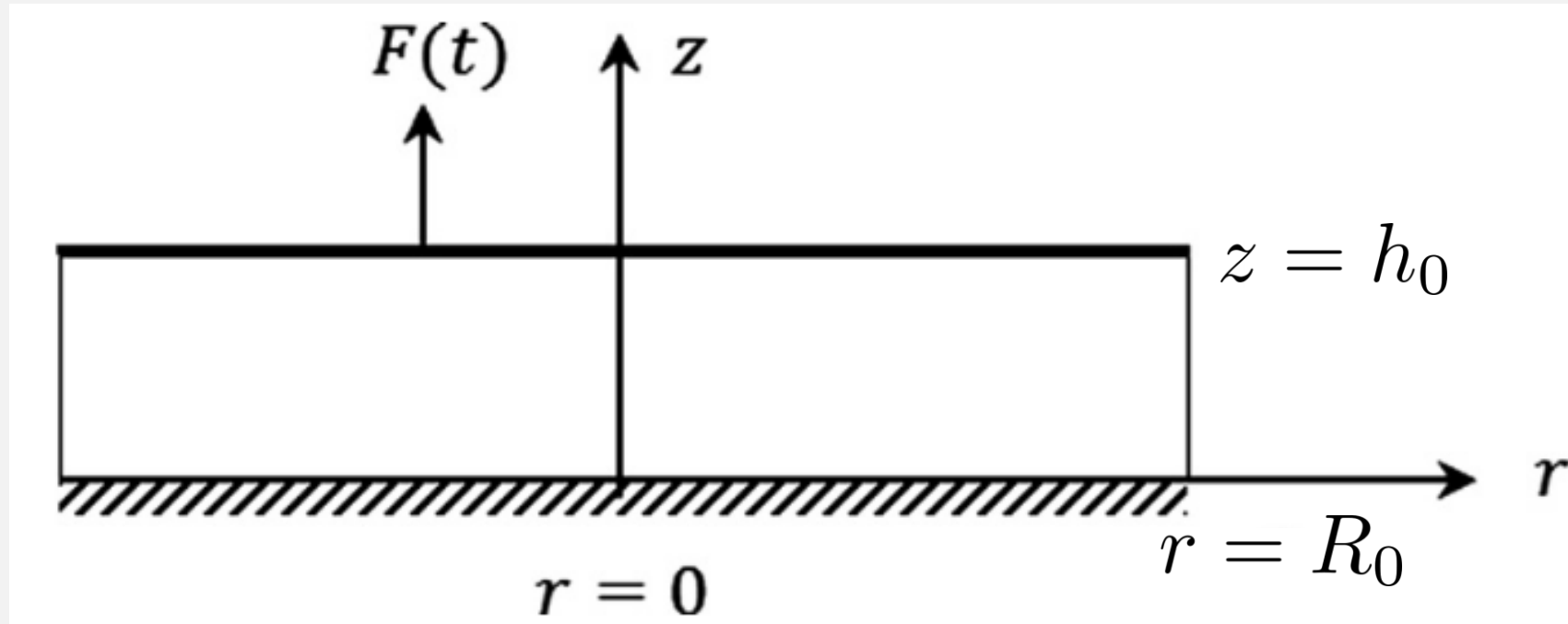
- May induce slip during shear tests
- Suffer structural breakdown subjected to steady shearing

Ewold et al., *Complex fluids in biological systems*, 2014

Phan-Thien, *ANZIAM J*, 1980



- Compressional also used for studying LVE behaviors in fluids
- Versatile and widespread experimental technique
- More research needed to establish the relation of LVE moduli



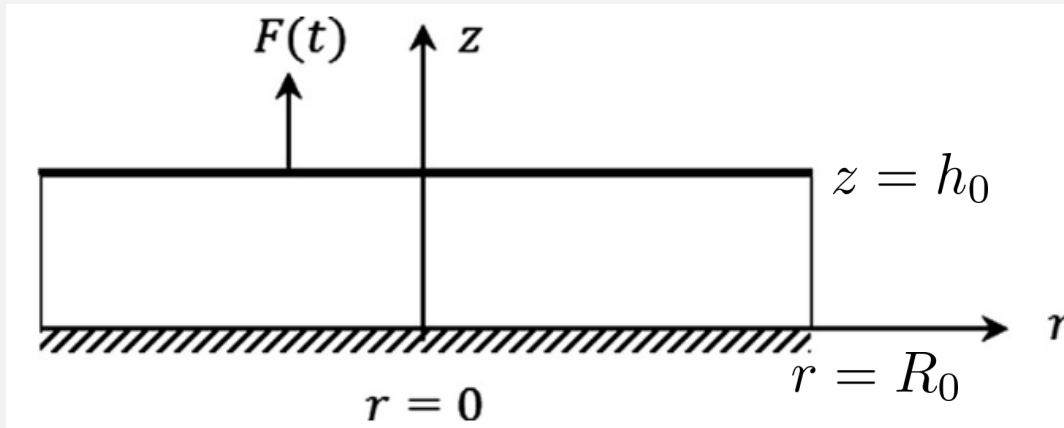
Viscoelastic fluid

$$\sum_{k=0}^n a_k \frac{\partial^k}{\partial t^k} \sigma = \sum_{k=0}^m b_k \frac{\partial^k}{\partial t^k} \gamma$$

with physical properties

Density  $\rho$

Characteristic viscosity  $\eta_c$



Imposed top plate motion

$$h(t) = h_0 \left( 1 + \varepsilon e^{i\omega t} + c.c. \right)$$

Amplitude

Stokes flow

$$\text{Re} = \frac{\rho \omega h_0^2}{\eta_c} < 0.015$$

Measured stress

$$\frac{\sigma}{\varepsilon} = \frac{F}{\varepsilon \pi R_0^2} = G'_{sq} \sin(\omega t) + G''_{sq} \cos(\omega t)$$

Shear-squeeze relation

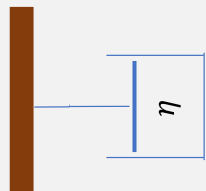
$$G^*_{sq} = \frac{3R_0^2}{2h_0^2} \left[ 1 + 2 \left( \frac{h_0}{R_0} \right)^2 \right] G^*_{sh}$$

# Three representative samples

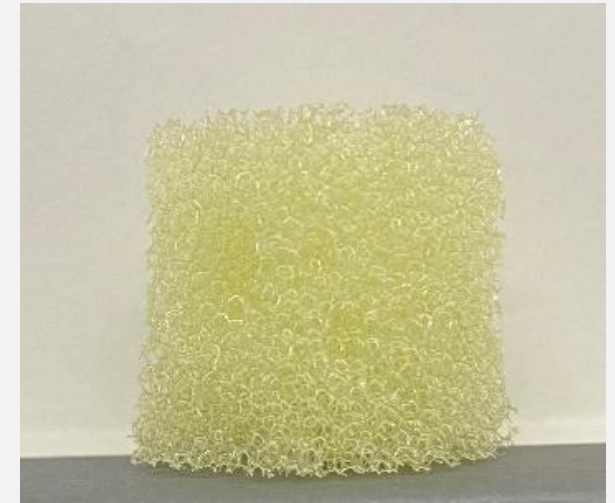
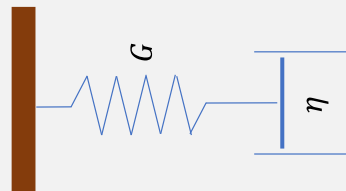
- Objective: obtain LVE moduli with both shear and squeezing



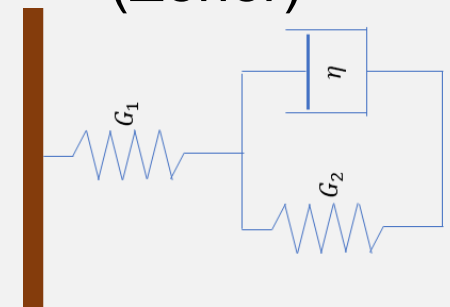
**Honey**  
Newtonian liquid



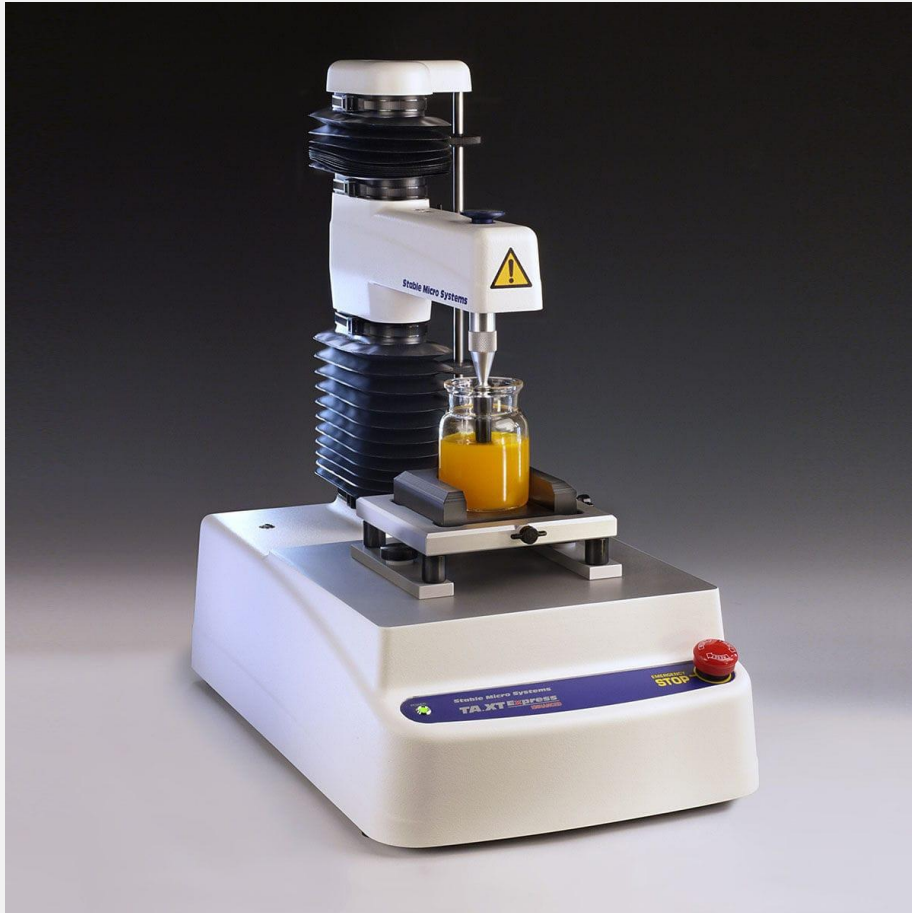
**Shampoo**  
Viscoelastic liquid  
(Maxwell)



**Foam**  
Viscoelastic solid  
(Zener)



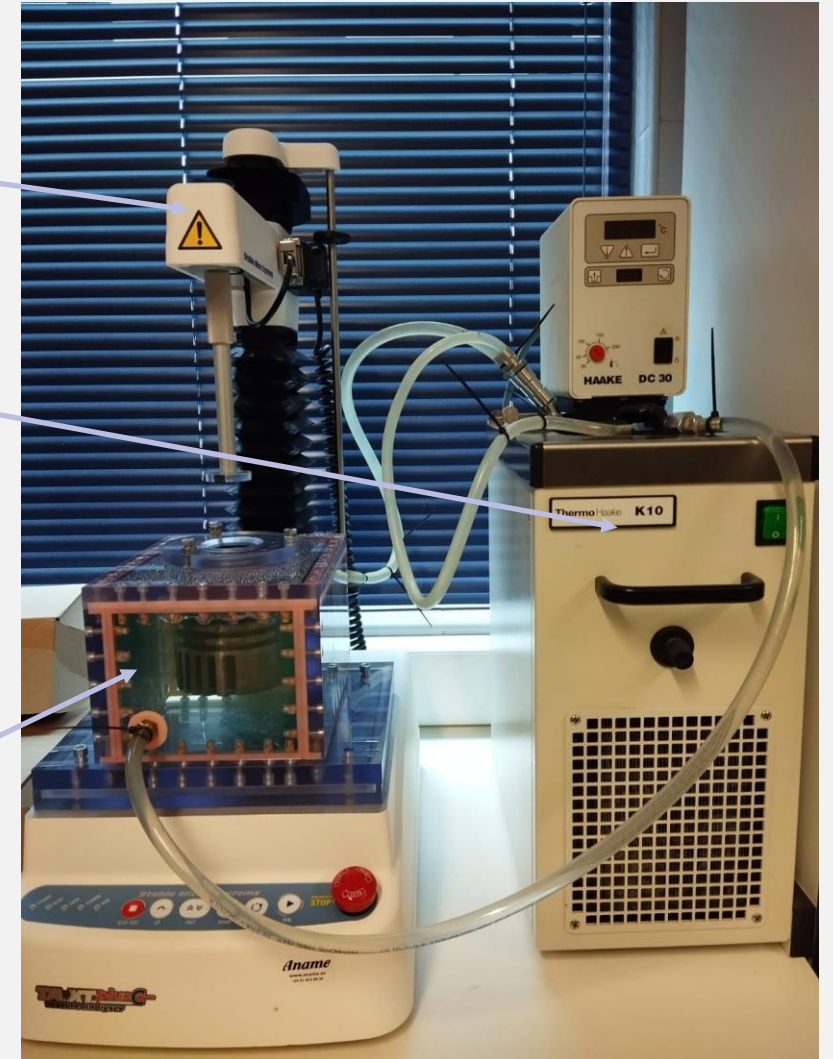
- Compressional experiments were carried out with a texture analyzer, TA.XT PLUS C



Texture analyzer

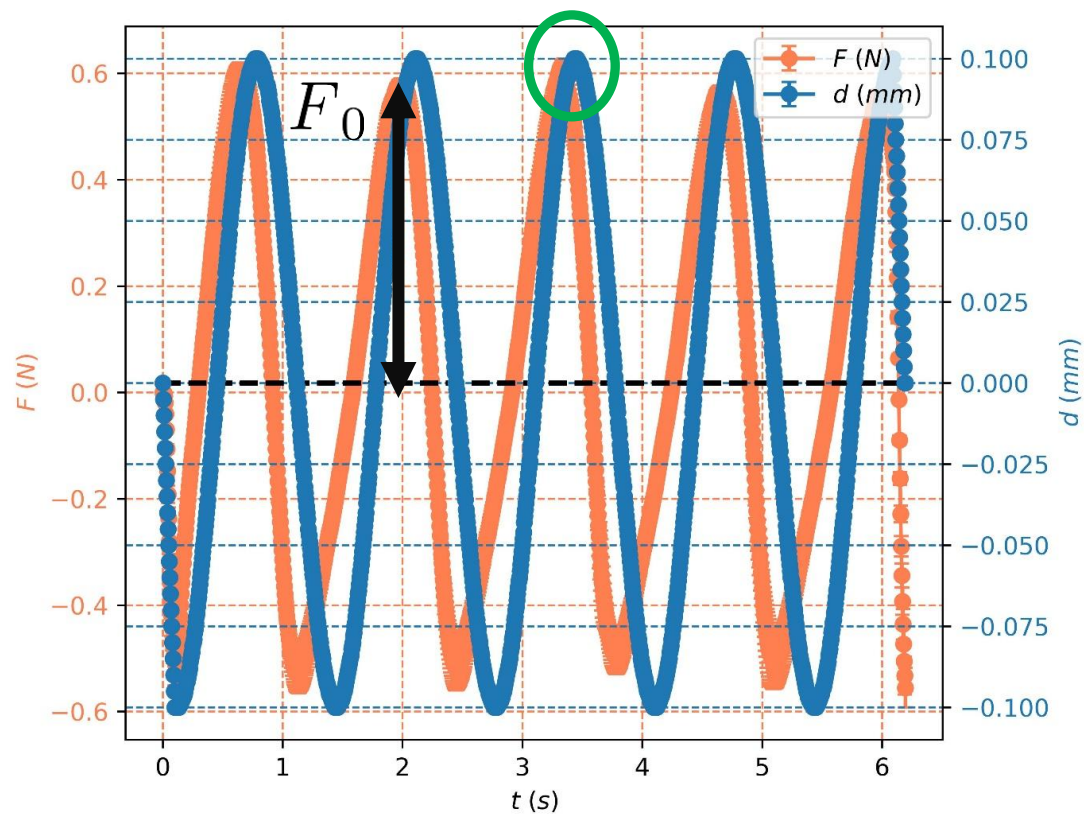
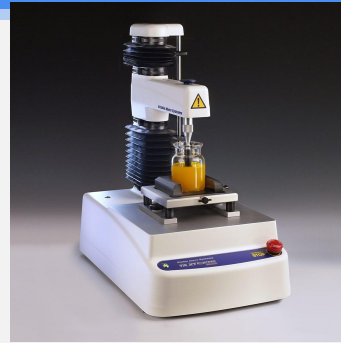
Refrigerated circulating water bath

Heat Exchanger

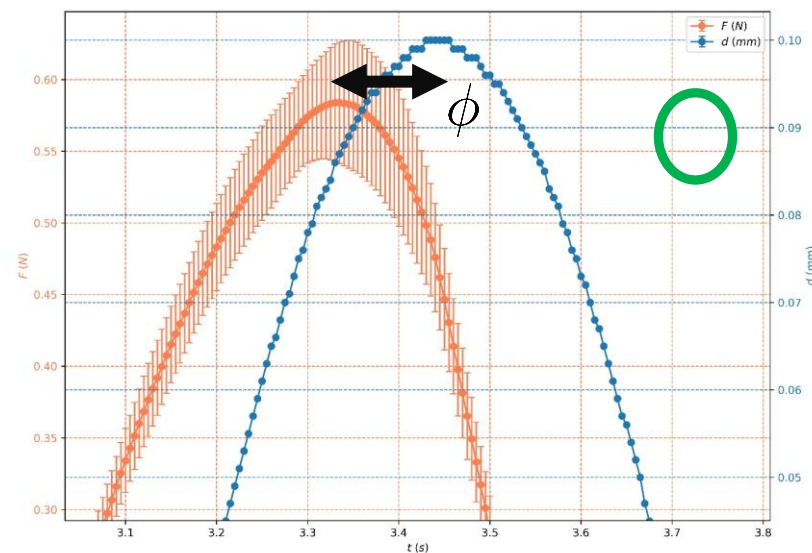


- Impose a displacement, measure a force

$$d(t) = d_0 \sin(\omega t) \quad F(t) = F_0 \sin(\omega t + \phi)$$



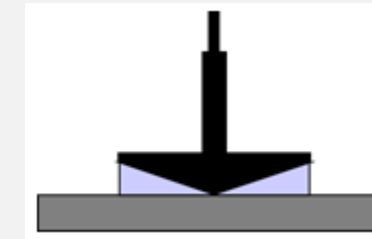
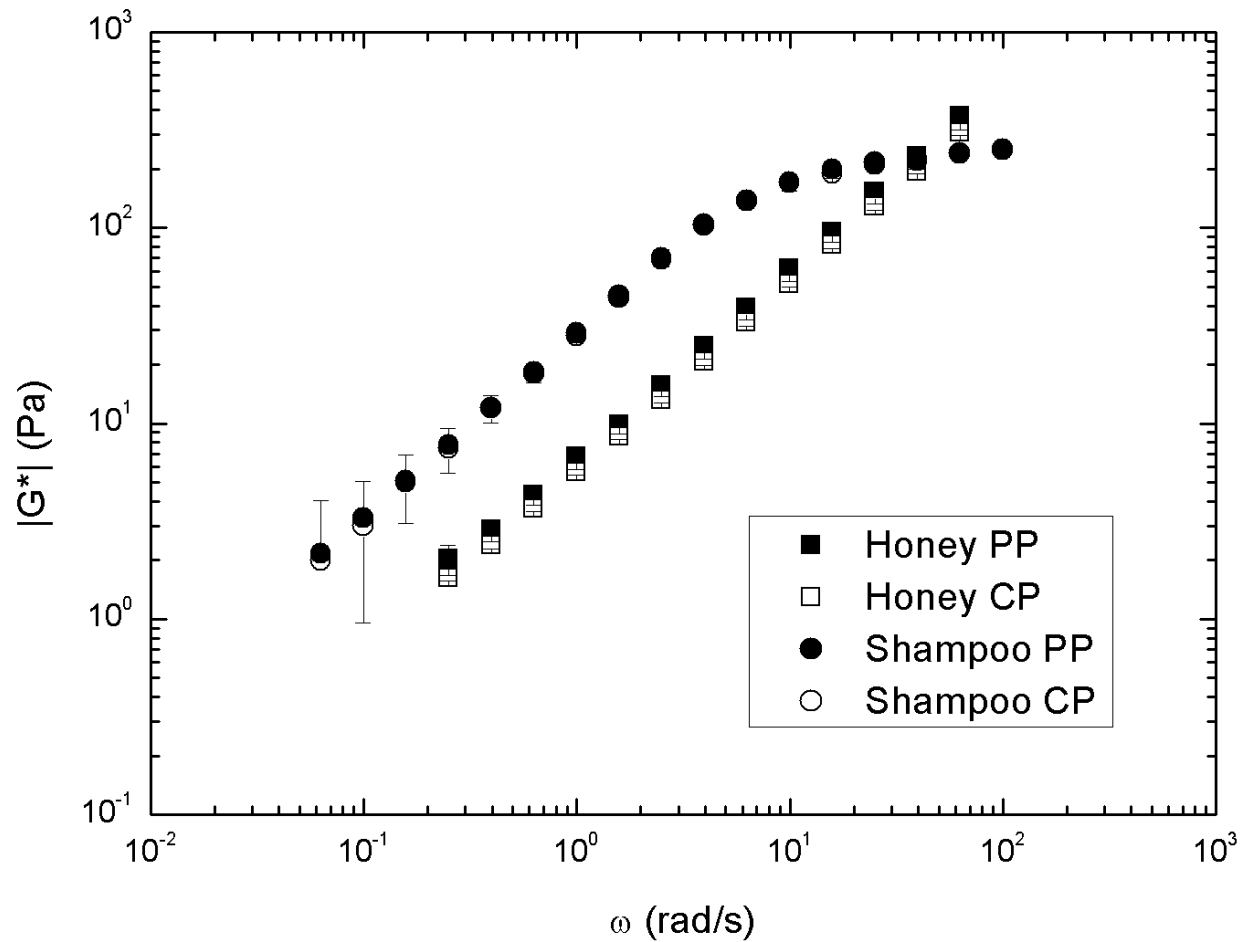
$$G'_{sq} = \frac{F_0}{\epsilon \pi R_0^2} \cos \phi \quad G''_{sq} = \frac{F_0}{\epsilon \pi R_0^2} \sin \phi$$



# Getting the reference values

JIRheo 2025

- Benchmarking: measuring the shear values



Cone – Plate (CP)

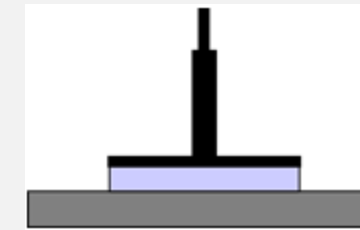
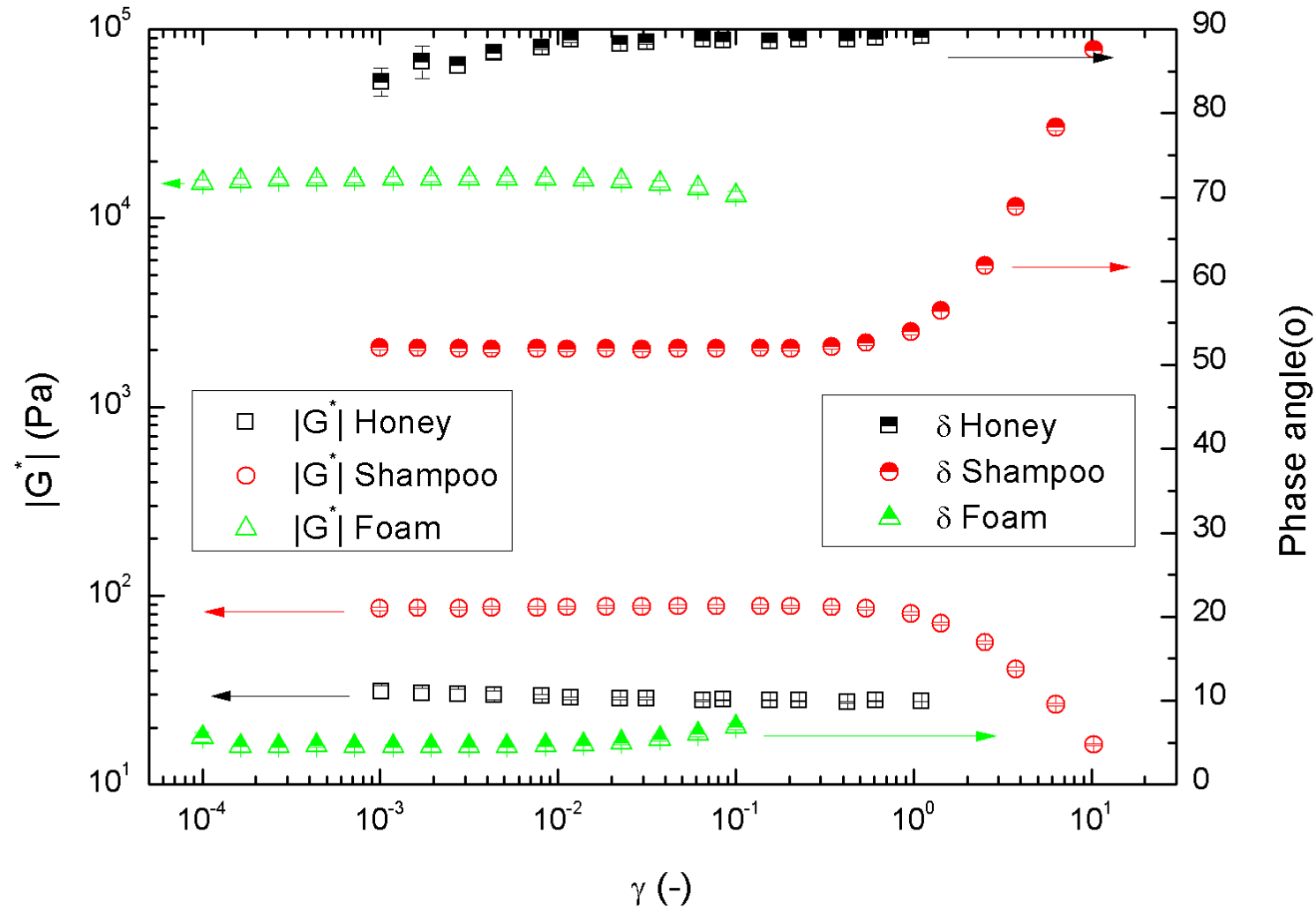


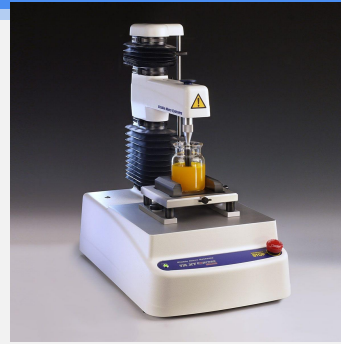
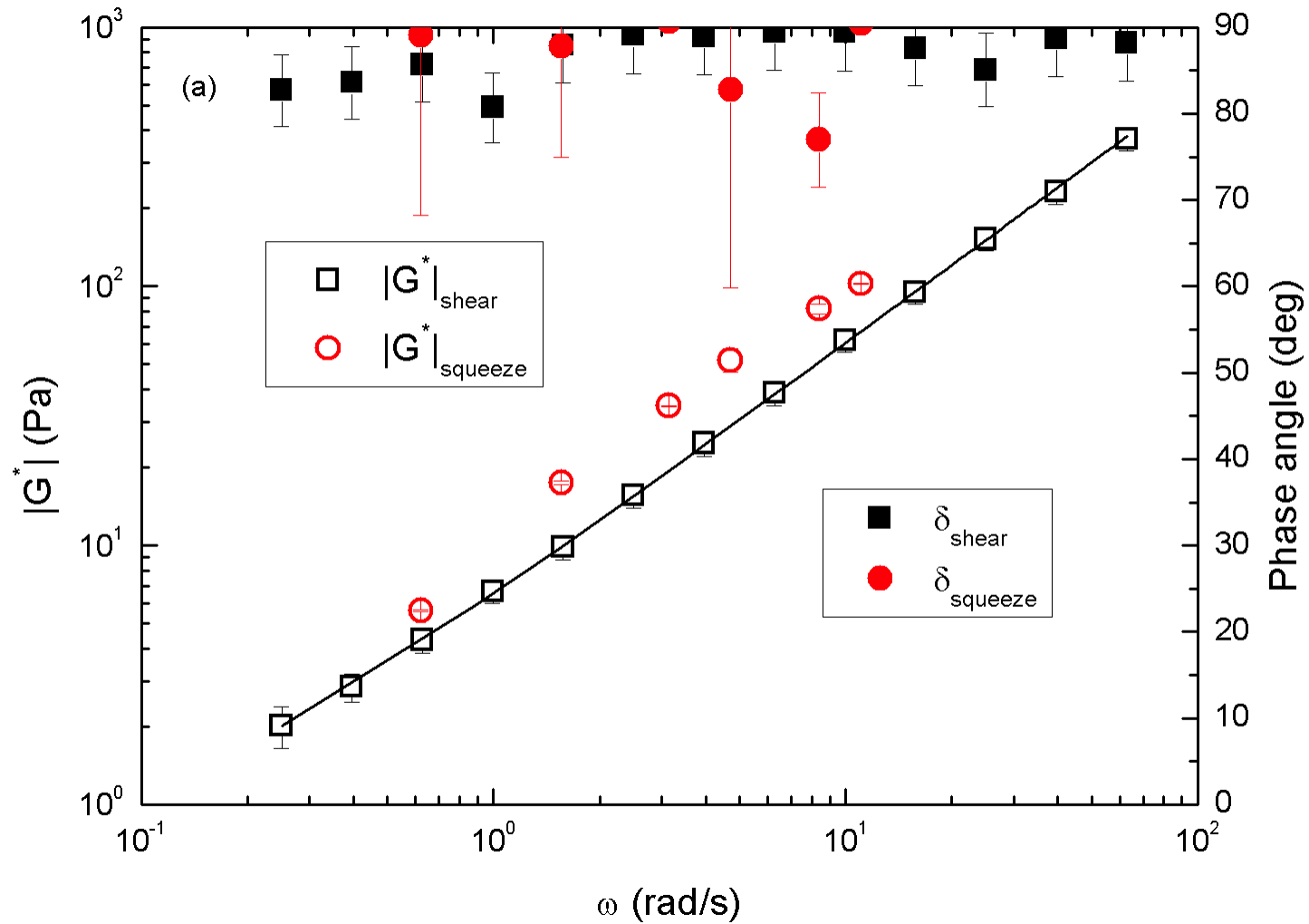
Plate – Plate (PP)





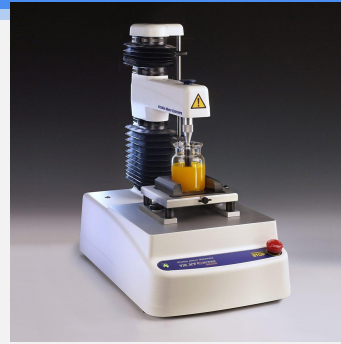
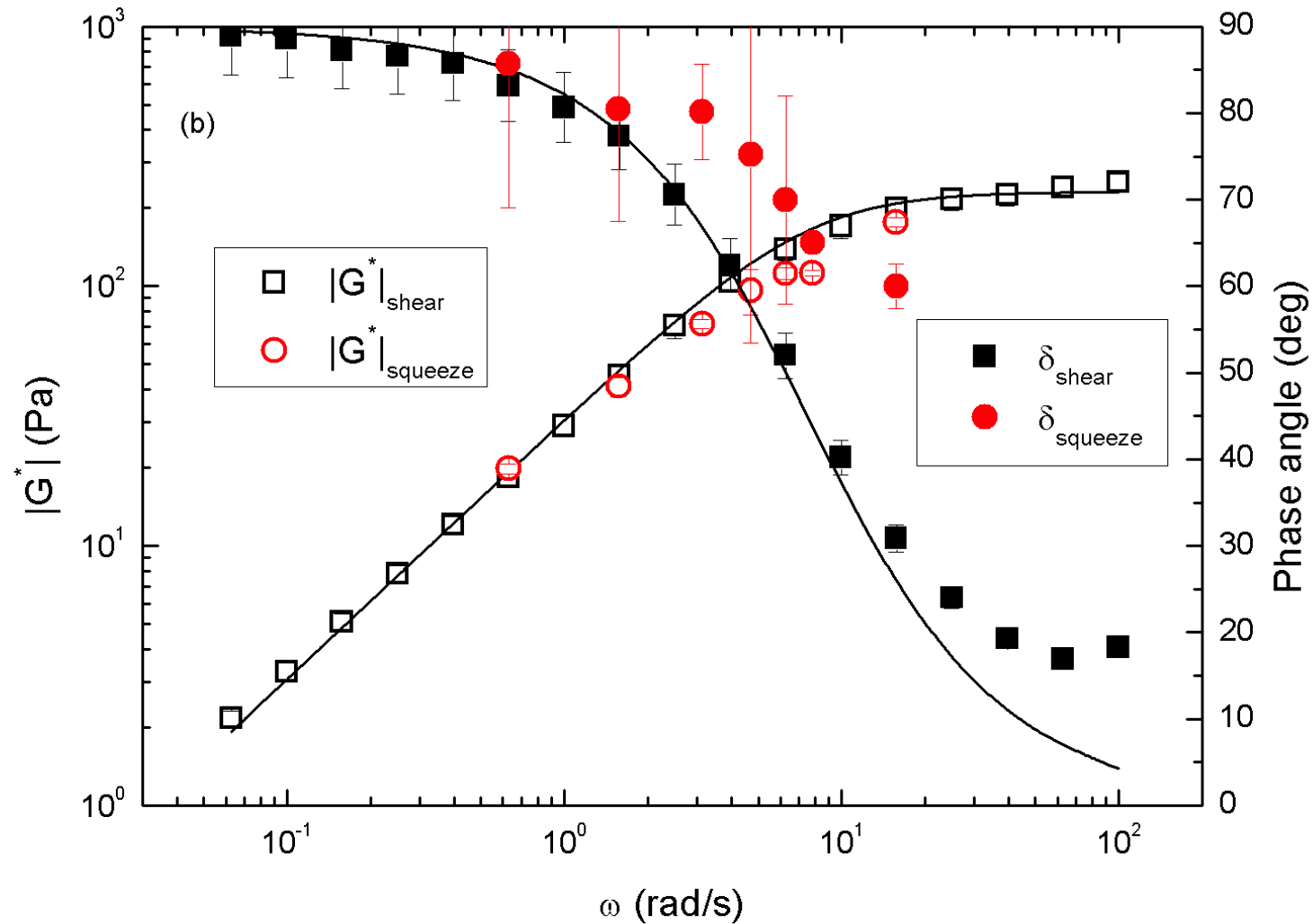
# First case: newtonian liquid

JIRheo 2025

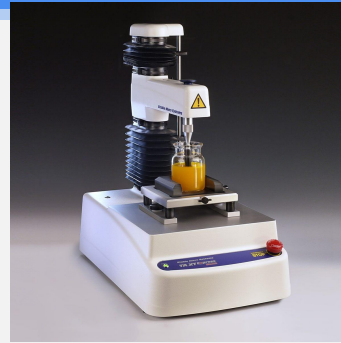
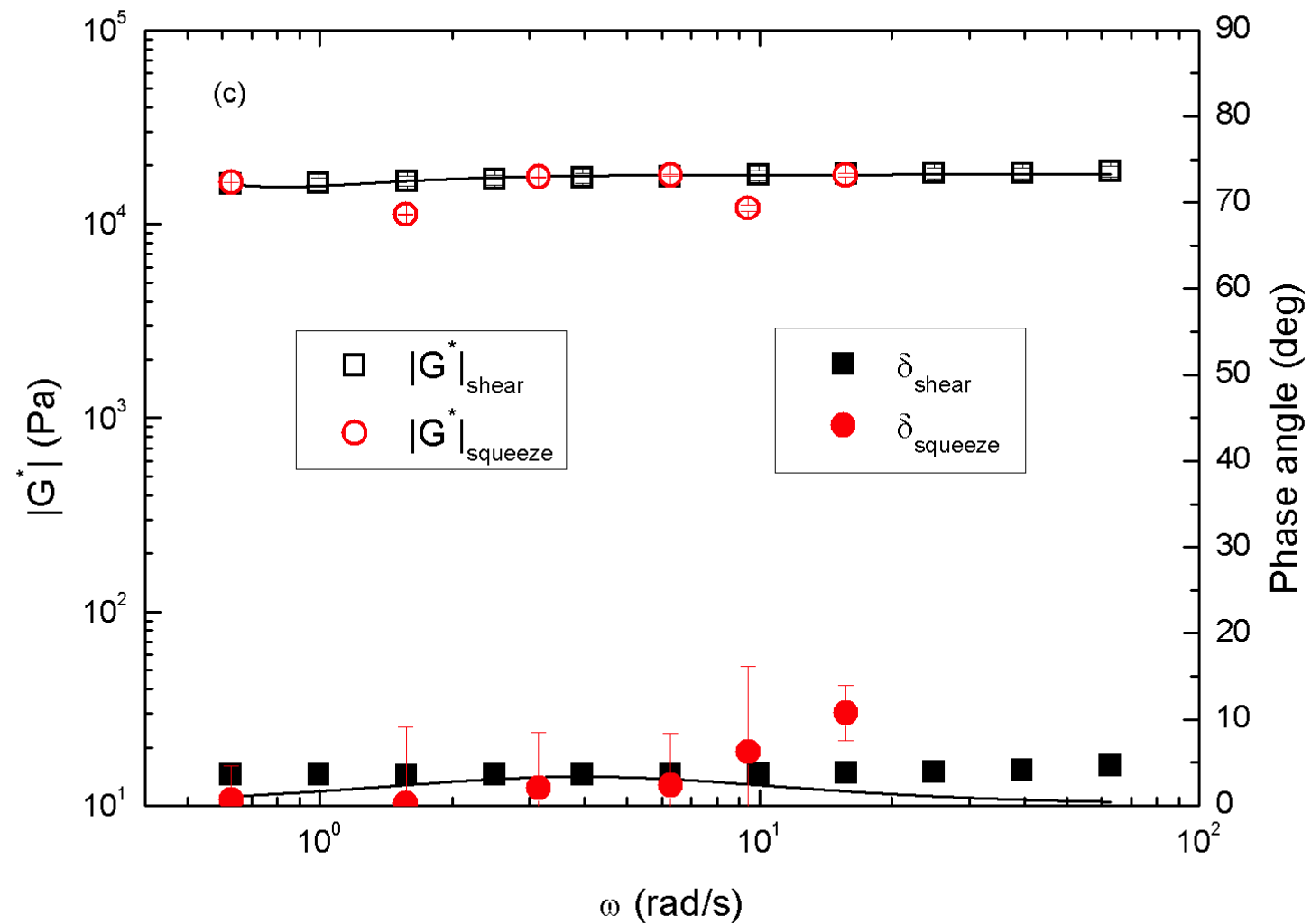


# Second case: viscoelastic liquid

JIRheo 2025



# Third case: viscoelastic solid



- Promising technique for studying linear viscoelasticity
- Squeeze experiments were compared to the reference values obtained with a shear rheometer with excellent agreement
- Linear viscoelastic moduli just differ by a geometrical factor dependent on the experimental setup
- Opening the possibility of studying extensional rheology with a validated setup

# Thank you for your attention!