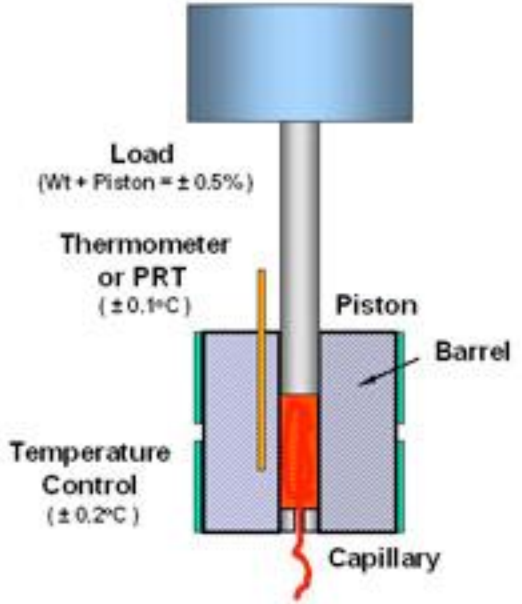
Rheometry

Questions and Reflections

- Besides of the capillary test,
  are there some other ways to measure the viscosity?
- What other moduli exist for solid and liquids?
- Are those moduli dependent from each other?
- If they are dependent, how can a given modulus be calculated from another one?

Melt flow indexer

- One of the most used equipment in the polymer industry
- A quality control tool
- Measures “flowability”
  - Melt flow rate: # grams/10 minutes
- According to Standards:
  - ISO 1133 and ASTM D1238



Brookfield Viscometer

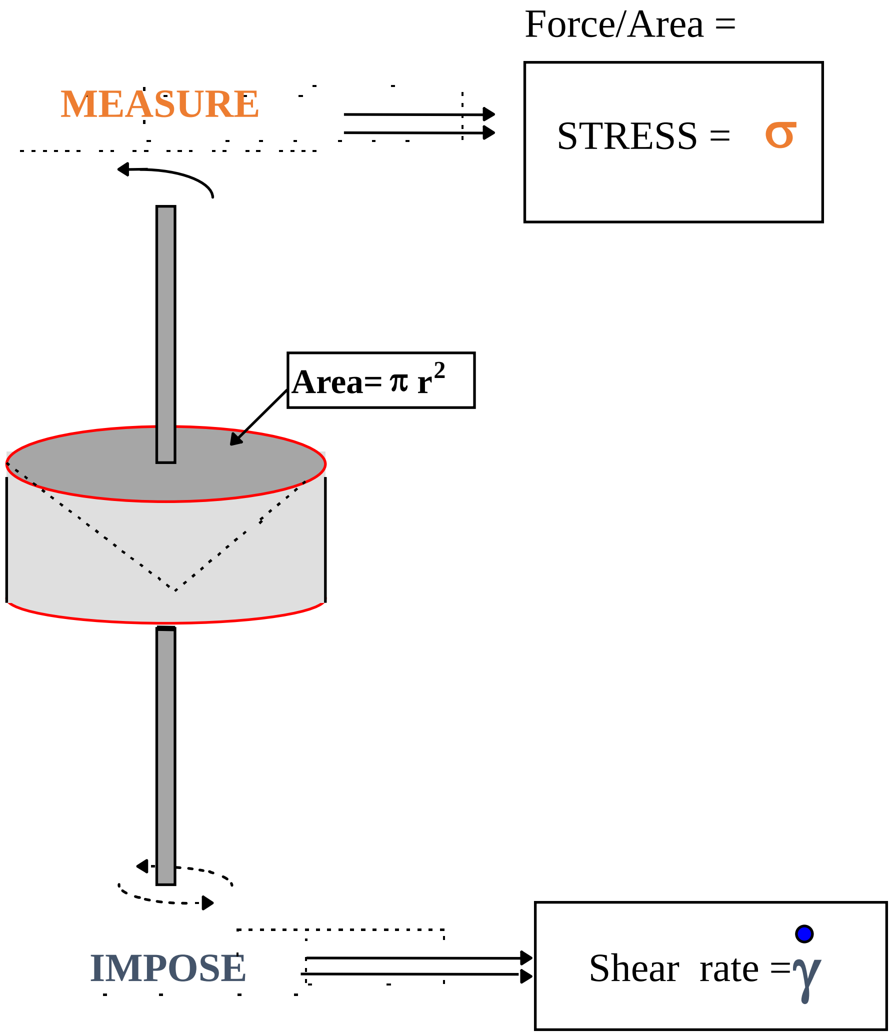
- For each “spindle” velocity, gives the modulus viscosity, based on the torque.
- The viscosity is typically reported in:
  - Centipoise or mPa.s

Other rheological tests:

- **Constant shear rate** (viscous modulus)
- **Constant stress** (creep and recovery compliance)
- **Constant strain** (relaxation modulus)

VISCOUS MODULUS

Viscous modulus:
the material´s response to a constant shear rate



$$\text{MODULUS} = \frac{\text{STRESS}}{\text{SHEAR RATE}}$$

Viscous modulus

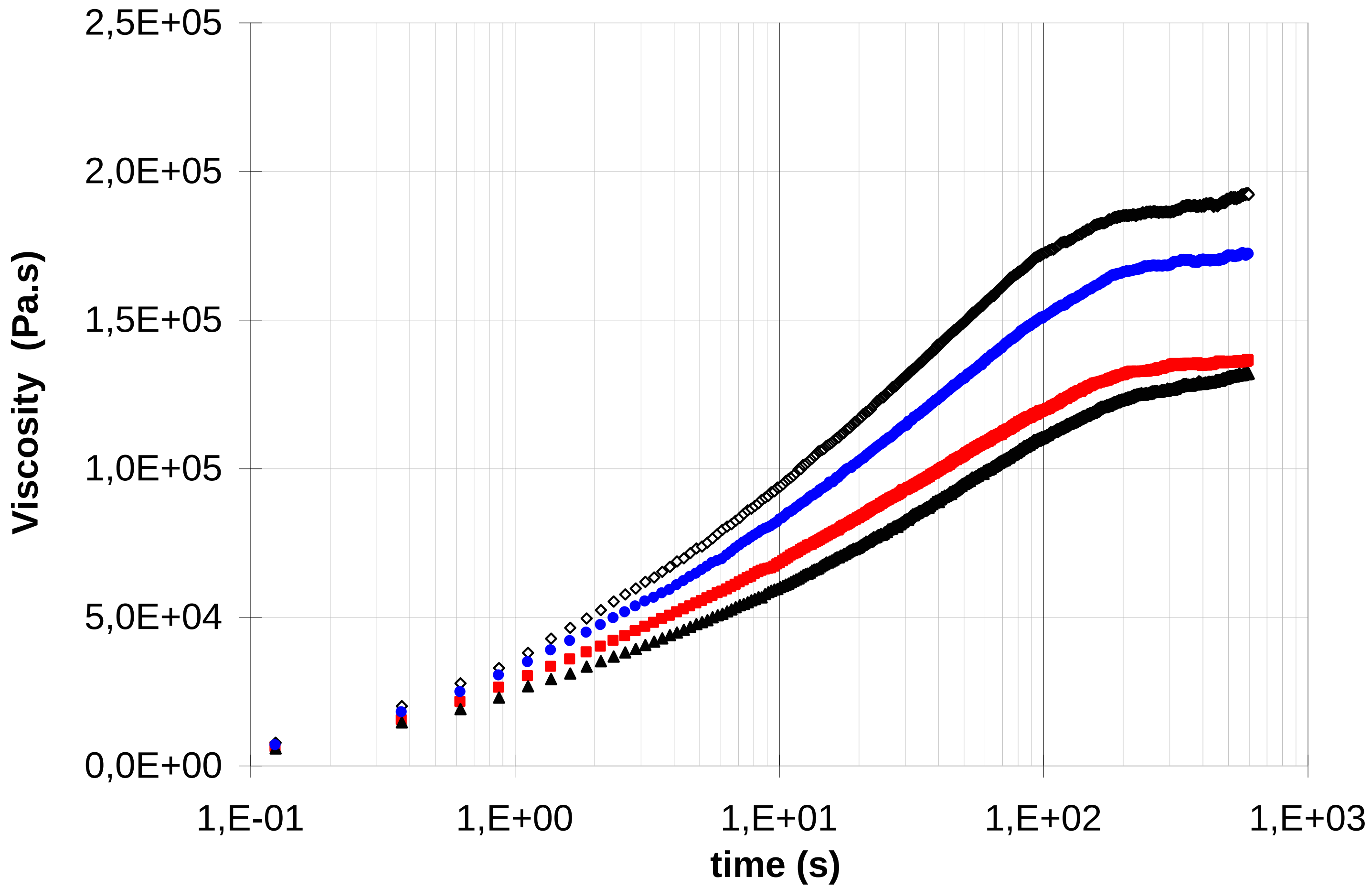
$$\eta = \sigma / \dot{\gamma}$$

$$\dot{\gamma} = dv_{\theta} / dz$$

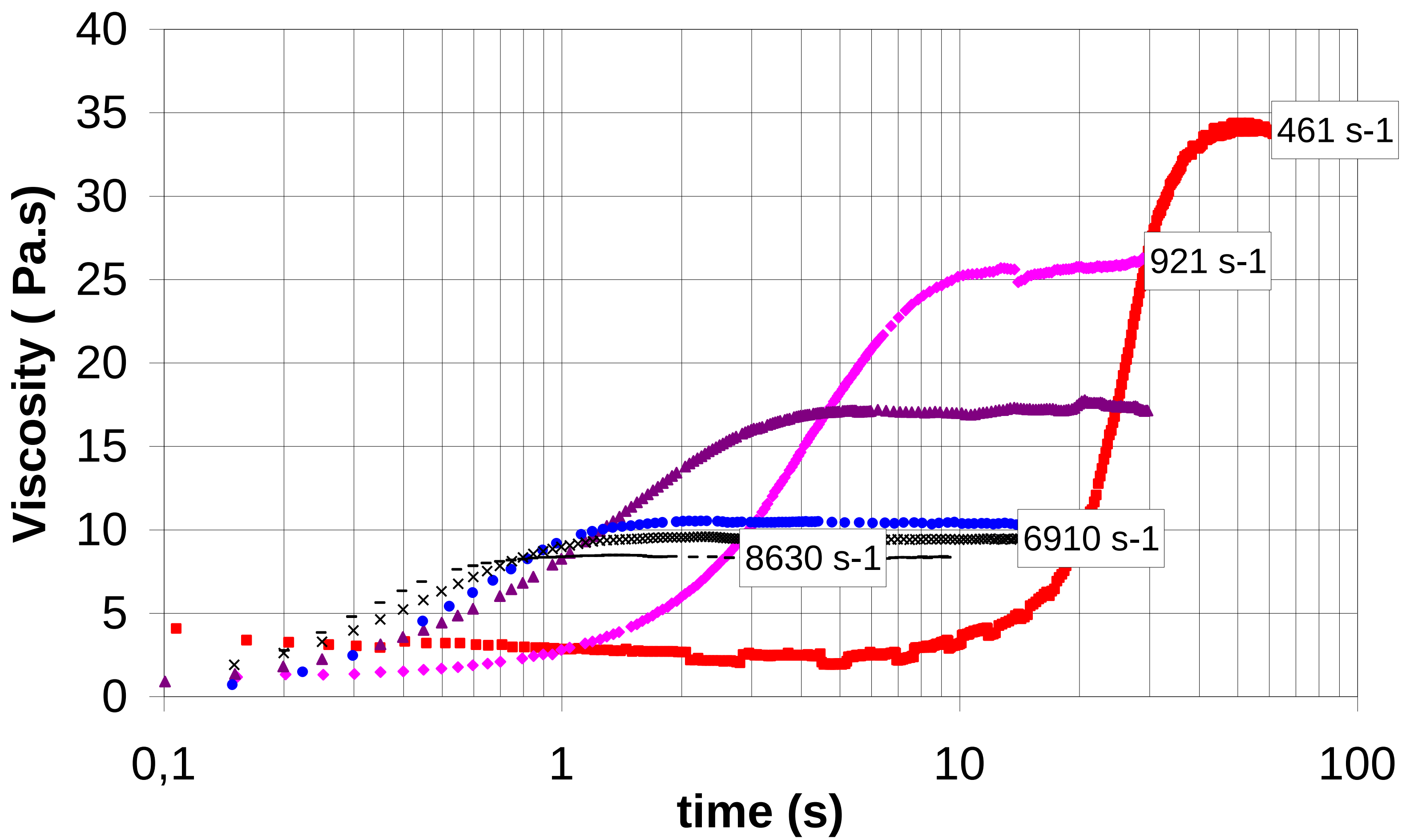
σ in Pa
and
shear rate in 1/s

η in Pa.s

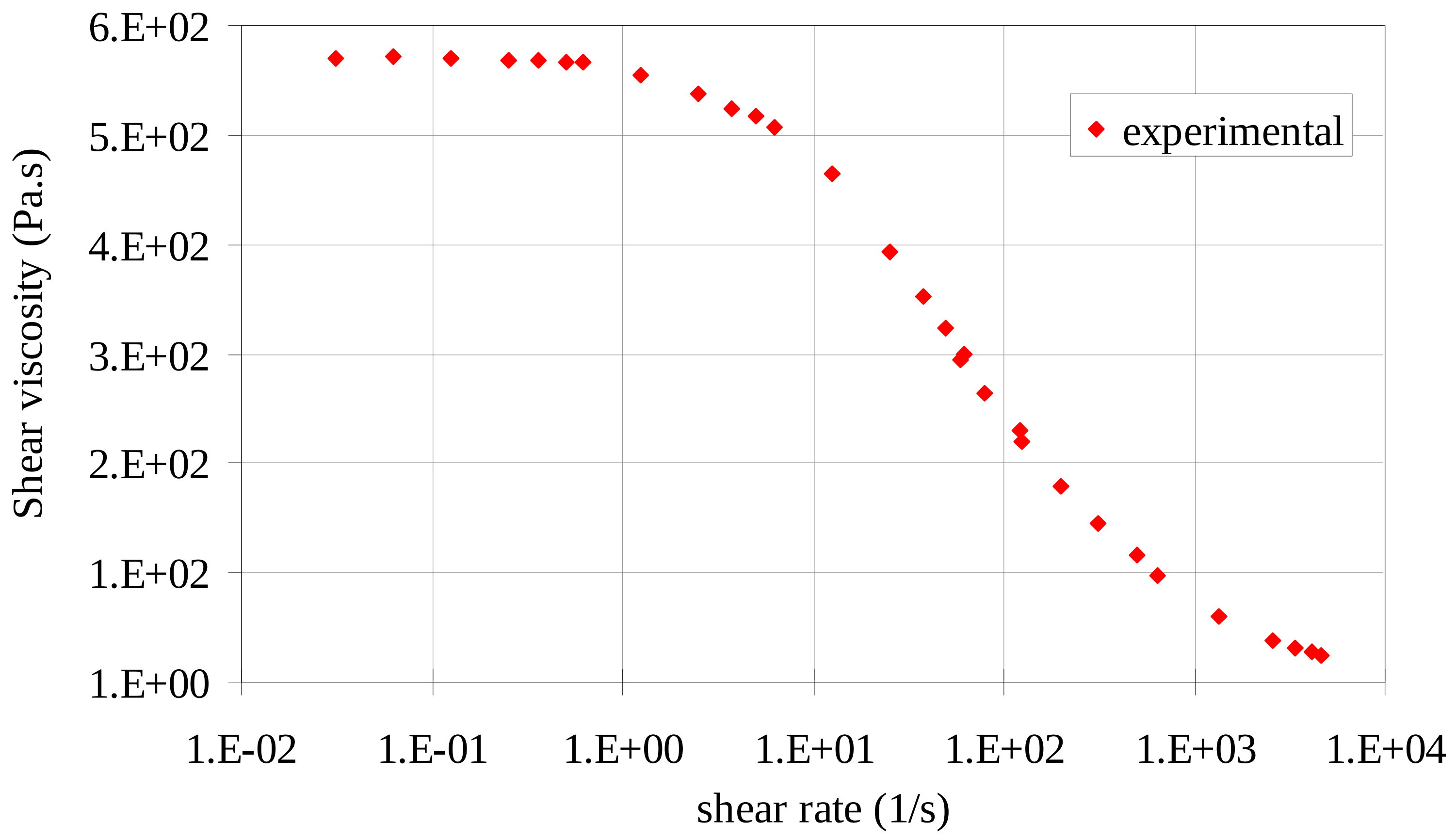
Viscosity versus time for 4 different HDPE resins when a sudden shear rate of 0.01 1/s is imposed in a parallel plate rheometer



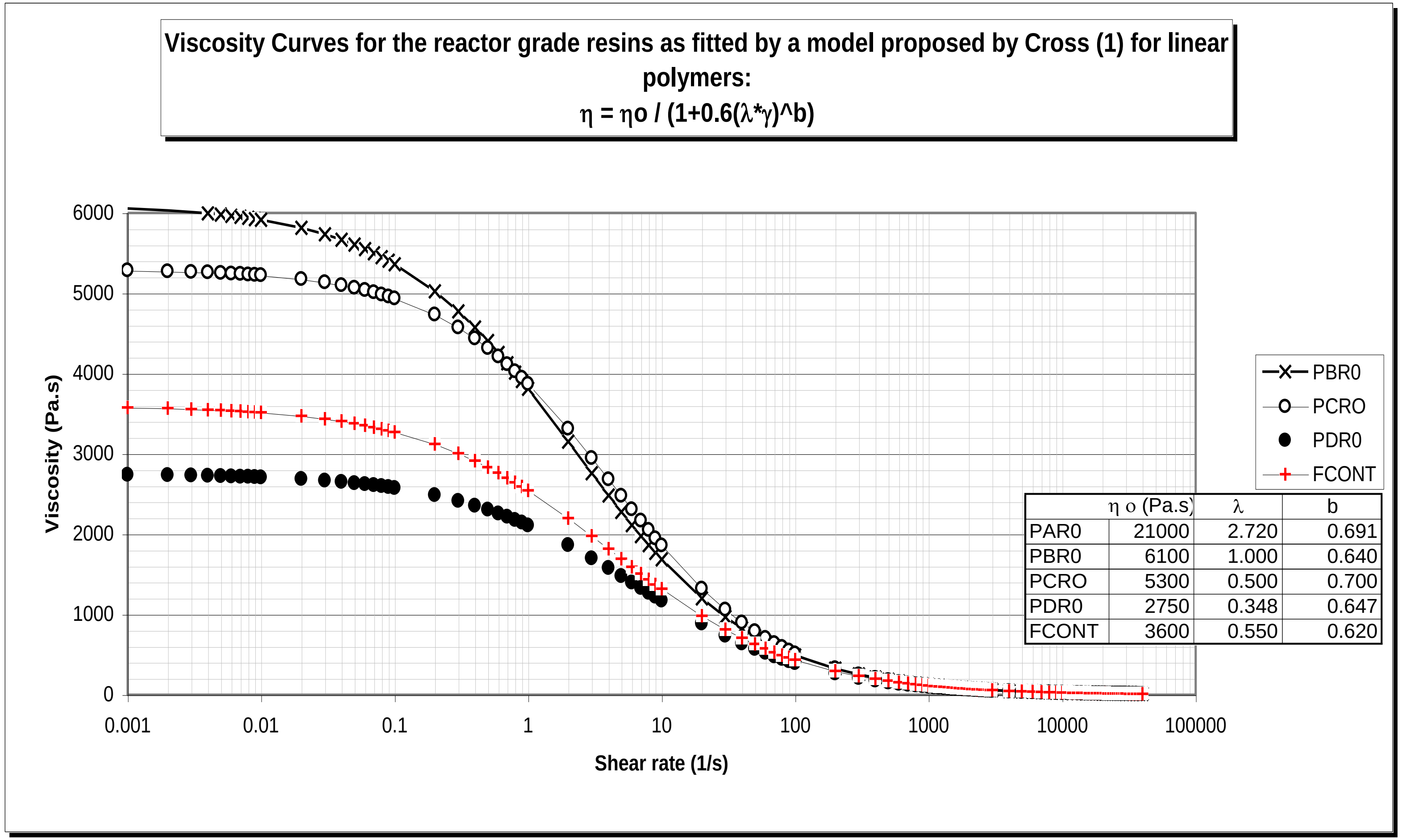
Viscosity versus time
(Capillary rheometer)



Shear viscosity versus shear rate for a polyproylene resin

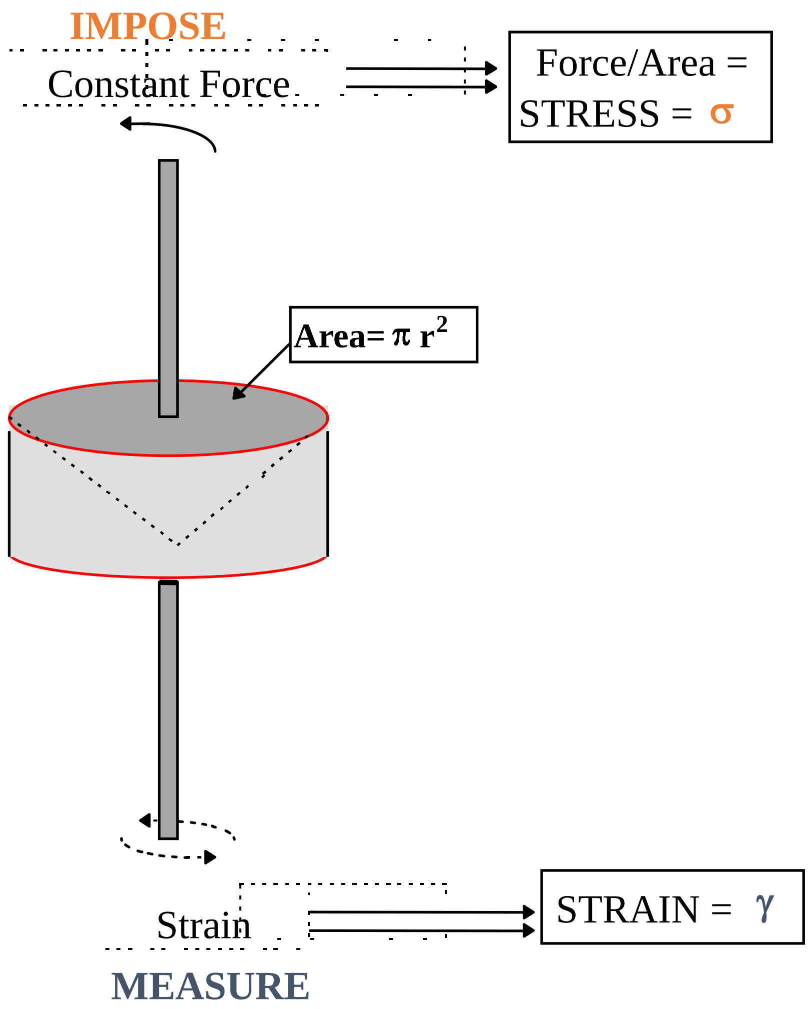


Shear viscosity vs. shear rate
(steady state shear viscosity vs. constant shear rate)
for a set of reactor grade polypropylene resins



CONSTANT STRESS RHEOMETRY

Constant stress rheometry: creep and recovery compliance



MODULUS = STRAIN/STRESS

Compliance modulus

$$J = \gamma / \sigma$$

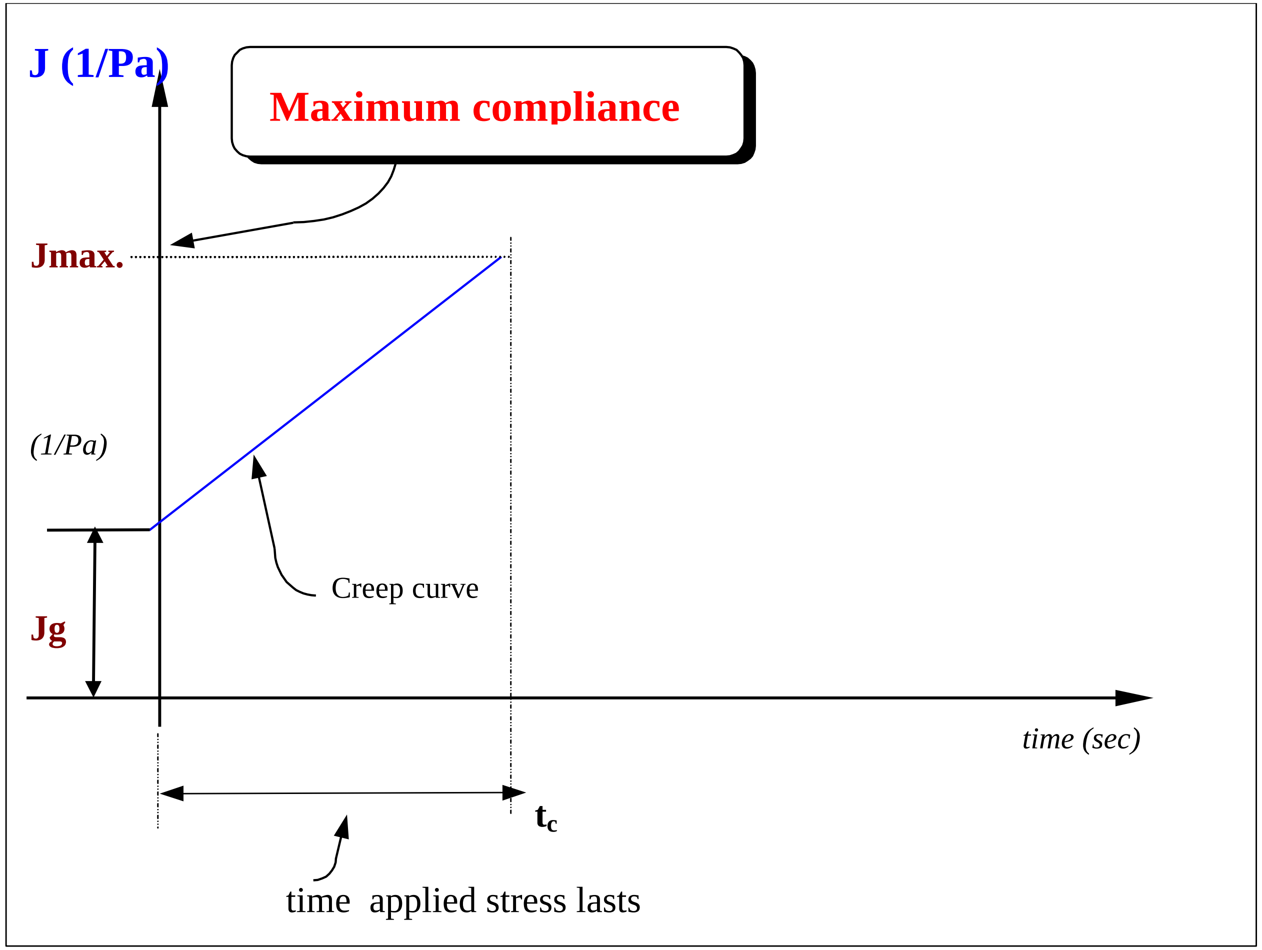
$$\gamma = (L - Lo) / Lo$$

σ in Pa

then

J in $1/Pa$

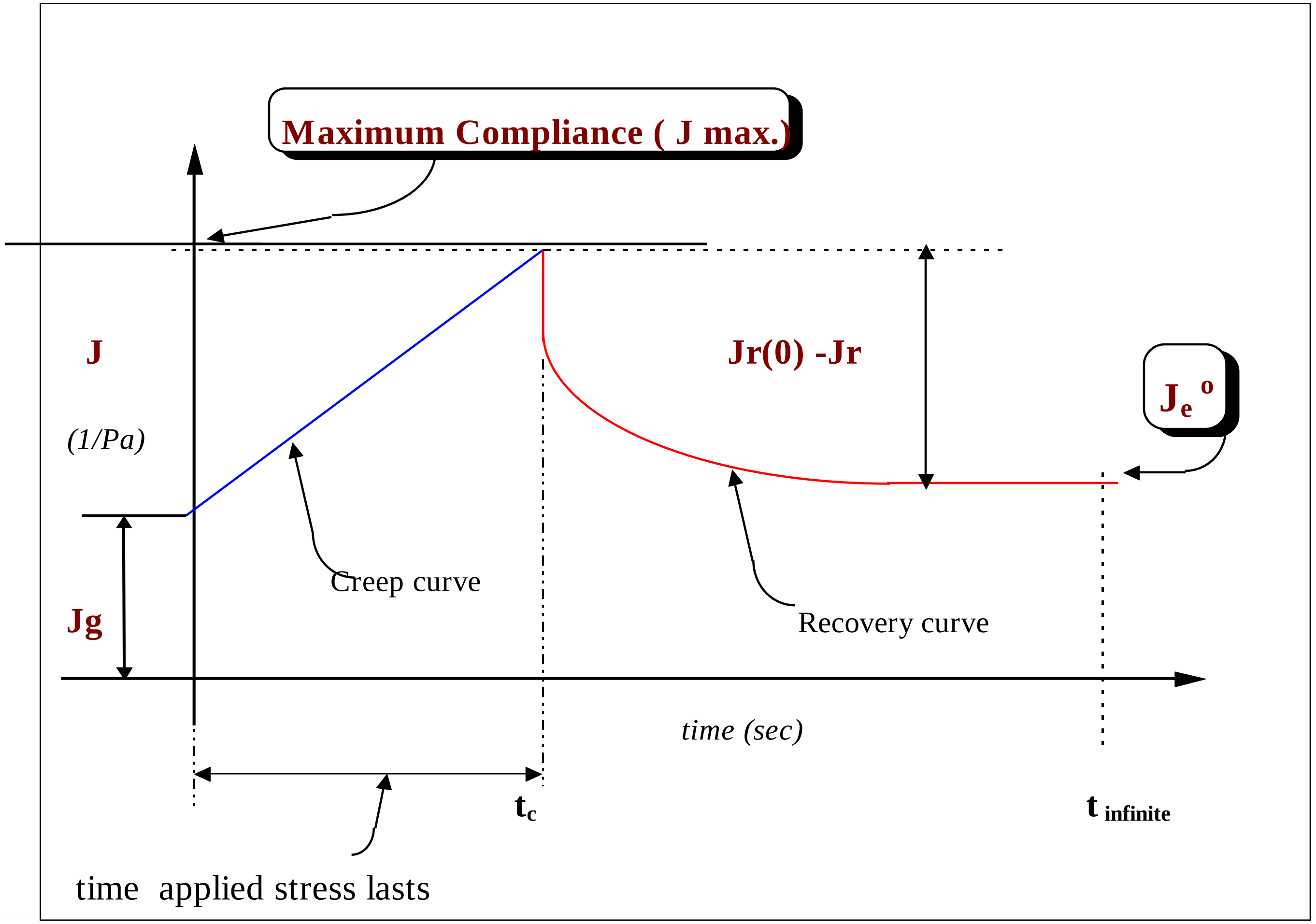
Constant stress rheology:



But, once the stress ceases the material...

Recoils and the extent of recoil with respect to the extent of deformation under constant stress is called the the **recovery compliance**

Constant stress rheology:
creep and recovery compliance



Where:

J is the compliance: Strain / Stress

Jr (0) is the compliance at the time at which the stress ceases (t_c)

Jr is the compliance at any time after the stress ceases.

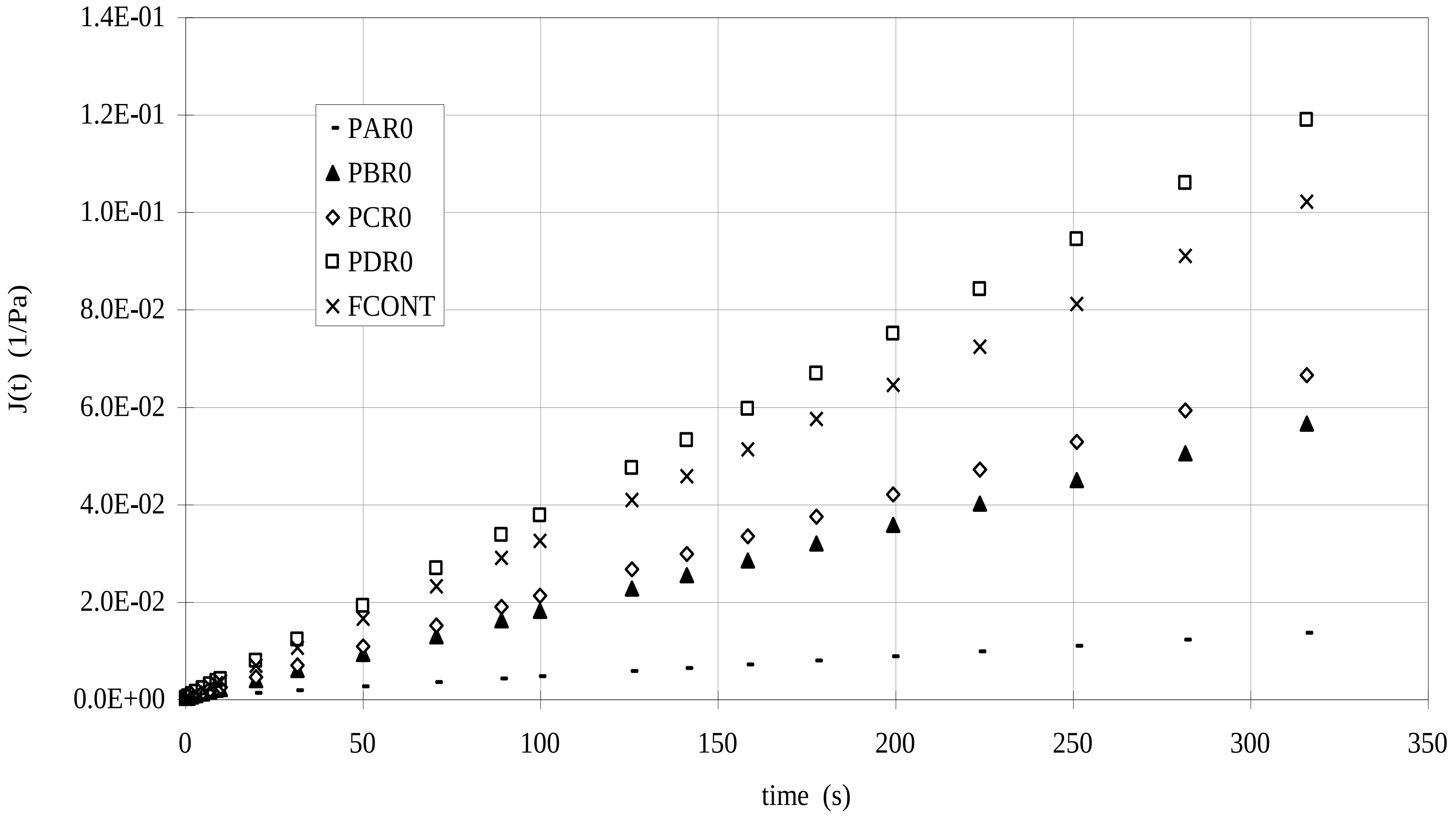
Jr(0)-Jr is the recoverable compliance at a given time ($t - t_c$)

Je° is the steady state recoverable compliance

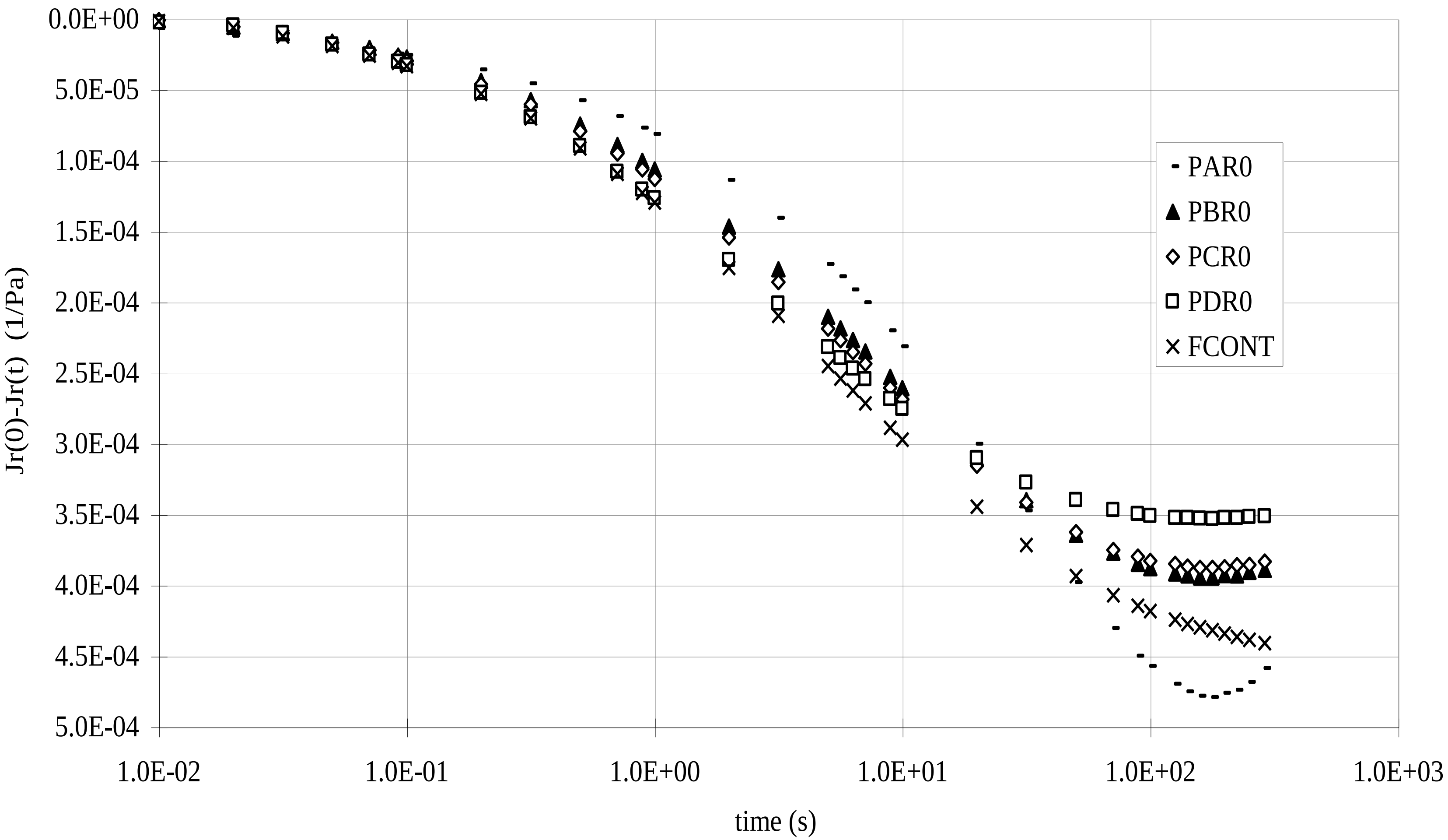
$$Jr(0) - Jr(t_{infinite}) \quad (\text{at } t >> t_c).$$

Jg instantaneous or glassy compliance.

Creep compliance vs. time
(strain under constant stress vs time)
for a set of reactor grade polypropylene resins



Recovery compliance vs. time
(strain under constant stress vs time)
for a set of reactor grade polypropylene resins



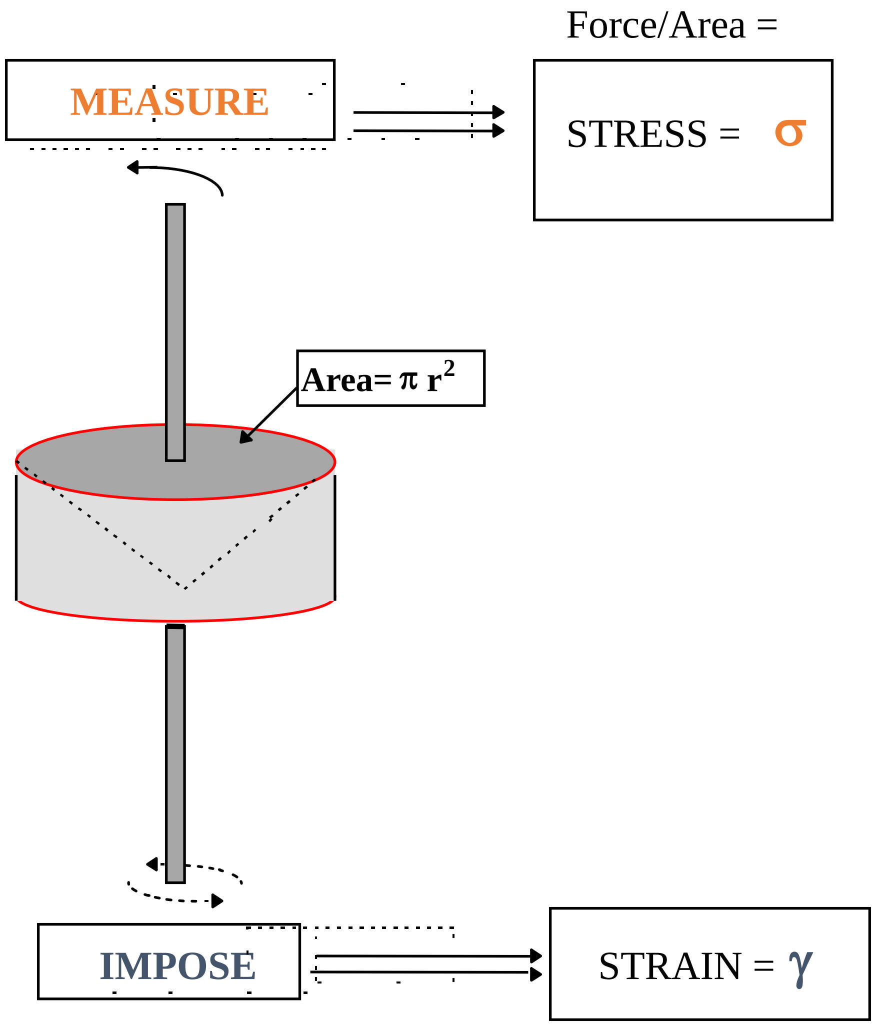
Creep and recovery compliance data for the RGPP resins

applied constant stress: 300 Pa

resin	time	strain	J_{max} x10^{-5} at 300 s	shear rate	eta	J_e^ox10^{-4} at 300 s
par0	316	4.05	1351	1.24E-02	24200	4.95
pbr0	316	16.98	5660	5.34E-02	5620	3.89
pcr0	316	19.95	6650	6.28E-02	4780	3.86
pdr0	316	35.70	11900	1.11E-01	2710	3.51
pcont	316	30.63	10210	9.55E-02	3140	4.41

RELAXATION MODULUS

Relaxation modulus: the material´s response to a sudden strain



MODULUS = STRESS / STRAIN

Relaxation modulus

$$G = \sigma / \gamma$$

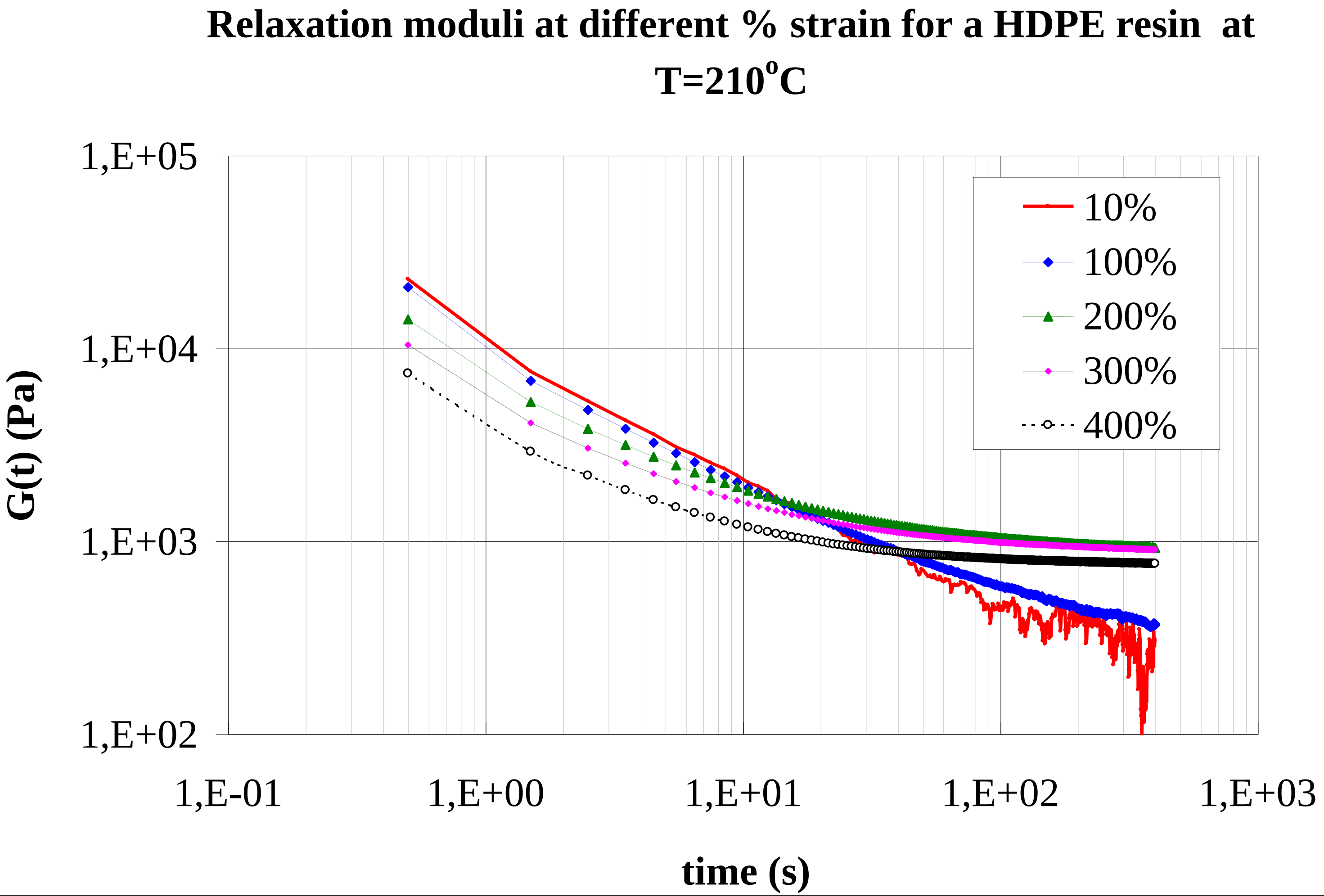
$$\gamma = (L - Lo) / Lo$$

σ in Pa

then

G in Pa

Typical Relaxation Moduli



Typical Relaxation Moduli